“Impact of international trade on regional ecosystem sustainability: Evidence from Ukraine amid war”

AUTHORS	Valeriia Shcherbak Oleh Kolodiziev Ihor Krupka Kseniia Vzhytynska Ilona Androshchuk Tetiana Kolodizieva Volodymyr Berehovyi

ARTICLE INFO	Valeriia Shcherbak, Oleh Kolodiziev, Ihor Krupka, Kseniia Vzhytynska, Ilona Androshchuk, Tetiana Kolodizieva and Volodymyr Berehovyi (2025). Impact of international trade on regional ecosystem sustainability: Evidence from Ukraine amid war. *Problems and Perspectives in Management*, *23*(1), 364-378. doi:10.21511/ppm.23(1).2025.27
DOI	http://dx.doi.org/10.21511/ppm.23(1).2025.27
RELEASED ON	Friday, 07 March 2025
RECEIVED ON	Monday, 16 December 2024
ACCEPTED ON	Friday, 28 February 2025
LICENSE	This work is licensed under a Creative Commons Attribution 4.0 International License
JOURNAL	"Problems and Perspectives in Management"
ISSN PRINT	1727-7051
ISSN ONLINE	1810-5467
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
56	**2**	**10**

BUSINESS PERSPECTIVES

LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine
www.businessperspectives.org

Received on: 16th of December, 2024
Accepted on: 28th of February, 2025
Published on: 7th of March, 2025

Valeriia Shcherbak, Doctor of Economics, Professor, Department of Economics and Entrepreneurship, Sumy National Agrarian University, Ukraine.

Oleh Kolodiziev, Doctor of Economics, Professor, Department of International Trade, Customs and Financial Technologies, Simon Kuznets Kharkiv National University of Economics, Ukraine. (Corresponding author)

Ihor Krupka, Doctor of Economics, Professor, Department of Analytical and International Economics, Ivan Franko National University of Lviv, Ukraine.

Kseniia Vzhytynska, Ph.D. in Economics, Associate Professor, Department of Trade Enterprise and Logistics, State University of Trade and Economics, Kyiv National University of Trade and Economics, Ukraine.

Ilona Androshchuk, Ph.D. in Economics, Associate Professor, Department of Economics, Management and Commercial Activities, Central Ukrainian National Technical University, Ukraine.

Tetiana Kolodizieva, Ph.D. in Economics, Associate Professor, Department of Management, Logistics and Innovation, Simon Kuznets Kharkiv National University of Economics, Ukraine.

Volodymyr Berehovyi, Ph.D. Student, Department of International Trade, Customs and Financial Technologies, Simon Kuznets Kharkiv National University of Economics, Ukraine.

Conflict of interest statement:
Author(s) reported no conflict of interest

Valeriia Shcherbak (Ukraine), **Oleh Kolodiziev** (Ukraine), **Ihor Krupka** (Ukraine), **Kseniia Vzhytynska** (Ukraine), **Ilona Androshchuk** (Ukraine), **Tetiana Kolodizieva** (Ukraine), **Volodymyr Berehovyi** (Ukraine)

IMPACT OF INTERNATIONAL TRADE ON REGIONAL ECOSYSTEM SUSTAINABILITY: EVIDENCE FROM UKRAINE AMID WAR

Abstract

The study aims to examine the impact of international trade on the sustainability of regional ecosystems in Ukraine, particularly amid the ongoing Russia-Ukraine war. The paper applies econometric modeling, factor analysis, cluster analysis, and geographic information systems (GIS) for spatial analysis. Sustainability indicators include environmental resilience indicators (carbon emissions, water quality), economic stability metrics (GDP per capita, investment in green technologies), and social sustainability factors (employment rate, access to education and healthcare). Results indicate that a 1% increase in exports enhances sustainability indicators by 0.9%, while a 1% rise in imports or demographic density reduces these indices by 0.94% and 0.75%, respectively. Cluster analysis identifies five groups of regions with varying ecological resilience, revealing critical vulnerabilities in southern and eastern Ukraine where resilience indices are below 0.5. War actions exacerbate these issues, causing infrastructure destruction, soil and water degradation, and pollutant emissions ranging from 152.5 to 16,311.4 thousand tons. Recommendations include scaling up environmental protection investments by 20% (from the current 5,965–165,228 thousand UAH) and integrating sustainability standards into international trade policies to harmonize economic activities with environmental management in crisis and post-war recovery contexts.

Keywords ecosystem sustainability, international trade, econometric modeling, cluster analysis, discriminant analysis, geographic information systems

JEL Classification F18, Q56, Q51, Q53, R11

INTRODUCTION

International trade plays a significant role in the economic development of regions, contributing to attracting investments, creating jobs, and increasing incomes. However, its impact on the environmental sustainability of regions remains a subject of debate. On the one hand, foreign economic activity can stimulate the adoption of environmentally friendly technologies and standards. On the other hand, increased trade often leads to ecosystem degradation, depletion of natural resources, and higher levels of environmental pollution.

The relevance of this study stems from the need to examine the impact of international trade on the sustainable development of ecosystems in Ukrainian regions during post-war recovery. Understanding the nature and scale of this impact will not only help mitigate the negative environmental consequences of war actions but also aid in developing effective measures to preserve natural resources and ensure the region's long-term sustainability. Therefore, it is necessary to analyze the

http://dx.doi.org/10.21511/ppm.23(1).2025.27

key factors of international trade that affect regional ecosystems, taking into account the consequences of war actions. Particular attention should be paid to the development of recommendations for the restoration and development of infrastructure, as well as the environmentally safe use of natural resources in the context of the Russia-Ukraine war.

1. LITERATURE REVIEW AND HYPOTHESES

The relationship between international trade and ecosystems has been a subject of growing academic interest (Freckleton et al., 2012; Kottaridi & Filippaios, 2015), evolving from early explorations of resource exploitation to comprehensive analyses of sustainability impacts (Melnyk et al., 2014; O'Riordan, 2000). Initial studies focused on trade's role in depleting natural resources, with attention to colonial trade practices (Nath, 2009), agricultural land use (Cai et al., 2016), and deforestation (Brundtland, 1985; Margulis, 2003). During this period, environmental concerns were secondary to economic growth, treated as externalities (Apergis et al., 2008; Folke et al., 2005).

With the rise of sustainable development in the 1980s (Burford et al., 2013; Glaser, 2012; Griggs et al., 2013), scholars began examining the trade-environment nexus more comprehensively (McAusland et al., 2004). Key developments included the concept of the ecological footprint for quantifying environmental impacts of consumption (Borensztein et al., 1998; Wang et al., 2020), including imports and exports (Rees, 2013), and studies on trade's effects on pollution and waste (Adhikary, 2011). Moreover, recent research highlights the role of digitalization and stakeholder collaboration in ensuring sustainable economic development through trade, highlighting the importance of coordinated policies between education, business, and scientific institutions (Siskos et al., 2023).

Modern studies adopt a more holistic approach, emphasizing sustainability and ecosystem services. For instance, Cima and Esty (2024) and Hak et al. (2012, 2007) stress the critical role of ecosystem services such as water purification and climate regulation in global trade (Lempert et al., 2006). Other research focuses on the adverse effects of trade (Tsitouras et al., 2017), including biodiversity loss, invasive species introduction, and ecosystem degradation (Pyšek & Richardson, 2010). Additionally, with the rise of digital marketing strategies, omnichannel approaches have been suggested as tools to improve efficiency in international trade while reducing environmental costs by optimizing supply chains and resource allocation (Darvidou, 2024).

The impact of international trade agreements, such as those governed by GATT/WTO, on environmental legislation is increasingly analyzed, emphasizing the integration of sustainability standards and the promotion of "green trade" (Brito, 2012; Pokharel & Baral, 2009). Vačkářová et al. (2023) quantified ecosystem service losses due to crop production for international trade, while Chaudhary and Brooks (2019) explored the biodiversity impacts of national consumption patterns, underlining the interconnectedness of trade and ecosystem resilience (Glaser, 2012; Griggs et al., 2013; Hák et al., 2015). Well-structured foreign trade policies can enhance economic growth and environmental sustainability by aligning trade agreements with ecological goals, particularly in developing economies (Telnova et al., 2023).

The onset of the Russia-Ukraine war has fundamentally altered the landscape of international trade. Export-import activities have been disrupted, trade flows reoriented, and the priorities of regional economies shifted toward wartime needs (WTO, 2022). While some sectors, such as military and humanitarian aid logistics, have expanded, others, including agriculture and industrial exports, have contracted significantly (Frolov et al., 2016). Such shifts exacerbate preexisting vulnerabilities in ecosystem management (Shcherbak et al., 2020) and environmental resilience (Vačkářová et al., 2023).

The collapse of trade in regions with active hostilities, particularly in southern and eastern Ukraine, has increased ecological risks, including infrastructure destruction, elevated emissions, and degraded resource quality (Malik et al., 2024). These disruptions are evident in the elevated material demands for rebuilding efforts and the intensified exploitation of natural resources, as noted in global analyses of resource flows and material consumption (Bruckner et al., 2012; Dittrich & Bringezu, 2010).

Regional trade dynamics also show stark contrasts in ecological impacts. For instance, trade in crop-based commodities has been linked to significant ecosystem service losses, particularly in areas with high agricultural productivity (Vačkářová et al., 2023; Kastner et al., 2014). Furthermore, disruptions in global biodiversity due to changes in trade flows highlight the interconnectedness of regional ecosystems and global markets (Chaudhary & Brooks, 2017).

The Russia-Ukraine war has shifted international trade priorities, emphasizing survival over sustainability. This change mirrors trends observed in crisis-stricken regions where immediate resource needs override longer-term ecological considerations (Klapper & Schröter, 2021; Shcherbak et al., 2024). However, integrating sustainability standards into recovery efforts, as advocated by studies on "green trade" and sustainable development practices, remains crucial for mitigating environmental risks (Malik et al., 2024; Pokharel & Baral, 2009).

These disruptions underscore the need to reframe discussions on trade's ecological impacts in the context of crisis and post-war recovery. Trade policies that align with environmental management can play a critical role in rebuilding regional ecosystems while supporting sustainable development goals (WTO, 2022; Frolov et al., 2016).

Empirical studies provide critical insights into the material dimensions of trade. For example, Bruckner et al. (2012) analyzed global material extraction between 1995 and 2005, revealing trade's significant contribution to resource depletion. Hudea and Stancu (2012) highlighted discrepancies in cropland use estimates due to varying methodological approaches, while Attaran (2006) quantified the physical dimensions of trade flows. These findings underscore the importance of aligning trade practices with sustainable resource management. Furthermore, new approaches in financial modeling, such as fuzzy logic-based credit assessments, offer tools for evaluating trade-related risks and sustainability in complex economic environments (Omelchenko et al., 2018).

Three major theoretical constructs provide the foundation for understanding the trade-environment relationship (Telles, 2024). A critical tool for assessing resource consumption and pollution, the ecological footprint quantifies how international trade affects natural resource depletion (Sutherland et al., 2013; Huan et al., 2021). While traditionally focused on cost efficiency, modern interpretations advocate integrating environmental costs into this framework to encourage sustainable specialization (Hickel et al., 2022; Hoover & Wible, 2020). Popularized by the Brundtland Report (Mudgal et al., 2012), this concept emphasizes balancing economic growth (Cash et al., 2003; Dahl, 2012; Evans & Steven, 2012) and environmental protection (Feeny et al., 2014; Gann et al., 2019; Geissdoerfer et al., 2017). It calls for embedding ecological standards into trade agreements to mitigate long-term environmental impacts.

A comprehensive literature review reveals a dual impact of international trade on ecosystems. Positive effects include improved resource efficiency and access to sustainable technologies, while negative outcomes often involve biodiversity loss, pollution, and resource depletion. Modern theoretical approaches emphasize incorporating environmental factors into global economic activities. Quantitative tools like the ecological footprint, alongside sustainable development theories and revised comparative advantage models, highlight trade's dual role in fostering growth while mitigating ecological harm. Integrating these concepts into international trade practices is crucial for steering global economies toward sustainable development. The reviewed literature also underscores the importance of integrating ecological considerations into trade policies, highlighting the need for robust methodologies, such as GIS and spatial analysis, to monitor trade's environmental impacts effectively. By aligning trade activities with sustainability principles, it is possible to minimize ecological risks while fostering long-term economic and environmental resilience.

The study aims to examine the impact of international trade on the sustainability of regional

http://dx.doi.org/10.21511/ppm.23(1).2025.27

ecosystems in Ukraine amid the ongoing Russia-Ukraine war. The hypotheses are as follows:

H1: *Export activities and investments in environmental protection positively impact the resilience of regional ecosystems, enhancing ecological sustainability and promoting balanced development.*

H2: *Import activities and demographic pressures exacerbate the ecological vulnerabilities of regional ecosystems, especially during the war, leading to natural resource degradation and increased pollution.*

2. METHODS

The research methodology involves a step-by-step approach consisting of regression, factor, cluster, and discriminant analyses.

The first stage is calculating the sustainable development indicator to assess the environmental situation. The indicator is designed to comprehensively evaluate the environmental situation in a specific region based on key Sustainable Development Goals related to environmental sustainability. It is determined through factor analysis, which enables the quantitative assessment of a region's progress in addressing environmental challenges and identifying areas that require prioritized attention.

The second stage is determining the extent of the impact of international trade on the region's ecosystem (regression analysis). An econometric regression model analyzes the relationship between trade indicators and ecosystem sustainability.

The third stage is cluster analysis, which classifies regions by the level of ecosystem sustainability. The *k*-means clustering method is applied to identify groups of regions with similar environmental characteristics and levels of trade impact. The goal is to create a foundational understanding of the current state of regional ecosystem sustainability and its dependence on international trade.

The fourth stage is discriminant analysis, which predicts changes in regional cluster membership

Table 1. Calculation methodology and key components

Calculation steps	Calculation method	Calculation components
Stage 1. Calculation of the sustainable development indicator (I_{ECOi}) to assess the environmental situation	$I_{ECOi}=\omega_1 C_{13}+\omega_2 C_{15}+\omega_3 C_6$ (1)	I_{ECOi} – sustainable development indicator in the *i-th* region C_{13} – progress on Goal 13 (Climate Action) in the *i-th* region; C_{15} – progress on Goal 15 (Life on Land) in the *i-th* region; C_6 – progress on Goal 6 (Clean Water and Sanitation) in the *i-th* region; ω_{1-3} – weights of the corresponding indicators determined by the statistical method.
Stage 2. Econometric modeling to assess the impact of trade on ecosystem sustainability	$ECO_i=\beta_0+\beta_1 E_i+\beta_2 I_i+\beta_3 T_i+\beta_4 P_i+\beta_5 G_i+\varepsilon_i$ (2)	ECO_i – ecosystem sustainability index in the *i-th* region; E_i – volume of exports in the *i-th* region; I_i – volume of imports in the *i-th* region; T_i – industrialization index (level of industrial development) of the *i-th* region; P_i – demographic load on the ecosystem (population density) in the *i-th* region; G_i – level of "green" investments (environmental programs) in the *i-th* region; β_{0-5} – model coefficients; ε_i – random error.
Stage 3. Cluster analysis to classify regions by the level of ecosystem sustainability	$\mu_k=\frac{1}{\lvert C_k\rvert}\sum_{i\in C_k} x_i$ (3)	μ_k – center of cluster *k*; C_k – set of objects belonging to cluster *k*; $\lvert C_k\rvert$ – number of objects in cluster *k*; x_i – values of characteristics of object *i*.
Stage 4. Using geographic information systems (GIS) for spatial analysis of the impact on ecosystems and identification of cluster affiliation using the discriminant method	$I_{ECO_i}=f(LU_i+T_{em_i}+R_{aq_i}+R_{for_i})$ (4)	I_{ECOi} – index of ecological condition in the *i-th* region; LU_i – land use (agriculture, industry, forest land) in the *i-th* region; T_{emi} – level of emissions (pollution) in the *i-th* region; R_{aqi} – water resources in the *i-th* region; R_{fori} – forest resources in the *i-th* region; *f* – functional dependence determined on the basis of discriminant analysis.

in connection with shifts in ecosystem sustainability and the influence of international trade. The equations used for calculations at each stage are presented in Table 1.

For the analysis of ecosystem sustainability and the impact of international trade in the regions of Ukraine, the following data, collected from official statistical information of the State Statistics Service of Ukraine, are used. The volume of exports (*X*1) reflects the value of goods and services exported from the region, which is an indicator of economic activity and trade flows. The volume of imports (*X*2) shows the volume of purchased goods and services, which affects the region's foreign trade balance. The population (*X*3) reflects the demographic pressure on the ecosystem and affects the intensity of natural resource consumption. The industrial production index (*X*4) characterizes the level of industrialization of the region, which is associated with the intensity of natural resource use and the volume of emissions. Capital investments in environmental protection (*X*5) demonstrate the amount of funds allocated for environmental measures, which helps to reduce the environmental burden. The volume of carbon dioxide emissions (*X*6) as an indicator of air pollution reflects the environmental burden from economic activities. The area of forest felling (*X*7) reflects the state of forest ecosystems, which play a key role in regulating the carbon balance. The volume of extracted aquatic biological resources (*X*8) shows the level of use of aquatic ecosystems. Sown areas (*X*9) reflect the degree of land use for agriculture, which is important for assessing the impact on ecosystems. All data were obtained from official statistical collections of the State Statistics Service of Ukraine and are presented in Appendix A. This ensures high reliability and relevance of the information used.

The research analysis was conducted in Ukraine using Ukrstat data for 2022–2024.

3. RESULTS AND DISCUSSION

Table 2 presents the results of the factor analysis performed at the first stage of calculating the sustainable development indicator I_{ECOi}, which assesses the environmental situation in the region.

Table 2. Factor analysis for calculating the sustainable development indicator

Source: STATISTICA 13 listing.

Variable	Factor Loadings (Unrotated) (Data_nor) Extraction: Principal components (Marked loadings are > .700000)		
	Factor 1	Factor 2	Factor 3
X5	0.889587	0.205546	–0.399793
X6	0.877106	0.178784	0.245370
X7	–0.435187	0.785085	–0.268451
X8	0.412147	–0.406761	0.860342
X9	0.275216	0.788204	–0.447351
Exp.Var	3.055884	2.239253	1.177845
Prp.Totl	0.542647	0.276005	0.160348

The indicator I_{ECOi} is formed as a weighted sum of progress on SDG 13 (Climate Action), SDG 15 (Life on Land), and SDG 6 (Clean Water and Sanitation). The weights ($\omega 1$, $\omega 2$, $\omega 3$) are determined on the basis of factor analysis using the principal component method. The factor loading values indicate which variables (*X*5, *X*6, *X*7, *X*8, *X*9) are most strongly associated with the corresponding factors. A high loading on *X*5 (0.889) indicates a significant contribution of this indicator to progress on SDG 13; *X*6 (0.877) confirms its impact on progress in the fight against climate change. Two indicators are associated with Factor 2: indicator *X*7 (0.785) reflects the contribution to the conservation of terrestrial ecosystems (SDG 15); indicator *X*9 (0.788) testifies to the importance of this indicator for assessing terrestrial ecosystems. The *X*8 indicator (0.860) is the most significant for Factor 3, which corresponds to the impact on SDG 6. Factor 1 explains 54.6%, Factor 2 explains 27.60%, and Factor 3 explains 16.03% of the total data variation. Together, the three factors explain 98% of the total variance, indicating the high informativeness of the model. The indicator is calculated as (5):

$$I_{ECOi} = \frac{1}{3.056}\left(0.889X5 + 0.877X6\right) + \frac{1}{2.239}\left(0.785X7 + 0.788X9\right) + \frac{1}{1.178}\left(X8\right), \tag{5}$$

where $\omega 1 = 1/3.056$; $\omega 2 = 1/2.239$; $\omega 3 = 1/1.178$ – weighting coefficients determined on the basis of the inverse values of the explained variance of the factors.

http://dx.doi.org/10.21511/ppm.23(1).2025.27

The results of the factor analysis confirm that indicators $X5$ and $X6$ make the main contribution to combating climate change (SDG 13), indicators $X7$ and $X9$ are important for preserving terrestrial ecosystems (SDG 15), and $X8$ reflects progress in the sustainable use of water resources (SDG 6). Equation (5) allows integrating these indicators into a single indicator of the region's environmental sustainability. At the second stage, econometric modeling was conducted to assess the impact of trade on ecosystem sustainability. The results of the regression analysis are presented in Table 3.

The results of the regression analysis of the dependence of ecosystem sustainability on the impact of international trade (Table 3) show a high degree of dependence of the explained variable ($X10$) on the independent variables ($X1$, $X2$, $X3$, $X4$, $X5$).

The coefficient of determination $R^2 = 0.9886$ indicates that 98.86% of the variation in ecosystem resilience ($X10$) is explained by changes in the independent variables. Adjusted $R^2_{adj} = 0.9856$ confirms the significance of the model, even taking into account the number of independent variables. F statistics: The value (5,19) = 328.52 and $p < 0.00000$ show that the model is statistically significant.

Each variable ($X1 – X5$) has a significant contribution to the model, as all p-values are less than 0.05:

- $X1$ (Export): $b^* = 0.915$ with $p = 0.000004$. Exports have a positive effect on ecosystem resilience, which may be related to their role in stimulating economic development and investment in environmental protection.
- $X2$ (Import): $b^* = -0.944$ with $p = 0.000002$. Imports have a negative effect, possibly due to increased dependence on external resources or environmental costs associated with transportation.
- $X3$ (Population): $b^* = -0.748$ with $p = 0.000001$. The increase in population puts pressure on the ecosystem, reflecting the effect of anthropogenic pressure.
- $X4$ (Industrial production index): $b^* = 0.782$ with $p = 0.000002$. The positive impact of industrial production can be attributed to the introduction of environmentally friendly technologies.
- $X5$ (Capital investment in environmental protection): $b^* = 0.960$ with $p = 0.000000$. The largest positive contribution among all variables, highlighting the importance of investment in environmental sustainability.

All independent variables are statistically significant ($p < 0.05$), indicating their importance for predicting ecosystem sustainability. Variables $X1$, $X4$, $X5$ have a positive effect, while $X2$ and $X3$ have a negative effect. This highlights the complex balance between economic development, demo-

Table 3. Regression analysis of the dependence of ecosystem sustainability on the influence of international trade

Source: STATISTICA 13 listing.

Predictor	N = 25 Regression Summary for Dependent Variable: X10 (Data) R = 0.99426612 R² = 0.98856511 Adjusted R² = 0.98555593 F(5,19) = 328.52, p < 0.00000 Std. Error of estimate: 0.12018					
	b*	**Std.Err. of b***	**b**	**Std.Err. of b**	***t*(19)**	***p*-value**
Intercept	–	–	–0.000000	0.024037	–0.00000	1.000000
X1	0.915337	0.013810	0.915337	0.013810	19.01341	0.000004
X2	–0.943952	0.048005	–0.943952	0.048005	–19.44846	0.000002
X3	–0.747561	0.030698	–0.747561	0.030698	–17.54932	0.000001
X4	0.782348	0.027085	0.782348	0.027085	18.08669	0.000002
X5	0.960286	0.045823	0.960286	0.045823	20.95642	0.000000

Note: * – Standardized coefficients (β).

Source: STATISTICA 13 listing.

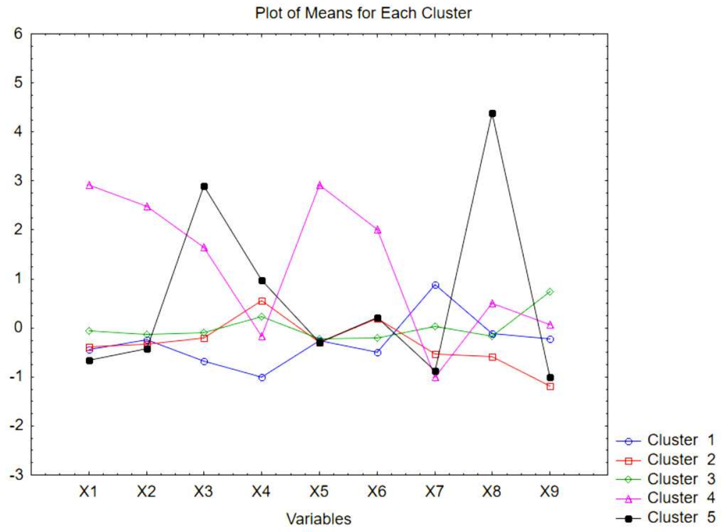

Figure 1. K-means clustering of regions of Ukraine depending on the level of international trade and environmental sustainability

graphic factors, and environmental sustainability. The low standard error (Std.Error = 0.12018) indicates high accuracy of the model.

Increasing investment in environmental protection ($X5$) should be a priority to achieve ecosystem sustainability. Developing export activities ($X1$) can have a positive effect on sustainability, provided that it is accompanied by environmentally friendly technologies. Reducing environmental costs of imports ($X2$) and managing demographic pressures ($X3$) require special attention to minimize their negative impact.

In the third stage, cluster analysis was conducted to classify regions by the level of ecosystem sustainability. The *k*-means graph is presented in Figure 1.

As a result of the cluster analysis, five clusters were obtained. The composition of all five clusters is given in Tables 4-8.

Table 4. Members of cluster 1 and distances from the respective cluster center

Source: STATISTICA 13 listing.

List of Members	Distance	List of Members	Distance
Volyn	0.274647	Ternopil	0.855561
Ivano-Frankivsk	0.740038	Khmelnytskyi	0.332439
Rivne	0.597441	Chernivtsi	0.571702
Zakarpattia	0.560774	Vinnytsia	0.733817
Lviv	0.602531	–	–

Note: Unit of measurement: Distance is measured in Euclidean units.

The first cluster (Table 4) includes nine western and central regions of Ukraine: Volyn, Ternopil, Ivano-Frankivsk, Khmelnytskyi, Rivne, Chernivtsi, Zakarpattia, Vinnytsia, and Lviv. Distances from the cluster center vary from 0.27 (Volyn) to 0.86 (Ternopil). The regions of the first cluster have a relatively stable position, as they are located far from active hostilities. Economic activity in these areas is supported by the agricultural sector and international trade. The sustainability of the ecosystem in these regions is above average, which may be due to less anthropogenic pressure and the absence of infrastructure destruction.

Table 5. Members of cluster 2 and distances from the respective cluster center

Source: STATISTICA 13 listing.

List of Members	Distance	List of Members	Distance
Kherson	0.279855	Sumy	0.376130
Zaporizhzhia	0.476872	Kharkiv	0.495418
Mykolaiv	0.436726	Odesa	0.637505

Note: Unit of measurement: Distance is measured in Euclidean units.

The second cluster includes six southern and eastern regions: Kherson, Sumy, Zaporizhzhia, Kharkiv, Mykolaiv, and Odesa. Distances from the cluster center range from 0.28 (Kherson) to 0.64 (Odesa). These regions are subject to active war actions or regular bombing. Economic activity is significantly limited, which negatively affects environmental sustainability (destruction of ecosystems and pollution). High risks for the resto-

http://dx.doi.org/10.21511/ppm.23(1).2025.27

ration of ecosystems require significant resources and planning after the end of war actions.

Table 6. Members of cluster 3 and distances from the respective cluster center

Source: STATISTICA 13 listing.

List of Members	Distance	List of Members	Distance
Zhytomyr	0.445393	Poltava	0.340172
Kyiv	0.425005	Cherkasy	0.300449
Kirovohrad	0.421971	Chernihiv	0.335647

Note: Unit of measurement: Distance is measured in Euclidean units.

The third cluster includes six central regions: Zhytomyr, Poltava, Kyiv region, Cherkasy, Kirovohrad, and Chernihiv. Distances from the cluster center range from 0.30 (Cherkasy) to 0.45 (Zhytomyr). The regions are characterized by a moderate level of sustainability, partly due to their location near the center of Ukraine. Although some areas are damaged, the overall state of the ecosystems remains relatively stable.

Table 7. Members of cluster 4 and distances from the respective cluster center

Source: STATISTICA 13 listing.

List of Members	Distance	List of Members	Distance
Dnipropetrovsk	1.280803	Kyiv City	1.280803

Note: Unit of measurement: Distance is measured in Euclidean units.

The fourth cluster includes two large members: Dnipropetrovsk region and the city of Kyiv. The distances from the cluster center are 1.28 for both regions. The high distance from the cluster center indicates a significant deviation of these regions from the rest in terms of sustainability and international trade levels. Kyiv, as the capital, maintains a high level of economic activity despite threats. Dnipropetrovsk region is also an important economic center, which explains its similarity to Kyiv.

Table 8. Members of cluster 5 and distances from the respective cluster center

Source: STATISTICA 13 listing.

List of Members	Distance	List of Members	Distance
Donetsk	0.040172	Luhansk	0.040172

Note: Unit of measurement: Distance is measured in Euclidean units.

The fifth cluster includes Donetsk and Luhansk regions. The distances from the cluster center are minimal (0.04), which indicates their almost identical position. These regions are almost completely destroyed due to active war actions. The level of environmental sustainability is extremely low due to the destruction of infrastructure, pollution of soil, water and air.

In the last fourth stage, models for identifying cluster affiliation (Table 9) and spatial analysis of the impact of international trade on ecosystems (Figure 2) were built using discriminant analysis.

Table 9. Discriminant analysis

Source: STATISTICA 13 listing.

Effect	Classification Functions for X10 Sigma-restricted parameterization				
	Cluster 1 $p = .2400$	Cluster 2 $p = .2000$	Cluster 3 $p = .4400$	Cluster 4 $p = .0800$	Cluster 5 $p = .0400$
Intercept	–8.32334	–16.7797	–2.90833	–328.330	–261.839
"X1"	–5.59918	13.3319	1.25229	–14.667	–17.505
"X2"	–7.51838	–32.3496	–2.28450	133.865	–35.742
"X3"	1.87515	5.5042	0.61572	–42.320	39.096
"X4"	–4.23149	–0.2953	1.09287	3.344	8.157
"X5"	–6.00579	–22.4045	–5.89981	145.441	–77.927
"X6"	–2.01748	3.0936	0.10547	–4.044	3.564
"X7"	3.46547	1.0590	0.11731	–18.261	9.143
"X8"	–1.73502	–7.6334	–0.99293	–8.929	77.358
"X9"	–3.80318	–12.6055	3.03930	33.525	–14.635

Table 9 presents the coefficients of the classification functions for each cluster, as well as the Sigma-restricted parameterization. The main goal is to determine how the region's affiliation with a particular cluster will change when the initial data change. The classification function for each cluster j takes the form:

$$D_j = Intercept_j + \sum_{i=1}^{9} X_i \cdot \beta_{ij}, \tag{6}$$

where D_j – the discriminant index for cluster j, $Intercept_j$ – free term for cluster j, X_j – values of the initial variables (parameters), β_{ij} – coefficients of the variables for cluster j.

The following algorithm is used to identify a cluster based on changes in the initial data. The values of variables $X1$-$X9$ are substituted into the classification functions for all clusters. Discriminant indices Dj are calculated for each cluster. A region belongs to cluster j, where Dj is maximum.

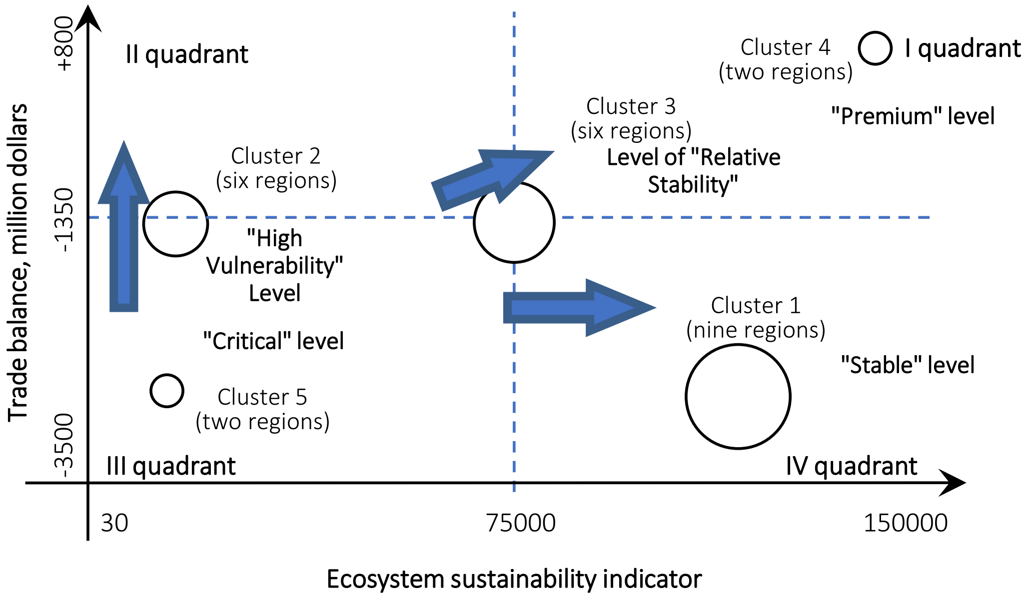

Figure 2. Matrix of spatial analysis of the impact of international trade on the ecosystem

Figure 2 is constructed in a coordinate system where the *X*-axis represents a complex indicator – the ecosystem sustainability indicator, the value of which for the regions was calculated using equation (1) (Appendix A). The *Y*-axis represents a complex indicator of the impact of international trade – the trade balance (Appendix A).

The first cluster ("Stable level") includes nine regions, predominantly western and central, characterized by a stable situation, a developed agricultural sector and international trade, and relatively high ecosystem sustainability. The second cluster ("High Vulnerability level") includes six southern and eastern regions exposed to active hostilities, with limited economic activity and low environmental sustainability. The third cluster ("Relative Stability level") includes six central regions, occupying an intermediate position between stable and most affected ones, with a moderate level of sustainability. The fourth cluster ("Premium level") includes two large regions (Kyiv and Dnipropetrovsk region), distinguished from the rest by a high level of economic activity and international trade. The fifth cluster ("Critical level") includes two regions (Donetsk and Luhansk regions), almost completely destroyed due to hostilities, with extremely low environmental sustainability.

Figure 2 also reflects the results of using discriminant analysis to predict transitions between clusters – in the form of arrows, that is, with the help of discriminant analysis, it is possible to predict the probability of a region's transition from one cluster to another when the initial parameters change. For example, the transition from "High Vulnerability level" to "Relative Stability level" is possible after the end of hostilities and the restoration of the economy and infrastructure; the regions of the second cluster can move to the third cluster. The discriminant analysis will allow for assessing the probability of such a transition based on changes in relevant indicators. The transition from "Relative Stability level" to "Stable level:" with further economic development and improvement of the environmental situation, the regions of the third cluster can move to the first cluster. The transition from "Stable level" to "Premium level:" with a significant increase in international trade volumes and further economic development, the regions of the first cluster can approach the characteristics of the fourth cluster.

The research results confirmed that international trade has both positive and negative impacts on ecosystem sustainability. The most significant variables influencing sustainability are capital investments in environmental protection and exports, which contribute to greater ecosystem resilience, while population size and imports tend to increase environmental pressures. These findings align with previous studies (Freckleton et al., 2012; Frolov et al., 2016), which highlight the dual nature of trade: it fosters economic growth and technological advancements while

http://dx.doi.org/10.21511/ppm.23(1).2025.27

simultaneously intensifying resource depletion and environmental degradation.

The study tested the hypothesis that the impact of international trade on the sustainable development of regional ecosystems depends on its structure, volume, and adherence to environmental standards. Specifically, export activities and environmental protection investments positively influence ecosystem resilience, while imports and demographic pressures exacerbate ecological vulnerabilities, particularly in regions affected by war. The findings support this hypothesis by demonstrating that trade policies and investment strategies directly influence environmental sustainability outcomes.

The results indicate that capital investments in environmental protection significantly mitigate negative trade-related impacts. This confirms earlier conclusions about the importance of considering external environmental costs in trade policy assessments (Tsitouras et al., 2017; Hák et al., 2015). Additionally, export-driven economies tend to implement greener technologies, as companies competing in international markets often adopt stricter environmental standards to meet global trade requirements. However, the negative consequences of trade – such as increased deforestation, resource overexploitation, and pollution – are exacerbated by uncontrolled imports and rapid population growth.

A regional analysis provides further insights into the differentiated impact of trade on ecosystem sustainability. Sumy, Kharkiv, Donetsk, and Luhansk regions, which share borders with the Russian Federation, experience significant ecological pressure due to hostilities, infrastructure destruction, and environmental pollution. These factors contribute to their classification as regions with increased vulnerability. In contrast, the western and central regions of Ukraine, which are less affected by war, demonstrate higher sustainability levels. This is attributed to lower anthropogenic pressure and active international trade, which fosters economic resilience and environmental investments.

The study also highlights the significant impact of the Russia-Ukraine war on regional trade dynamics and ecosystem sustainability. The disruption of trade routes, destruction of infrastructure, and increased demand for war-related resources have shifted economic priorities from sustainability to survival. While some sectors, such as military and humanitarian logistics, have expanded, others – especially agriculture and industrial production – have faced severe constraints. The environmental consequences of this shift include an increased carbon footprint due to intensified resource extraction and reconstruction activities, as well as reduced oversight of ecological standards in war-affected areas.

Several limitations should be acknowledged. First, the reliance on official statistics may not fully account for hidden environmental costs, particularly in regions experiencing active hostilities. The ongoing war introduces a high degree of uncertainty, making it difficult to develop long-term sustainability forecasts. Additionally, the study does not encompass all environmental factors, such as air and water pollution resulting from war actions, which may distort the estimated impact of trade on ecosystem sustainability.

Despite these limitations, the findings provide valuable insights for policymakers. Addressing the environmental consequences of trade requires a balanced approach that promotes green technologies, strengthens regulatory frameworks, and integrates sustainability considerations into international trade agreements. Future research should focus on longitudinal studies assessing the post-war economic recovery and its implications for regional ecosystem sustainability.

CONCLUSION

The study aims to examine the impact of international trade on the sustainability of regional ecosystems in Ukraine, particularly amid the ongoing Russia-Ukraine war. To analyze this impact, the paper examined export-import dynamics, environmental investments, and demographic pressures. The findings confirm that international trade has a dual impact on the sustainability of regional ecosystems, with its effects depending on the trade structure, volume, and adherence to environmental standards. Export activities and capital investments in environmental protection positively influence ecosystem resilience, improving sustainability indices by 0.9%. In contrast, imports and demographic pressures exacerbate ecological vulnerabilities, reducing sustainability indices by 0.94% and 0.75%, respectively. These dynamics are particularly evident in southern and eastern regions, such as Donetsk and Luhansk, where resilience indices fall below 0.5 due to extensive infrastructure destruction, environmental pollution, and large-scale war actions.

The war significantly amplifies environmental risks, with pollutant emissions in the affected regions ranging from 152.5 to 16,311.4 thousand tons. GIS-based spatial analysis has proven effective in identifying the most vulnerable areas and facilitating the development of targeted restoration strategies. Cluster analysis further revealed substantial disparities in ecosystem sustainability: western and central regions exhibit higher resilience, whereas southern and eastern regions face critical ecological challenges.

The study confirms that international trade has a dual impact on the sustainability of regional ecosystems. While exports and investments in environmental protection enhance resilience, imports and demographic pressures exacerbate ecological vulnerabilities, particularly in war-affected areas. The Russia-Ukraine war has further intensified environmental risks, shifting economic priorities and disrupting trade flows. Three key measures should be prioritized for sustainable recovery and development. The first measure is ecological recovery. To achieve this, it is necessary to focus on post-war regions with sustainability indices below 0.5, restoring soils, water resources, and biodiversity. The second measure is increasing investment in environmental protection. To achieve this, increasing funding by at least 20% is necessary to address growing environmental problems. The third measure is the integration of sustainability standards. To achieve this, it is necessary to introduce environmental criteria into trade policy to balance economic and environmental goals. Additionally, advanced monitoring systems using GIS and modern technologies are essential for effective ecosystem management. Ensuring sustainable trade practices and environmental governance is critical for long-term regional stability, particularly in post-war recovery scenarios.

AUTHOR CONTRIBUTIONS

Conceptualization: Valeriia Shcherbak, Oleh Kolodiziev.
Data curation: Ihor Krupka, Kseniia Vzhytynska.
Funding acquisition: Ihor Krupka, Kseniia Vzhytynska, Ilona Androshchuk, Tetiana Kolodizieva.
Investigation: Valeriia Shcherbak, Ilona Androshchuk.
Methodology: Oleh Kolodiziev, Tetiana Kolodizieva.
Project administration: Valeriia Shcherbak, Volodymyr Berehovyi.
Resources: Oleh Kolodiziev, Tetiana Kolodizieva, Volodymyr Berehovyi.
Software: Ihor Krupka, Tetiana Kolodizieva.
Supervision: Oleh Kolodiziev, Ihor Krupka.
Validation: Ilona Androshchuk, Volodymyr Berehovyi.
Visualization: Oleh Kolodiziev, Kseniia Vzhytynska.
Writing – original draft: Oleh Kolodiziev, Kseniia Vzhytynska, Volodymyr Berehovyi.
Writing – review & editing: Valeriia Shcherbak, Oleh Kolodiziev, Ihor Krupka, Ilona Androshchuk, Tetiana Kolodizieva.

REFERENCES

1. Adhikary, B. K. (2011). FDI, trade openness, capital formation, and economic growth in Bangladesh: A linkage analysis. *International Journal of Business and Management, 6*(1), 16-28. http://dx.doi.org/10.5539/ijbm.v6n1p16
2. Apergis, N., Lyroudi, K., & Vamvakidis, A. (2008). The relationship between foreign direct investment and economic growth: Evidence from transition countries. *Transition Studies Review, 15*(1), 37-51. https://doi.org/10.1007/s11300-008-0177-0
3. Attaran, A. (2006). Correction: An immeasurable crisis? A criticism of the millennium development goals and why they cannot be measured. *PLoS Medicine, 3*(5), Article e224. https://doi.org/10.1371/journal.pmed.0030224

4. Borensztein, E., De Gregorio, J., & Lee, J. (1998). How does foreign direct investment affect economic growth? *Journal of International Economics, 45*(1), 115-135. https://doi.org/10.1016/s0022-1996(97)00033-0
5. Brito, L. (2012). Analyzing sustainable development goals. *Science, 336*(6087). https://doi.org/10.1126/science.1224531
6. Bruckner, M., Giljum, S., Lutz, C., & Wiebe, K. S. (2012). Materials embodied in international trade – Global material extraction and consumption between 1995 and 2005. *Global Environmental Change, 22*(3), 568-576. https://doi.org/10.1016/j.gloenvcha.2012.03.011
7. Brundtland, G. H. (1985). World Commission on environment and development. *Environmental Policy and Law, 14*(1), 26-30. https://doi.org/10.1016/s0378-777x(85)80040-8
8. Burford, G., Hoover, E., Velasco, I., Janoušková, S., Jimenez, A., Piggot, G., Podger, D., & Harder, M. (2013). Bringing the "missing pillar" into sustainable development goals: Towards intersubjective values-based indicators. *Sustainability, 5*(7), 3035-3059. https://doi.org/10.3390/su5073035
9. Cai, X., Lu, Y., Wu, M., & Yu, L. (2016). Does environmental regulation drive away inbound foreign direct investment? Evidence from a quasi-natural experiment in China. *Journal of Development Economics, 123,* 73-85. https://doi.org/10.1016/j.jdeveco.2016.08.003
10. Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., Guston, D. H., Jäger, J., & Mitchell, R. B. (2003). Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences, 100*(14), 8086-8091. https://doi.org/10.1073/pnas.1231332100
11. Chaudhary, A., & Brooks, T. M. (2019). National consumption and global trade impacts on biodiversity. *World Development, 121,* 178-187. https://doi.org/10.1016/j.worlddev.2017.10.012
12. Cima, E., & Esty, D. C. (2024). Making international trade work for sustainable development: Toward a new WTO framework for subsidies. *Journal of International Economic Law, 27*(1), 1-17. https://doi.org/10.1093/jiel/jgae008
13. Dahl, A. L. (2012). Achievements and gaps in indicators for sustainability. *Ecological Indicators, 17,* 14-19. https://doi.org/10.1016/j.ecolind.2011.04.032
14. Darvidou, K. (2024). Omnichannel marketing in the digital age: Creating consistent, personalized and connected customer experiences. *Technium Business and Management, 10,* 34-54. https://doi.org/10.47577/business.v10i.11903
15. Dittrich, M., & Bringezu, S. (2010). The physical dimension of international trade: Part 1: Direct global flows between 1962 and 2005. *Ecological Economics, 69*(9), 1838-1847. https://doi.org/10.1016/j.ecolecon.2010.04.023
16. Evans, A., & Steven, D. (2012). *Sustainable development goals – A useful outcome from Rio + 20.* New York: New York University, Centre on International Cooperation. Retrieved from http://www.globaldashboard.org/wp-content/uploads/SDGs-briefing1.pdf
17. Feeny, S., Iamsiraroj, S., & McGillivray, M. (2014). Growth and foreign direct investment in the Pacific Island countries. *Economic Modelling, 37,* 332-339. https://doi.org/10.1016/j.econmod.2013.11.018
18. Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources, 30*(1), 441-473. https://doi.org/10.1146/annurev.energy.30.050504.144511
19. Freckleton, M., Wright, A., & Craigwell, R. (2012). Economic growth, foreign direct investment and corruption in developed and developing countries. *Journal of Economic Studies, 39*(6), 639-652. https://doi.org/10.1108/01443581211274593
20. Frolov, S., Savytska, O., & Ostapenko, L. (2016). Impact of social and economic development of the region on the international trade by the example of Ukraine. *Public and Municipal Finance, 5*(3), 7-15. https://doi.org/10.21511/pmf.5(3).2016.01
21. Gann, G. D., McDonald, T., Walder, B., Aronson, J., Nelson, C. R., Jonson, J., Hallett, J. G., Eisenberg, C., Guariguata, M. R., Liu, J., Hua, F., Echeverría, C., Gonzales, E., Shaw, N., Decleer, K., & Dixon, K. W. (2019). International principles and standards for the practice of ecological restoration. Second edition. *Restoration Ecology, 27*(S1), S1-S46. https://doi.org/10.1111/rec.13035
22. Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The circular economy – A new sustainability paradigm? *Journal of Cleaner Production, 143,* 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048
23. Glaser, G. (2012). Base sustainable development goals on science. *Nature, 491*(7422), Article 35. https://doi.org/10.1038/491035a
24. Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., & Noble, I. (2013). Sustainable development goals for people and planet. *Nature, 495*(7441), 305-307. https://doi.org/10.1038/495305a
25. Hák, T., Janoušková, S., & Moldan, B. (2015). Sustainable development goals: A need for relevant indicators. *Ecological Indicators, 60,* 565-573. https://doi.org/10.1016/j.ecolind.2015.08.003
26. Hak, T., Kovanda, J., & Weinzettel, J. (2012). A method to assess the relevance of sustainability indicators: Application to the indicator set of the Czech Republic's Sustainable Development Strategy. *Ecological Indicators, 17,* 46-57. https://doi.org/10.1016/j.ecolind.2011.04.034
27. Hak, T., Moldan, B., & Dahl, A. (2007). *Sustainability indicators: A scientific assessment. SCOPE 67*. Island Press. Retrieved from https://www.researchgate.net/publication/258261619_Sustainability_Indicators_A_Scientific_Assessment_SCOPE_67

28. Hickel, J., Dorninger, C., Wieland, H., & Suwandi, I. (2022). Imperialist appropriation in the world economy: Drain from the global South through unequal exchange, 1990–2015. *Global Environmental Change, 73,* Article 102467. https://doi.org/10.1016/j.gloenvcha.2022.102467

29. Hoover, N., & Wible, N. (2020). Ricardian inference: Charles S. Peirce, economics, and scientific method. *Transactions of the Charles S Peirce Society: A Quarterly Journal in American Philosophy, 56*(4), 521-557. https://doi.org/10.2979/trancharpeirsoc.56.4.02

30. Huan, Y., Yu, Y., Liang, T., & Burgman, M. (2021). A method for assessing the impacts of an international agreement on regional progress towards sustainable development goals. *The Science of the Total Environment, 785,* Article 147336. https://doi.org/10.1016/j.scitotenv.2021.147336

31. Hudea, O. S., & Stancu, S. (2012). Foreign direct investments, technology transfer and economic growth. A panel approach. *Romanian Journal of Economic Forecasting, 2,* 85-102. Retrieved from https://ipe.ro/rjef/rjef2_12/rjef2_2012p85-102.pdf

32. Kastner, T., Schaffartzik, A., Eisenmenger, N., Erb, K., Haberl, H., & Krausmann, F. (2014). Cropland area embodied in international trade: Contradictory results from different approaches. *Ecological Economics, 104,* 140-144. https://doi.org/10.1016/j.ecolecon.2013.12.003

33. Klapper, J., & Schröter, M. (2021). Interregional flows of multiple ecosystem services through global trade in wild species. *Ecosystem Services, 50,* Article 101316. https://doi.org/10.1016/j.ecoser.2021.101316

34. Kottaridi, C., & Filippaios, F. (2015). The FDI and trade relationship revisited under structural change: Evidence from a sector-based analysis in Central and Eastern European countries. *East-West Journal of Economics and Business, 18*(2), 1-40. Retrieved from https://www.u-picardie.fr/eastwest/fichiers/art192.pdf

35. Lempert, R. J., Groves, D. G., Popper, S. W., & Bankes, S. C. (2006). A general, analytic method for generating robust strategies and narrative scenarios. *Management Science, 52*(4), 514-528. https://doi.org/10.1287/mnsc.1050.0472

36. Malik, A., Lenzen, M., Li, M., Mora, C., Carter, S., Giljum, S., Lutter, S., & Gómez-Paredes, J. (2024). Polarizing and equalizing trends in international trade and sustainable development goals. *Nature Sustainability, 7*(10), 1359-1370. https://doi.org/10.1038/s41893-024-01397-5

37. Margulis, S. (2003). *Causes of deforestation of the Brazilian Amazon*. Washington, DC: World Bank. https://doi.org/10.1596/0-8213-5691-7

38. McAusland, C., Copeland, B. R., & Taylor, M. S. (2004). Trade and the environment: Theory and evidence. *Canadian Public Policy, 30*(4), 456-458. https://doi.org/10.2307/3552527

39. Melnyk, L., Kubatko, O., & Pysarenko, S. (2014). The impact of foreign direct investment on economic growth: Case of post communism transition economies. *Problems and Perspectives in Management, 12*(1), 17-24. Retrieved from https://www.businessperspectives.org/index.php/journals/problems-and-perspectives-in-management/issue-44/the-impact-of-foreign-direct-investment-on-economic-growth-case-of-post-communism-transition-economies

40. Mudgal, S., Tan, A., Lockwood, S., Eisenmenger, N., Fischer-Kowalski, M., Giljum, S., & Brucker, M. (2012). *Assessment of resource efficiency indicators and targets* (Final Report). European Commission. Retrieved from https://op.europa.eu/sv/publication-detail/-/publication/69d2b988-657d-4167-84a6-cdf6182dc92b/language-en

41. Nath, H. K. (2009). Trade, foreign direct investment, and growth: Evidence from transition economies. *Comparative Economic Studies, 51*(1), 20-50. https://doi.org/10.1057/ces.2008.20

42. O'Riordan, T. (2000). Sustainability indicators: Measuring the immeasurable: Simon Bell and Stephen Morse; Earthscan Publications, London, 1998, 175pp, paperpack, ISBN 1 85389 498, £14.95. *Journal of Rural Studies, 16*(3), 395. https://doi.org/10.1016/s0743-0167(99)00036-4

43. Omelchenko, O., Dorokhov, A., Kolodiziev, O., & Dorokhova, L. (2018). Fuzzy modeling of creditworthiness assessments of bank's potential borrowers in Ukraine. *Economic Studies (Ikonomicheski Izsledvania), 27*(4), 100-125. Retrieved from http://repository.hneu.edu.ua/bitstream/123456789/20277/1/Omelchenko_Kolodiziev_Dorokhov.pdf

44. Pokharel, B., & Baral, J. (2009). From green to REDD, from aid to trade: Translating the forest carbon concept into practice. *Journal of Forest and Livelihood, 8*(1), 37-40. Retrieved from https://www.nepjol.info/index.php/JFL/article/view/1881

45. Pyšek, P., & Richardson, D. M. (2010). Invasive species, environmental change and management, and health. *Annual Review of Environment and Resources, 35*(1), 25-55. https://doi.org/10.1146/annurev-environ-033009-095548

46. Rees, W. E. (2013). Ecological footprint, concept of. In *Encyclopedia of Biodiversity* (2nd ed., pp. 701-713). Academic Press. https://doi.org/10.1016/b978-0-12-384719-5.00037-x

47. Shcherbak, V., Danko, Y., Tereshchenko, S., Nifatova, O., Dehtiar, N., Stepanova, O., & Yatsenko, V. (2024). Circular economy and inclusion as effective tools to prevent ecological threats in rural areas during military operations. *Global Journal of Environmental Science and Management, 10*(3), 969-986. https://doi.org/10.22034/gjesm.2024.03.03

48. Shcherbak, V., Ganushchak-Yefimenko, L., Nifatova, O., Fastovets, N., Plysenko, G., Lutay, L., Tkachuk, V., & Ptashchenko, O. (2020). Use of key indicators to monitor sustainable development

of rural areas. *Global Journal of Environmental Science and Management, 6*(2), 175-190. https://doi.org/10.22034/gjesm.2020.02.04

49. Siskos, E., Darvidou, K., & Ostapenko, V. (2023). Analytical support for identification trends and problems in the development of interaction between stakeholders of education, science and business. *Economics of Development, 22*(4), 8-22. https://doi.org/10.57111/econ/4.2023.08

50. Sutherland, W. J., Aveling, R., Brooks, T. M., Clout, M., Dicks, L. V., Fellman, L., Fleishman, E., Gibbons, D. W., Keim, B., Lickorish, F., Monk, K. A., Mortimer, D., Peck, L. S., Pretty, J., Rockström, J., Rodríguez, J. P., Smith, R. K., Spalding, M. D., Tonneijck, F. H., & Watkinson, A. R. (2013). A horizon scan of global conservation issues for 2014. *Trends in Ecology & Evolution, 29*(1), 15-22. https://doi.org/10.1016/j.tree.2013.11.004

51. Telles, K. (2024). Pursuing a grand theory: Douglass C. North and the early making of a new institutional social science (1950–1981). *EconomiA, 25*(1), 109-156. https://doi.org/10.1108/econ-07-2023-0119

52. Telnova, H., Kolodiziev, O., Petchenko, M., Yakushev, O., Shulga, N., & Kochetkov, V. (2023). Foreign trade policy and its impact on economic growth. *Financial and Credit Activity Problems of Theory and Practice, 4*(51), 345-357. https://doi.org/10.55643/fcaptp.4.51.2023.4097

53. Tsitouras, A., Koulakiotis, A., Makris, G., & Papapanagos, H. (2017). International trade and foreign direct investment as growth stimulators in transition economies: Does the impact of institutional factors matter? *Investment Management and Financial Innovations, 14*(4), 148-170. https://doi.org/10.21511/imfi.14(4).2017.13

54. Vačkářová, D., Medková, H., Krpec, P., & Weinzettel, J. (2023). Ecosystem services footprint of international trade: Economic value of ecosystem services lost due to crop production. *Ecosystem Services, 64,* Article 101560. https://doi.org/10.1016/j.ecoser.2023.101560

55. Wang, S., Wang, H., & Sun, Q. (2020). The impact of foreign direct investment on environmental pollution in China: Corruption matters. *International Journal of Environmental Research and Public Health, 17*(18), Article 6477. https://doi.org/10.3390/ijerph17186477

56. World Trade Organization (WTO). (2022). *World Trade Report 2022: Climate Change and International Trade*. Retrieved from https://www.wto.org/english/res_e/booksp_e/wtr22_e/wtr22_e.pdf

Problems and Perspectives in Management, Volume 23, Issue 1, 2025

APPENDIX A

Table A1. Key economic and environmental indicators by region

Region	Export, million US dollars	Import, million US dollars	Trade balance, million dollars	Population, people	Industrial production index	Capital investments in environmental protection, thsd. UAH	Carbon dioxide emissions, thsd. t	Forest felling area, thsd. ha	Volume of extracted aquatic bioresources, tones	Planted area, thsd. ha	I_{ECOi}
Symbol	X1	X2	X1-X2	X3	X4	X5	X6	X7	X8	X9	X١٠
Vinnytsia	1,698.9	899.7	799.2	1,501,541	83.1	5,965.0	3,860.1	15.6	82.1	1,634.4	3,346.16
Volyn	823.8	2,577.9	–1,754.1	1,018,335	77.0	78,583.0	437.9	32.6	80.3	593.4	10,383.63
Dnipropetrovsk	4,696.4	4,411.7	284.7	3,091,509	92.2	4,005,235.4	16,311.4	1.4	227.8	1,892.2	136,848.5
Donetsk	199.4	60.1	139.3	4,045,003	95.5	88,640.0	3,482.8	2.2	632.3	305.0	3,063.76
Zhytomyr	531.1	1,427.4	–896.3	1,179,067	73.1	47,736.4	565.4	53.0	64.9	1,048.5	3,866.30
Zakarpattia	1,359.2	1,391.2	–32	1,241,265	88.9	126,785.0	152.5	16.5	113.1	168.4	9,207.22
Zaporizhzhia	1,456.7	829.9	626.8	1,636,603	82.0	165,228.1	6,862.9	0.0	7.8	272.9	10,783.66
Ivano-Frankivsk	616.2	555.3	60.9	1,348,467	81.3	128,395.0	9,975.0	17.8	100.9	376.7	18,161.79
Kyiv	1,837.6	4,561.7	–2,724.1	1,789,531	86.5	213,275.7	3,771.9	26.1	83.3	1,180.5	11,312.82
Kirovohrad	810.2	258.2	552	896,578	84.7	142,207.0	476.5	7.5	98.1	1,724.1	7,322.79
Luhansk	0.4	2.1	–1.7	2,097,690	109.9	109.1	0.0	0	0	156.9	32.83
Lviv	2,552.4	5,785.5	–3,233.1	2,458,753	86.5	332,700.5	2,208.3	17.0	99.2	747.1	15,133.49
Mykolaiv	1,000.7	544.3	456.4	1,090,442	91.8	80,764.5	547.9	2.0	132.3	1,231.0	6,982.52
Odesa	1,797.9	2,351.2	–553.3	2,339,511	74.8	41,962.1	723.3	3.4	118.9	1,866.0	5,045.91
Poltava	1,433.2	922.6	510.6	1,343,586	94.9	166,358.4	1,928.9	10.1	100.2	1,735.6	12,284.49
Rivne	594.6	737.6	–143	1,140,283	91.0	434,241.9	1,608.4	33.5	70.7	632.3	22,195.63
Sumy	701.7	546.2	155.5	1,032,876	92.9	58,385.7	849.5	18.6	81.4	1,074.1	4,756.38
Ternopil	686.7	666.3	20.4	1,018,082	48.9	41,455.9	305.4	6.5	122.3	849.9	3,832.66
Kharkiv	778.0	1,544.2	–766.2	2,581,970	88.2	398,244.1	3,837.9	12.0	43.3	1,256.3	10,292.83
Kherson	21.6	19.9	1.7	999,552	91.2	15,125.9	97.9	0.0	0	0	239.74
Khmelnytskyi	777.9	660.2	117.7	1,224,989	75.0	106,572.7	2,029.1	18.0	104.5	1,208.4	7,676.76
Cherkasy	1,221.2	659.3	561.9	1,156,343	88.4	62,521.7	2,898.8	22.2	98.6	1,218.6	7,367.90
Chernivtsi	193.7	505.2	–311.5	887,128	73.0	38,779.2	152.5	7.1	163.8	310.1	2,301.58
Chernihiv	893.2	279.3	613.9	949,948	85.9	97,600.1	554.4	19.4	93.8	1,263.4	5,302.81
Kyiv City	9401.1	27,980.9	799.2	2,910,195	72.5	1,407,155.0	3,968.3	0	120.9	0	55,094.67

http://dx.doi.org/10.21511/ppm.23(1).2025.27