ISSN 0350-137X UDK: 338 (497,1)

ЕКОНОМИКА

2

LXXII NIŠ, 2026

МЕЂУНАРОДНИ ЧАСОПИС
ЗА ЕКОНОМСКУ ТЕОРИЈУ И ПРАКСУ И ДРУШТВЕНА ПИТАЊА

ЕКОНОМИКА

Часопис излази четири пута годишње Година LXXII, IV-VI 2026, број 2

ИЗДАВАЧ: Друштво економиста "Економика" Ниш
СУИЗДАВАЧИ: Институт за економику пољопривреде - Београд, Економски факултет у Суботици, Друштво економиста Ниша, Факултет за примењени менаџмент економију и финансије МЕФ - Београд

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МИЛАН Д. РАЊЂЕЛОВИЋ

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WEB: http://www.ekonomika.org.rs
Жиро рачун: динарски 160-19452-17

Штампа:
"MEDIVEST"
18000 Ниш
Тираж: 300 примерака

INTERNATIONAL JOURNAL
FOR ECONOMIC THEORY AND PRACTICE AND SOCIAL ISSUES

ЕКОНОМИКА

The Journal is issued four times a year. Year LXXII, IV-VI 2026, Vol. 2

PUBLISHER: Society of Economists "Ekonomika", Nis
COPUBLISHERS: Institute of agricultural economics - Belgrade, Faculty of Economics - Subotica, Economic Association of Nis, Faculty of Applied Economics and Management Finance MEF - Belgrade

1. The journal EKONOMIKA was initiated in July 1954. It was published as “Nis Economic Messenger” till June, 1957 and as “The Economic Messenger” till the end of 1969. The title “Science and Practice” it had till the issue 1/1973 when it changed its name into EKONOMIKA as it entitled today.

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EBSCO host	EconPapers	ProQuest
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Lector
VLADIMIR IVANOVIC

Prepress:
MILAN D. RANDJELOVIC
Cover:
PETAR OGNJANOVIC, DRAGAN MOMCILOVIC

Address:
"EKONOMIKA", Society of Economists
18000 Nis, Maksima Gorkog 5/36

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e-mail: zoki@medianis.net; ekonomika1954@gmail.com; ekonomika.journal@aol.com
WEB: http://www.ekonomika.org.rs

Bank Account: 160-19452-17

Printed by:
“MEDIVEST”
18000 Niš
Copies: 300

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ISSN 0350-137X, EISSN 2334-9190, UDK 338 (497,1)
Vol. 72, april-june 2026, № 2
P. 1-19

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ORIGINAL SCIENTIFIC ARTICLE
DOI: 10.5937/ekonomika2602001P
Received: November 24, 2025
Accepted: February 10, 2026

ECOLOGICAL FOOTPRINT OF THE WESTERN BALKANS IN THE ERA OF TECHNOLOGICAL PROGRESS

Abstract

Environmental protection is a key component of the sustainable development of the countries of the Western Balkans. This implies efficient management of energy and natural resources, with reliance on technological innovations that contribute to the improvement of development dynamics. The aim of this empirical analysis is to examine the impact of key socioeconomic and environmental factors, including information and communication technologies (ICT), carbon dioxide emissions (CO_2), degree of urbanization (URB), consumption of renewable energy sources (REN) and economic growth (GDP) on environmental degradation, through an analysis of the ecological footprint (EF) in the countries of the Western Balkans (Albania, Bosnia and Herzegovina, Montenegro, North Macedonia and Serbia) in the period 2001-2022. The region shared historical, institutional and economic characteristics, which make it a coherent analytical framework for examining the relationships explored in the study. The information base of the research consists internationally comparable databases of World Development Indicators (WDI) of the World Bank, as well as the Global Footprint Network. Within the research, correlation analysis was used to assess the direction and strength of the relationship between the variables, as well as simple linear regression in order to examine the individual impact of each factor on the ecological footprint. The results show that CO_2 emissions and economic growth have a positive and statistically significant relationship with the ecological footprint, which indicates their role in the deterioration of the environment. In contrast, ICT and the consumption of renewable energy sources are associated with a reduction in the ecological footprint, while the impact of urbanization is both positive and negative. The obtained research results can serve as a guideline for the formulation of more effective sustainable development policies in the countries of the Western Balkans region, with an emphasis on the improvement of digital infrastructure and the transition to renewable energy sources.

Key words: *sustainable development, information and communication technologies, CO_2 emissions, urbanization, renewable energy sources, economic growth*

JEL classification: *Q42, Q54, Q55, Q56, R11*

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ЕКОЛОШКИ ОТИСАК ЗАПАДНОГ БАЛКАНА У ЕРИ ТЕХНОЛОШКОГ НАПРЕТКА

Апстракт

Очување животне средине представља кључну компоненту одрживог развоја земаља Западног Балкана. То подразумева ефикасно управљање енергетским и природним ресурсима, уз ослањање на технолошке иновације које доприносе унапређењу развојне динамике. Циљ ове емпиријске анализе је испитивање утицаја кључних социоекономских и еколошких фактора, укључујући информационо-комуникационе технологије (ИКТ), емисију угљен-диоксида (ЦО2), степен урбанизације (УРБ), потрошњу обновљивих извора енергије (ОИЕ) и привредни раст (БДП), на деградацију животне средине, кроз анализу еколошког отиска у земљама Западног Балкана (Албанија, Босна и Херцеговина, Црна Гора, Северна Македонија и Србија) у периоду 2001-2022. Регион има сличне историјске, институционалне и економске карактеристике, што га чини кохерентним аналитичким оквиром за испитивање односа који се проучавају у студији. Информациону основу истраживања чине међународно упоредиве базе података Индикатори светског развоја (ИСР) Светске банке, као и Глобална мрежа економског отиска (ГМЕО). У оквиру истраживања примењена је корелациона анализа ради процене правца и јачине односа између променљивих, као и једноставна линеарна регресија у циљу испитивања појединачног утицаја сваког фактора на еколошки отисак. Резултати показују да емисија ЦО2 и привредни раст имају позитивну и статистички значајну повезаност са еколошким отиском, што указује на њихову улогу у погоршању стања животне средине. Насупрот томе, ИКТ и потрошња обновљивих извора енергије повезани су са смањењем еколошког отиска, док је утицај урбанизације како позитиван, тако и негативан. Добијени резултати истраживања могу послужити као смерница за формулисање ефикаснијих политика одрживог развоја у земљама региона Западног Балкана, са нагласком на унапређење дигиталне инфраструктуре и транзиције ка обновљивим изворима енергије.

Кључне речи: *одрживи развој, информационо-комуникационе технологије, емисије ЦО2, урбанизација, обновљиви извори енергије, привредни раст*

Introduction

The modern age of technological progress poses new challenges, but also opens opportunities for the improvement of sustainable development, especially in regions that are in the process of structural and economic transformations. In this context, the countries of the Western Balkans face the need to harmonize economic growth with requirements for environmental protection and European integration processes.

In this paper, sustainable development is viewed through the interdependence of economic growth, technological progress, and ecological limitations, whereby

environmental protection is a key dimension of long-term stability and resilience of the economic system. As an indicator of the pressure of economic activities on natural resources, the paper uses the ecological footprint per capita, which is a measure of "the total ecological impact generated by the average individual within a specified population, and typically measures the biologically productive land and water area required to supply all consumed resources and absorb all generated waste, expressed per person" (Lifestyle sustainability directory). In particular, ecological footprint on consumption per capita is used to measure the total ecological footprint generated by final consumption in the observed countries. Technological innovations, especially in the area of information and communication technologies (ICT), offer the potential to reduce the ecological footprint through more efficient use of resources, improvement of energy efficiency and support for the circular economy. At the same time, carbon dioxide (CO_2) emissions, urbanization and traditional energy-intensive economic growth models can increase pressure on the environment. CO_2 emissions are not viewed as equivalent to the ecological footprint, but as one of the relevant factors associated with its change, bearing in mind that the carbon footprint represents a significant part of the total environmental footprint.

Bearing in mind the above, the aim of this research is to examine the connections and long-term interdependencies between ICT, CO_2 emissions, urbanization, energy consumption from renewable sources, GDP and ecological footprint in the countries of the Western Balkans in the period 2001-2022. Understanding these interdependencies can contribute to the creation of policies that balance technological progress and environmental responsibilities. The analysis has an explanatory character, with the aim of identifying socioeconomic factors associated with changes in the ecological footprint in the region. The orientation of the analysis towards the countries of the Western Balkans is justified by the fact that the countries of the region share similar development patterns, have similar transition trajectories and institutional frameworks, but are also characterized by the common goal of adapting to European Union standards in the field of sustainable development and climate policy. These characteristics make the region coherent and suitable for analysing the relationship between technological progress, economic factors and environmental sustainability. Through the European Green Deal, the European Union sets ambitious goals of reducing greenhouse gas emissions, increasing the share of renewable energy sources and improving energy efficiency, which further emphasizes the importance of sustainable development research in candidate countries and potential candidates for membership.

In the existing literature, a large number of empirical studies are directed towards the analysis of the relationship between economic growth and CO_2 emissions in order to examine the existence of the ecological Kuznets curve in both developed and developing countries. The results of various studies indicate that economic growth does not necessarily lead to a reduction in environmental degradation, but they also confirm the negative impact of energy consumption on the environment through the increase of harmful gas emissions (Petrović-Ranđelović et al., 2025). This paper extends existing research by including the role of renewable energy sources, urbanization and ICT in explaining changes in the ecological footprint in the countries of the region. The role of renewable energy sources in sustainable development is reflected in the harmonization of energy demand and preservation of ecological balance; urbanization increases the consumption of resources and pollution, but also enables more efficient infrastructure

and greater availability of environmental technologies; ICT reduces the ecological footprint by optimizing resource consumption, digitizing processes and supporting the development of sustainable solutions.

Literature Review

In the available literature, a growing trend in the number of studies evaluating various aspects of environmental protection in the European Union and the Western Balkans is noticeable. They are focused on sustainable development, energy transition, climate change, urban and technological development and contribute to the understanding of the complex relationships of interdependence between socioeconomic and environmental factors. This literature indicates that the Western Balkans represent a specific analytical framework due to similar development patterns, transition processes and institutional capacities in relation to the European Union.

Methodological Approach to Ecological Footprint

The ecological footprint is a comprehensive indicator of pressure on the environment that measures the demand for bio-productive resources and the absorptive capacity of ecosystems (Wackernagel & Rees, 1996). The methodological framework for calculating the ecological footprint was developed through standardized national accounts published by the Global Footprint Network, which enabled international comparability and application in panel analyses (Global Footprint Network, 2026). Recent studies provide a solid methodological foundation for ecological footprint (EF) analysis, highlighting the distinction between carbon footprint, water footprint, land footprint, and ecological footprint as components of the broader environmental footprint (Nepal & Shrestha, 2024). These works emphasize the need for integrating socio-economic, technological, and environmental factors in panel data models to accurately capture EF dynamics.

Economic Growth, CO_2 Emissions and Environmental Pressures

A significant part of the literature analyzes the relationship between economic growth, energy and CO_2 emissions, as key determinants of environmental pressures.

Beka et al. (2024) analyze the relationship between economic, financial and institutional development and CO_2 emissions in OECD and Western Balkan countries (2010-2022), using OLS and panel models. The results indicate that a higher level of economic development, efficient institutions, clear regulatory frameworks and enforcement of environmental protection laws, as well as a well-developed financial sector encourage investments in cleaner technologies and sustainable infrastructure. The authors emphasize the need for region-specific policies.

Pejović et al. (2021) using the panel vector autoregressive approach show that in the European Union member states and the Western Balkan countries, the majority of variations in CO_2 emissions are determined by variations in GDP (2008-2018). It is emphasized that the long-term reduction of CO_2 emissions can be achieved by continuously increasing economic growth and increasing energy consumption from renewable energy sources.

Tomić et al. (2022) found that technological development and renewable energy reduce CO_2 emissions, while total primary energy increases CO_2 emissions. This paradox emphasizes the need for careful creation of energy policy, which should be aimed at encouraging research and development as key factors of the green transition.

Ali et al. (2021) analyse the relationship between GDP per capita, CO_2 emissions, non-renewable energy consumption and waste for 13 selected EU countries in the period 1990-2019. The results indicate a positive effect of non-renewable energy consumption and waste on emissions, but also a negative effect of CO_2 emissions on GDP per capita. The authors recommend increasing the production of energy from renewable sources based on biomass and waste to stimulate economic growth in developed EU countries, whith the caution of applying such a strategy in less developed economies. This is especially because, due to the lower level of energy efficiency and insufficient application of technological innovations, the use of energy from biomass can significantly slow down GDP growth in four countries of the Visegrad Group (Hungary, Slovakia, the Czech Republic and Poland).

Energy Transition and Renewable Energy Sources

The literature on the energy transition emphasizes the importance of the energy sector for the environmental sustainability of the region.

Ignjatović et al. (2024) indicate that the biggest challenge of the green transition of the Western Balkans is reforming the energy sector, because the countries of the region are highly dependent on coal and energy-intensive industries. It is particularly emphasized that the region has an unused potential of renewable energy sources, but also that the improvement of energy efficiency is limited by factors that slow down the green transition, such as weaknesses in regulatory and institutional capacity, insufficient sectoral coordination and weak financial opportunities (Ignjatović et al., 2024). The authors indicate that the Western Balkan countries have five times lower resource productivity than the EU average and that the generation of waste per unit of GDP is significantly lower than the European level, which indicates the potential of the circular economy as a driver of the green transition in the region (Ignjatović et al., 2024).

Knez et al. (2022) identify industry, energy and the heating sector based on coal exploitation as the main sources of harmful emissions and climate change. While Croatia has harmonized the regulatory framework with the European Union, other Western Balkan countries are in the process of harmonizing regulations and strategies for mitigating climate change, with limited implementation of policies due to a lower level of economic development and lack of investment.

The study by Filipović et al. (2022) analyses the connection between two important goals of the EU Green Plan, namely the achievement of net zero emissions by 2050 and sustainable development goals based on the of economic, environmental and social sustainability pillars. The authors point out that climate neutrality requires the harmonization of economic and regular policies, the definition of quantitative goals and the improvement of consumption patterns, in order to reduce the international spill-over effect on the environment through cooperation. The environmental pillar should be strengthened by new environmental standards and the investment plan of the European Union for the period 2021-2027, including the Just Transition Mechanism.

Large regional differences in different living standards, resources, needs and socio-economic characteristics in both the EU member states and the Western Balkan countries were emphasized, which confirms the need for adapted policies and mechanisms for monitoring and evaluating strategic goals.

Recent studies on renewable energy and the ecological footprint confirm that higher shares of renewable sources reduce ecological footprint and contribute to sustainability (Li et al., 2023).

Urbanization and Structural Changes

The impact of urbanization on environmental pressures and resource consumption is an important topic in contemporary literature.

Gürsoy & Kodaz (2021) emphasize that urbanization in the Western Balkans offers the potential to stimulate economic development and improve living conditions, but also to generate environmental pressures that transcend national borders and require regional cooperation. Integration into European policies and funds can promote sustainable urban development, with the strengthening of local capacities and the establishment of effective coordination mechanisms between different levels of government, as well as the implementation of modern technological solutions, the promotion of recycling and sustainable mobility and transport.

Shahini (2025) shows that FDI and urbanization increase energy consumption in the region, while higher average winter temperatures reduce energy demand and heating needs. Also, GDP growth is not statistically significant, which can be attributed to structural changes in the economic structure of the region.

Systematic reviews also highlight that urban development patterns significantly affect ecological footprint, emphasizing the need to integrate urban planning in EF assessments (Sarwar et al., 2024).

Technological Development and Information and Communication Technologies (ICT)

The role of technological innovations and ICT in environmental sustainability is increasingly present in empirical research.

Grujić (2016) emphasizes the impact of ICT on environmental sustainability at different levels, namely increasing electronic waste, saving energy and reducing resource use. The impact of IT on the environment should be monitored throughout its life cycle through reduced consumption of resources, reduction of pollution and reuse of materials.

Majeed (2018) shows that ICT has positive effects on environmental sustainability in developed countries and negative effects in developing countries. Manasijević (2024) analyzes the role of strategic management and artificial intelligence for achieving balanced and sustainable regional development in Serbia, promoting regenerative economic models that contribute to resource renewal and increasing social resilience. Similarly, Sessa (2025) introduces the concept of regenerative business models as the next stage of sustainability.

Contemporary literature increasingly examines the connection between information and communication technologies and the ecological footprint, where the

results point to a double effect of ICT - reducing emissions through efficiency and digitization, but also increasing energy consumption in the stages of production and use of technology (Salahuddin et al., 2016). Also, the integration of renewable energy sources and digital technologies has been identified as an important factor in reducing the ecological footprint in modern economies (Destek & Sarkodie, 2019).

Institutional and Regional Context of the Western Balkans

The institutional and development context of the Western Balkans points to the specificities of the region as an analytical framework.

Erić et al. (2024) analyse the implications of the EU's green transformation on the economic development of the Western Balkans with a special focus on the Green Deal and climate neutrality. The research is based on the application of cluster analysis based on the data of the Green Economy Index. The key indicators of the green economy were analysed in terms of their impact on macroeconomic indicators and opportunities for economic development were identified, including increased investment in renewable energy sources and the development of sustainable infrastructure projects, but also the lack of capacity, financial resources and public sector support for the implementation of sustainable policies. The risk of increasing economic and social inequalities in the process of green transformation was emphasized.

Uvalić & Cvijanović (2018) emphasize more intensive regional cooperation for accelerated sustainable economic development of the Western Balkans. The coordination of national policies in some priority areas, such as research and development, energy, transport, agriculture or certain industries, for the joint implementation of regional initiatives is particularly important for the accelerated growth of small economies such as the Western Balkans in the medium term. The authors cite insufficient investments from budget sources and EU funds as the main limitation for the implementation of reforms in the Western Balkans region.

Empirical analysis of energy consumption in the Balkan region was carried out by Zaimaj & Xhafa (2023) using panel data through a fixed effects model, taking into account economic, political, technological and financial factors. The results showed that the main drivers of energy consumption are the Human Development Index-HDI, foreign direct investments-FDI and the innovation index.

Comparative research highlights that institutional quality and policy coherence are critical for integrating ICT, renewable energy, and urbanization into sustainable development strategies (Saba et al., 2024).

Overall, the existing literature confirms the strong links between economic growth, energy, urbanization, technology and environmental sustainability in the countries of the Western Balkan and the European Union. However, most studies consider these factors separately or focus on CO_2 emissions as a single indicator of environmental pressure. Fewer studies integrate economic, technological and structural determinants into a single empirical framework for ecological footprint analysis. This paper seeks to fill that research gap.

Research Methodology

The aim of this research was to empirically examine the impact of key socioeconomic and environmental factors on the ecological footprint (Ecological footprint – EF), which is a part of the wider Environmental footprint (EF), in the Western Balkan countries over the period from 2001 to 2022. In this paper, ecological footprint represents a specific indicator of the pressure of human activities on natural resources and ecosystems, while the broader term Environmental Footprint (EF total) is usually used to include different components, such as Carbon footprint, Water footprint, Land footprint and Ecological footprint (EF). Emissions of CO_2 were considered as an independent variable and not synonymous with EF, in order to clearly separate different aspects of environmental burden. The paper used a quantitative research approach, using data from the World Development Indicators (WDI) database of the World Bank, while the ecological footprint data was taken from the Global Footprint Network database. The focus of the analysis was on five countries of the region: Albania, Bosnia and Herzegovina, Montenegro, North Macedonia and Serbia, with a note that until 2006, Serbia and Montenegro were analysed as a single country due to the availability of data. These countries were selected due to their regional relevance, similar transition processes and the availability of reliable data for the period 2001–2022.

The dependent variable in the research is the ecological footprint per capita (EF), expressed in global hectares, which represents a complex indicator of the overall pressure that human activity exerts on natural resources and ecosystems.

Independent variables include the following factors:

- emission of carbon dioxide (CO_2) - measured in metric tons per capita, as an indicator of air pollution and the intensity of fossil consumption, separated from EF,
- gross domestic product (GDP) per capita - expressed in constant US dollars, as an indicator of economic growth,
- degree of urbanization (URB) - expressed as a percentage of the urban population in the total population (note that URB can have a two-way impact on EF depending on the quality of urban planning),
- consumption of renewable energy sources (REN) - as a percentage of the total final energy consumption, green energy transition indicator,
- information and communication technologies (ICT) - operationalized through indicators of penetration of the Internet, mobile telephony and ICT infrastructure, indicator of technological capacities that can contribute to the reduction of environmental burden.

The methodological framework of the research is based on the application of the following quantitative methods:

1. Comparative descriptive analysis - The first step of the research included a descriptive and comparative analysis of the EF in selected countries during the entire observed period. Trends and differences between countries were visualized using graphs. Special attention was paid to the analysis of the dynamics of Serbia's ecological footprint, while identifying the key years of oscillation;

2. Correlation analysis - Pearson's correlation coefficient was used to examine the direction and strength of the linear relationship between the EF and selected independent variables. This method enables the identification of positive and negative correlations, as well as their statistical significance.

Pearson correlation analysis was conducted for each of the independent variables in relation to the EF. Statistical significance criteria were considered at a significance level of $p < 0.05$. The results were interpreted through the average values of the coefficients and their directions (positive or negative).

3. Multiple linear regression analysis - For a more in-depth assessment of the impact of each independent variable on the EF, a multiple linear regression analysis was conducted with the ecological footprint as the dependent variable. Before carrying out the regression analysis, a diagnosis of multicollinearity was performed, by calculating Tolerance and VIF (Variance Inflation Factor) values. As all Tolerance coefficients were above 0.1, and VIF values below the threshold of 10, the absence of significant multicollinearity among independent variables was confirmed. The models were evaluated based on the coefficient of determination (R^2) and the statistical significance of the regression coefficients, which allows insight into the relative contribution of each variable. The use of panel data is justified due to the dynamic nature of EF and independent variables over time and across countries, which allows precise control for heterogeneity between countries.

Statistical data processing was performed using software packages such as SPSS, which enabled reliable and precise analysis of correlation and regression relationships.

Based on the theoretical framework and research objectives, the following main hypothesis was set:

H1: Economic growth and CO_2 emissions contribute significantly to the increase of the EF, while information and communication technologies and the use of renewable energy sources contribute to its reduction.

In order to further examine the contribution of individual factors, the following auxiliary hypotheses were formulated:

H1a: CO_2 emission has a positive and statistically significant effect on increasing the EF.

H1b: Economic growth (GDP) has a positive effect on the EF.

H1c: The use of ICT has a negative impact on the EF.

H1d: The consumption of renewable energy sources (REN) contributes to the reduction of the EF.

H1e: Urbanization (URB) has a two-way effect on EF, depending on the quality of urban planning and institutional efficiency.

The null hypothesis (H0) is: There is no statistically significant influence of the observed factors on the EF in the Western Balkan countries in the period 2001–2022.

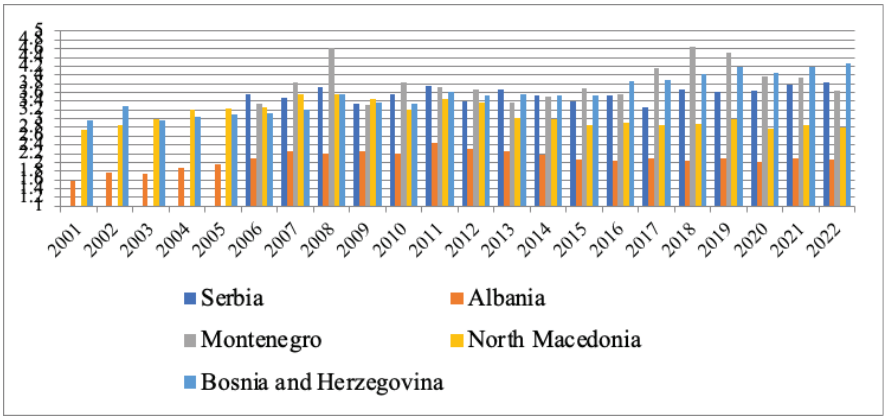
Research Results and Discussion

The research is based on the value of the total ecological footprint in the period from 2001-2022 for the Western Balkan countries. Also, it should be noted that until 2006,

Serbia and Montenegro were considered together as one country and that data for the earlier period are not available. By means of a comparative analysis of values, each country is compared with the others included in the analysis and the situation of Serbia is presented in detail. The Ecological footprint (EF) values indicate pressure on natural resources, while actual ecological sustainability should be assessed in relation to available biocapacity. Analysing the values of the ecological footprint of the countries during the mentioned years, it can be noted that Albania is the best positioned. More precisely, Albania has the lowest ecological footprint values over the years ranging from 1.76 to 2.45. Following the value of the ecological footprint of this country during the analysed years, a slight upward trend can be observed, but the values are still lower than in other Western Balkan countries. On the other hand, Bosnia and Herzegovina as well as Montenegro achieve high ecological footprint values (3.12 - 4.65) compared to the other countries of the observed group, which points to significant environmental degradation, excessive depletion of natural resources and a low degree of sustainability during the observed years. A growing oscillatory trend can be seen in their deterioration of the value of the ecological footprint. North Macedonia is the only country from the group of observed countries that has had a changing trend over the years with a noticeable decline in value over the last few years. In the observed time period, this country achieved an average ecological footprint of around 3.07 (Figure 1).

When looking at the place of Serbia according to the value of the ecological footprint in the group of analysed countries, it is somewhere in the middle with an average value of 3.57 over the years. A slight upward oscillatory trend in the value of the ecological footprint is characteristic for Serbia in the period from 2006 to 2022 with several negative peaks (2012, 2015, 2017). According to the value of the ecological footprint, Serbia has a significant ecological footprint driven by high carbon emissions per capita, mainly from energy production, transport and energy-inefficient buildings. With the increasing presence of climate change, Serbia relies heavily on agriculture, where primary production generates most of the carbon dioxide emissions, while urban centres face major challenges reflected in aging public transport and inefficient infrastructure.

Figure 1. Presentation of the achieved value of the ecological footprint in the Western Balkan countries for the period 2001-2022



Source: Authors' presentation according to Global Footprint Network data

Since there are studies that indicate a possible connection between the value of the ecological footprint and key socioeconomic and environmental factors (Zeb et al., 2025; Magazzino et al., 2025; Özcan, 2024), the paper applied a correlation analysis on selected indicators (economic growth (GDP), carbon dioxide emissions (CO_2), individual Internet use (ICT), renewable energy consumption (REN) and urbanization (URB)). More precisely, correlation analysis was applied in order to understand the interrelationships among the main research variables (ecological footprint and key socioeconomic and environmental factors). By calculating the Pearson coefficients when looking at the selected variables for the Western Balkan countries in the period from 2001 to 2022, it is concluded that there are different types of correlations between them in terms of direction and strength. The highest degree of quantitative agreement during the entire period chosen for analysis is present between the value of the ecological footprint and the GDP, where the Pearson coefficient had an average value of 0.774, which indicates a great agreement between these two variables. At the same time, the movement of the analysed variables was in the same direction, or rather a strong, positive correlation was present throughout all the years. It is clear that high GDP values are associated with greater consumption of resources, that is, to overloading the planet Earth with excessive consumption of resources, which indicates a decrease in the degree of environmental sustainability. A higher level of economic development followed by GDP is associated with the use of more resources than the planet Earth can regenerate. Similar results regarding the degree of correlation were obtained between the value of the ecological footprint and CO_2, whereby a positive, moderate to strong correlation relationship was achieved. The average value of the Pearson correlation coefficient among the observed variables during the analysed period is 0.650 with acceptable statistical significance. It is clear that high CO_2 emissions led to an increase in the value of the ecological footprint in the Western Balkan countries. The results of the correlation show that there is a statistically significant positive relationship between the examined variables, so it can be concluded that the values of the variables such as ecological footprint, GDP and CO_2 in the Western Balkan countries in the analysed time period are growing at the same time, however, it should be taken into account that this relationship is not causal and that its existence does not mean that the growth of the value of one variable is caused by another variable, but that they just move in the same direction (Table 1).

Table 1. Average values of the Pearson coefficient of the ecological footprint and selected variables in the Western Balkans for the period from 2001 to 2022

P (sig.)	GDP	CO_2	ICT	REN	URB
EF	0.774 (0,032)	0.650 (0.044)	0.437 (0.027)	0.342 (0.039)	0.549 (0.022)

Source: Authors' presentation

Contrary to the variables GDP and CO_2 that have a positive correlation with the ecological footprint, ICT and REN have a negative correlation during all analysed years for the Western Balkan countries. According to the value of the Pearson correlation coefficient (average value 0.437) in the analysed time period between ICT and ecological footprint there is a moderate intensity of quantitative agreement which is statistically

significant. The negative correlation between these variables depicts a situation in which the value of the ecological footprint decreases when the value of ICT increases. The transition to digital platforms, smart technologies and sustainable consumption tends to be linked with reduction in carbon dioxide emissions, resource consumption and the amount of waste, which leads to environmental protection and a higher degree of sustainability in the future. The situation is similar when considering variable REN and ecological footprint. The obtained results indicate a statistically significant weak correlation (average value of Pearson coefficient is 0.342) between these variables for all Western Balkan countries during the years included in the analysis. Renewable energy consumption has the lowest correlation value with the ecological footprint of all analysed variables, which suggests that the increase in the value of the ecological footprint is weakly related to the use of renewable resources. This correlation makes sense because the use of renewable energy contributes significantly to achieving sustainability, reducing the ecological footprint and protecting the biocapacity of the planet.

By analysing the linear relationship between URB and ecological footprint in the period 2001-2022 for the Western Balkans, a moderate correlation was established (average value of Pearson coefficient is 0.549) of varying direction depending on the observed year. In the period from 2006 to 2012, there is a positive correlation relationship, while in other years the relationship is negative and statistically significant. The growth of the urban population certainly puts pressure on the biocapacity and thereby affects the level of environmental sustainability, which causes an increase in the value of the ecological footprint.

Table 2. Values of the regression coefficient of selected variables for the Western Balkan countries in the period 2001-2022

Variables / Years	Const. β	CO_2	ICT	URB	GDP	REN
2001	9.649	0.095	-0.962	0.918	1.834	-0.389
2002	5.941	0.145	-0.963	1.357	1.542	-0.673
2003	2.014	0.233	-0.981	1.013	2.315	-0.445
2004	5.281	1.172	-1.509	1.059	1.351	-0.435
2005	6.560	1.109	-1.107	0.128	1.669	-0.470
2006	1.403	0.431	-0.740	0.039	1.950	-0.137
2007	1.482	0.875	-1.280	0.486	2.239	-0.646
2008	1.055	0.652	-1.877	1.055	1.734	-0.903
2009	7.478	0.482	-1.825	1.037	1.990	-0.355
2010	5.374	0.984	-0.739	0.612	3.111	-0.601
2011	1.083	0.597	-1.002	0.495	1.697	-0.284
2012	3.822	1.244	-0.908	0.317	1.641	-0.204
2013	1.488	1.335	-0.446	0.249	1.173	-0.739
2014	2.065	0.754	- 0.954	0.731	2.002	-0.547
2015	0.837	1.395	-1.917	0.084	2.417	-0.444
2016	4.714	1.274	-0.286	0.643	1.223	-0.785
2017	3.111	0.835	-1.742	0.551	1.086	-0.085
2018	6.806	0.589	-0.266	1.246	1.533	-0.662

2019	5.044	1.102	-1.240	0.846	1.882	-0.363
2020	3.219	1.057	-1.027	1.358	3.702	-0.833
2021	2.742	1.038	-1.663	1.059	6.248	-0.131
2022	4.515	1.874	-1.995	1.015	6.664	-0.479

Source: Authors' presentation

In order to determine the extent to which the selected socioeconomic and environmental factors contribute to the value of the ecological footprint for the countries of the Western Balkans in the selected time period, a multiple regression analysis was applied with the ecological footprint as the dependent variable (Table 2). As a prerequisite for the conducted multiple regression analysis, the diagnosis of collinearity of the variables was used. Since all independent variables have a Tolerance amount above 0.1, and VIF values below the maximum statistically acceptable threshold of 10, the absence of multicollinearity in the regression model is proven. The obtained regression models are statistically representative based on the value of the coefficient of determination. It is noted that the variable URB with a unit value increase affects a slight increase in the value (0.039 - 1.358) of the ecological footprint. The regression coefficient of the URB variable varies over the years, suggesting that urban population growth has a moderate and variable effect on EF. The growth of the second variable CO_2 at a unit value increase also causes an increase in the value of the ecological footprint in the Western Balkan countries. When the ICT variable changes by 1%, there is a significant increase in the value of the ecological footprint (0.266 - 1.995).

A summary table with the results of both analyses is provided below (Table 3).

Table 3. Summary of the correlation and regression analysis of the ecological footprint and selected factors in the Western Balkan countries (2001-2022)

Variable	Average EF	Pearson r (p-value)	Regression coefficient β (range)	Note
BDP	3.57	0.774 (0.032)	1.086 – 6.664	Strong positive correlation: EF tends to be higher with GDP growth
CO_2	3.57	0.650 (0.044)	0.095 – 1.874	Moderate to strong positive correlation
ICT	3.57	-0.437 (0.027)	0.266 – 1.995	Pearson negative, regression positive → a complex relationship when controlling for other variables
REN	3.57	-0.342 (0.039)	-0.085 – -0.903	Weak negative effect: minimal impact on EF
URB	3.57	0.549 (0.022)	0.039 – 1.358	Moderate correlation: regression effects vary across years

Notes:

1. *EF shows pressure on resources, while sustainability depends on biocapacity, which is not included in this analysis.*
2. *Pearson r shows a linear relationship between EF and variables, while regression β shows the marginal effect of controlling for other factors.*
3. *The terms are neutral - the term «tends to be associated with», not «causes», is used.*

Source: Authors' presentation

Pearson's correlation shows that the increased use of ICT in the Western Balkans is moderately related to the reduction of the ecological footprint. However, in a regression model controlling for other factors (GDP, CO_2, REN, URB), the coefficient for ICT is positive, indicating a complex relationship: although digitization may reduce pressure on resources, countries with higher GDP and infrastructure have more ICT, but also a larger overall ecological footprint. This shows that the relationship between ICT and EF depends on the context and the presence of other socioeconomic and environmental factors. In the context of the Western Balkan countries, this finding can be explained as follows: in the model of ecologically unsustainable GDP growth, based primarily on the use of fossil fuels, higher investments in the production and use of ICT lead to a larger ecological footprint, which is in accordance with the research of Salahuddin et al. (2016). An examination of the REN variable indicates that its influence on the increase in the value of the ecological footprint is very small. The effect of renewable energy sources (REN) on EF is minimal, which indicates that their increase in the analysed period was not pronounced enough to significantly reduce the ecological footprint. The most influential component on the value of the ecological footprint is the GDP per capita in the entire analysed time period.

Conclusion

The empirical analysis indicates that the Western Balkan countries are going through a complex balancing process between economic growth, technological progress and conservation of natural resources. By comparing the countries of the region, research has established that Albania stands out with the lowest ecological footprint values, while Bosnia and Herzegovina and Montenegro record the highest level of environmental degradation, which indicates an unequal degree of sustainability and different effects of economic development and energy policy in the region. Serbia is in the middle, with a slight upward trend in the ecological footprint, where high CO_2 emissions and inefficient infrastructure are key challenges for reducing the environmental resilience.

Based on the conducted correlation and regression analysis, as well as observation of empirical trends in the observed period (2001–2022), the following hypotheses were confirmed:

Hypothesis H1a (CO_2 emission has a positive and statistically significant effect on increasing the ecological footprint) was confirmed both by correlation analysis (Pearson coefficient = 0.650, $p < 0.05$), which indicates a moderate to strong positive correlation, and by a regression model that shows that increasing CO_2 emissions leads to an increase in ecological footprint. Hypothesis H1b (Economic growth (GDP) has a positive effect on ecological footprint) is fully confirmed. GDP has the strongest positive correlation with ecological footprint (Pearson coefficient = 0.774, $p < 0.05$), as well as the most pronounced influence within the regression model, thus confirming its significant contribution to environmental degradation. The results clearly confirm that economic growth and the growth of CO_2 emissions have a strong and statistically significant positive impact on increasing the ecological footprint, which confirms that the development dynamics in the region is still based on a model of intensive use of resources and energy inputs with negative environmental consequences. This reaffirms the existence of the "ecological

paradox of growth", that is, that economic growth, although desirable, in the absence of appropriate corrective policies, inevitably leads to environmental degradation.

Hypothesis H1c (ICT use has a negative impact on ecological footprint) was partially confirmed. Namely, the results of the correlation analysis confirm a statistically significant negative connection between ICT and ecological footprint (Pearson coefficient = –0.437, $p < 0.05$), which indicates that greater application of information and communication technologies can contribute to reducing the environmental burden. However, the regression analysis shows a certain increase in the environmental footprint with the growth of ICT in certain contexts, which suggests the need for additional research on the effect of digitization, but based on the dominant findings, the hypothesis can be considered confirmed.

Hypothesis H1d (Consumption of renewable energy sources (REN) contributes to the reduction of ecological footprint) was confirmed by a moderate but statistically significant negative correlation between REN and ecological footprint (Pearson coefficient = –0.342, $p < 0.05$). Although the intensity of the relationship is weak, the direction of the relationship and the significance confirm that the increase in the consumption of renewable energy sources has a positive effect on the environment. Regression analysis, on the other hand, indicates a weak direct effect of REN on ecological footprint, but without statistically rejecting the hypothesis. Therefore, it could be concluded that information and communication technologies (ICT) and the use of renewable energy sources (REN) show a negative association with ecological footprint, indicating their potential in reducing environmental degradation. The results of the research indicate that information and communication technologies and increased consumption of renewable energy sources have significant potential in reducing the environmental burden, so they represent key levers for the sustainable transformation of the countries in the region. ICT enables the transition to digital and smart technologies that reduce resource consumption and CO_2 emissions, that is, digitization enables the improvement of efficiency in the use of resources, the optimization of energy systems and the wider application of innovative solutions. In addition, REN contributes to the preservation of biocapacity through sustainable energy production, since a greater share of renewable energy sources reduces dependence on fossil fuels and mitigates the negative effects of economic growth on the environment.

Hypothesis H1e (Urbanization has a two-way impact on the ecological footprint, depending on the quality of urban planning and institutional efficiency) is empirically confirmed, since the correlation analysis shows a moderate association (Pearson coefficient = 0.549, $p < 0.05$) with a changing direction depending on the time period: positive correlation in the period 2006–2012, negative in later years. Such oscillatory nature confirms that urbanization can have both positive and negative effects on the ecological footprint, in accordance with institutional capacities and strategic management of urban development.

The null hypothesis (H0) is rejected, given that all analysed factors (CO_2, GDP, ICT, REN and URB) showed statistically significant relationships with the ecological footprint, either positive or negative, which confirms the existence of the influence of the observed socioeconomic and ecological determinants on the state of the environment in the region.

Considering all the above, it could be concluded that the obtained results empirically confirm the set main hypothesis (H1), as well as all auxiliary hypotheses (H1a–H1e),

while the null hypothesis (H0) was rejected based on statistical findings. These results indicate the need to redefine development policies in the direction of integrating economic growth with the principles of ecological sustainability, while strengthening the digital infrastructure and accelerating the transition to renewable energy sources.

Based on the obtained research results, it could be concluded that the countries of the Western Balkans must intensify their efforts towards shaping development policies that integrate the goals of economic growth with environmental sustainability. This means:

1. intensification of investment in digital infrastructure and development of the ICT sector, with the aim of reducing resource consumption and optimizing processes in industry, transport and the public sector;
2. encouraging the transition to renewable energy sources, including solar, hydro and wind energy, in order to reduce CO_2 emissions and the overall ecological footprint;
3. adoption of regulations that limit CO_2 emissions and encourage energy efficiency;
4. creation of smart urban policies that turn urban growth into a generator of innovation and sustainable practices, rather than an additional source of degradation;
5. formulating regional sustainable development policies that take into account the specific ecological and socioeconomic characteristics of each Western Balkan country, with the aim of reducing disparities in the ecological footprint and strengthening collective sustainability.

The theoretical contribution of this research is reflected in the empirical confirmation of the importance of information and communication technologies and renewable energy sources as factors that can neutralize the negative effects of growth and urbanization on the environment. Also, the research provides additional evidence of the complexity of the relationship between development and sustainability in the specific regional context of the Western Balkan countries, which are characterized by structural weaknesses, slower institutional development and pronounced developmental dependence on fossil fuels.

Taking into account all the above, it could be concluded that the sustainable development of the region can be achieved only through an integrated approach in which technological progress, green transition and responsible management of resources will be complementary processes. This creates space for the Western Balkans, despite existing challenges, to become an example of successful transformation in the direction of sustainable and inclusive development.

Future research will focus on comparing biocapacity, examining the differences between carbon and ecological footprints, and analysing resource consumption patterns in the Western Balkan countries, in order to address the gap present in the current, relatively limited literature in this field.

Acknowledgements: The paper is the result of research based on the obligations under the Agreement on the transfer of funds for financing SRW in 2025 (registration number 451-03-137/2025-03), concluded between the Ministry of Science, Technological

Development and Innovation of the Republic of Serbia and the Faculty of Economics of the University of Niš.

This research is part of the 101136834 – CROSS-REIS – HORIZON-WIDERA-2023-ACCESS-03 project, funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Executive Agency. Neither the European Union nor the European Research Executive Agency can be held responsible for them.

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ЕКОНОМИКА
ISSN 0350-137X, EISSN 2334-9190, UDK 338 (497,1)
Vol. 72, april-june 2026, № 2
P. 21-32

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ORIGINAL SCIENTIFIC ARTICLE
DOI: 10.5937/ekonomika2602021B
Received: October 25, 2025
Accepted: March 19, 2026

STRATEGIC ANALYSIS OF COMPETITION AND DOMINATION IN THE INSURANCE MARKET IN SERBIA: SV MATRIX[2]

Abstract

The article investigates competition and dominance in the insurance market in Serbia (excluding Kosovo and Metohia). The SV (Strength vs. Variety) matrix method was applied, and the required indicators were calculated based on the total insurance premiums collected by insurance companies, as per data from the National Bank of Serbia for the period 2015–2024. The results showed a relatively high overall concentration (CRSV) and relatively low differentiation within the dominant group (HTSV). In addition, in the last few years (since 2020), there has been a clear tendency to decrease in both key indicators that define the SV matrix: CRSV and HTSV, which shows an approach to the RO quadrant of the SV market, i.e., a strengthening of the role of competition both within the dominant group and in relation to other market participants.

Key words: *concentration, competition, domination, SV matrix, Serbia, insurance sector*

JEL classification: *L13, L20, L22, G22*

СТРАТЕШКА АНАЛИЗА КОНКУРЕНЦИЈЕ И ДОМИНИРАЊА НА ТРЖИШТУ ОСИГУРАЊА У СРБИЈИ: МАТРИЦА SV

Апстракт

У раду се истражују конкуренција и доминирање на тржишту осигурања у Србији (без Косова и Метохије). Примењен је метод матрице SV (Strenght vs Variety), а потребни показатељи прерачунати су на основу укупне наплаћене премије осигурања осигуравајућих компанија, према подацима Народне банке Србије за период 2015–2024. Резултати су показали релативно висок укупни степен концентрације (CRSV), као и релативно малу диференцијацију унутар доминантне групе (HTSV). Поред тога, током последњих година (од 2020) запажа се јасна тенденција смањења вредности оба кључна индикатора који дефинишу матрицу SV: CRSV и HTSV, што показује приближавање квадранту RO матрице SV, односно јачање улоге конкуренције и унутар доминантне групе као и у односу на остале учеснике на тржишту.

Кључне речи: *концентрација, конкуренција, доминирање, матрица SV, Србија, сектор осигурања*

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[2] The paper is an expanded and significantly modified version of a paper presented by the author at the 52nd Symposium on Operations Research (Буквић, 2025).

Introduction

In economics, as well as in other social and natural sciences, dominance is a frequently used term and concept. It is used in two basic meanings: 1) ruling, i.e., possessing dominance in the sense of forcing others to choose a certain behavior, and 2) dominating by volume (size) in a corresponding (economic or other) space. These two meanings can be determined by the phrases "domination as influence" and "domination by size" (Блохин, 2023: 8). While in other sciences (for example, in political science or zoology) the first meaning is more often used, economic science mainly uses the second. Such is the case, for example, in antitrust theory (and politics), that is, the theory and practice of regulation. This approach, characteristic of the theory of monopolistic competition, has led to the widespread use of the term "market share" as an indicator of competition in a particular market. Although in the relevant theory (and practice) there is a part that could be treated as another meaning of the term dominance (for example, unfair competition, or abuse of a dominant position), it is usually reduced to ephemeral (and controversial, as the famous abuse of dominant position of Delta company case from year 2007) cases, and the dominant position itself is determined precisely by the aforementioned quantitative criterion - the market share of the leading firm in the market. In doing so, it can be stated that coherent considerations of "dominance as an influence" on other market participants are lacking.

The last point should be particularly emphasized. Namely, it is evident, even without special considerations, that the size of a company brings certain advantages in the market, but something else is perhaps even more significant, although it is not emphasized so often. It is about the increase in market influence through institutions, which perhaps grows even more with the company's size. Textbook categories like monopoly, monopolistic competition, oligopoly, and perfect competition can be useful, but they often do not accurately reflect real-world company operations. This refers to situations in which some of them have additional institutional advantages over others (such as close ties with the state, easier access to less expensive resources, innovative technologies, etc.), which allow them to influence market standards and accepted rules. In fact, this influence of firm size on institutions is what makes super-large businesses distinctive, as Pappe and Galukhina (Паппэ и Галухина, 2009) underline. Numerous studies of the development of individual global companies confirm that their influence on state and market infrastructure increases with their size, but there is no appropriate measure to quantify it.

Domination in the Modern Multi-level Economy

Although economists of both classical and neoclassical schools paid some attention to these problems, it was only with the development of institutional economics that they became a subject of research in the true sense. In fact, as Blokhin states (Блохин, 2023: 12), the market and dominance were inseparable from the very beginning, and dominance became independent over time as a separate sphere of activity, transforming from an individual into a state, a church, and, in a general sense, an intermediary. As a comprehensive concept, the theory of economic dominance was formulated recently

(Блохин и др., 2019) to conceptualize dominance and its role in economic science, and to consider the interrelationship between value theory and institutional research. It was created based on an analysis of existing practice across different economic systems, which showed that economic entities operate under different institutional conditions. Some of them have access to cheaper or higher-quality resources – state support, material resources, technologies, personnel, financing, and information - while others are deprived of them due to legislative measures, law enforcement practices, business rules, international sanctions and restrictions, or other formal reasons. As a result, the former receive institutional rent – income conditioned by institutional advantages compared to other market participants (Блохин, 2023: 14). Although other names are used for this income in the economic literature (political, bureaucratic, administrative, corruption, status, etc. rent), Blokhin insists on the name institutional rent, believing that it best expresses the essence of this type of income. We will not dwell on these considerations, as they fall outside the scope of our research.

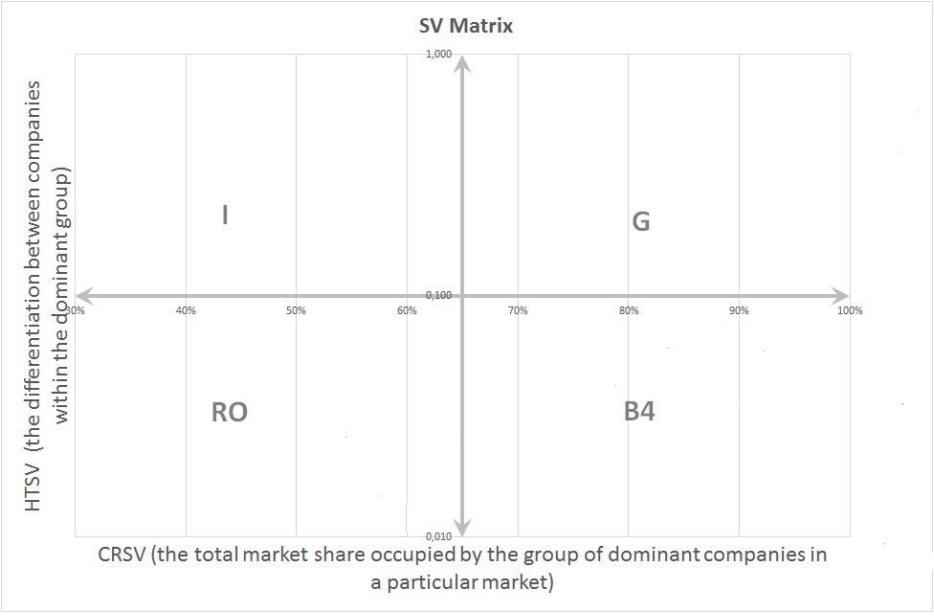
The theory of economic dominance (TED) divides market participants (companies) into three groups: the largest, large, and others, calling them, by analogy with other scientific disciplines, alpha, beta, and gamma companies (Блохин, 2015). Alpha, beta, and gamma businesses are distinguished not only by their size, but also by their respective market behaviors and the reputational positions they cultivate for themselves and others. The main difference between alpha businesses and others is the uniqueness of their market, limited only by their own capabilities. Alpha businesses are groups of companies that have systemic institutional advantages and dominate markets, determining (and changing) market institutions through their influence on the state and market infrastructure, thereby occupying a unique position in them. Beta businesses multiply the effects of using their specific assets. It consists of a group of companies that acquire (receive) from the alpha group the ability to leverage or expand specialized institutional advantages as their "specific assets", thanks to which these companies' become leaders in industry or regional markets. Gamma Business competes in the remaining market niches. These are companies that lack significant institutional advantages.

This approach to dominance, in a certain sense, also required the search for new methodological solutions. In this research, methodological notes and explanations of this new procedure will first be provided in the following section, and then the dominant companies (alpha companies) in the insurance sector in Serbia (excluding Kosovo and Metohija) for the period 2016–2024 will be determined. The analysis will be based on the determination of the SV (Strength - Variety) matrix, a new analytical tool, which has already found application in numerous areas of analysis, see, for example, (Марков, 2023; Исаков и Суслова, 2024), etc., among others, also in the insurance sector (Вертоградов et al., 2022). The foundations of the CV matrix methodology, which is used to research alpha-business, or the operations of alpha-companies, were laid down by a group of Russian authors (Щелокова и Вертоградов, 2021; Говорова и др., 2025, starting precisely from the characteristics and, above all, the limitations of traditionally applied indicators of concentration and competition, as well as from the premises of the theory of economic dominance. Review of publications using the SV matrix see in (Публикации с использованием матрицы SV, https://svmatrix.online/ru/Публикации/).

Methodological Explanations

Considering market issues of dominance within the framework of the new theory, with an emphasis on "dominance as influence", also required the development of adequate methodological solutions. Unlike the usual analyses of market conditions, based on a single indicator with the possible additional use of one of the other indicators, the new methodology (the SV matrix methodology) is characterized by a complex approach. A large number of analytical instruments not only complement each other, but also pursue a single goal – the development of a matrix that shows the degree of concentration in a given market, the existence of a dominant group (alpha company), and the differences in the strength of companies within this group (see figure 1).

Figure 1. Matrix SV



Source: (Щелокова и Вертоградов, 2021)

To achieve the stated goal, more indicators are calculated and used. The usual concentration coefficient was chosen to determine the degree of concentration CRn.

$$CRn = \sum_i^n s_i \quad (1)$$

where s_i is the share of company i in the total value of the size (most often revenue, but it can also be assets, capital, number of employees, etc.) within the corresponding branch (industry), while n is the number of companies (firms) that make up the so-called core of the market and on the basis of which the degree of concentration is determined. Indicator (1) considers only a subset of major market participants, typically the largest four, though other methods are possible. In fact, number 4 is most often uncritically taken, patterned on the example of the monograph of the Temporary National Economic

Committee (TNEC), in which, however, this number was selected for practical reasons, without theoretical explanations. See: (Adelman, 1951).

Unlike the CRn concentration coefficient (1), the HH (Hirschman-Herfindahl) coefficient (or index) is determined by accounting for the market shares of all market participants (companies). Because the participants' shares always total one, the model uses the squares of these shares for the coefficient.

$$HHI = \sum_{i=1}^{m} s_i^2, \tag{2}$$

which means that the market shares of the participants are weighted by their own shares. Although the HH coefficient also has certain shortcomings, it is still considered superior to the CRn coefficient and is used much more often; it has been accepted as an indispensable instrument by antitrust bodies worldwide.

While the choice of the number n in standard research is arbitrary, here it is determined by the needs of the research and the results obtained by applying another instrument, namely the Linda index system (Linda, 1976):

$$ILn = \frac{1}{n(n-1)} \sum_{i}^{n-1} \frac{n-1}{i} \frac{CR_i}{CR_n - CR_i} \tag{3}$$

which indicates (identifies) a possible group that dominates (oligopoly). The number of members of such a group is determined by the sequence of the obtained indices (3), as the number for which ILn < ILn+1, thus by the interruption of the decreasing sequence ILi.

This also determines the value of CRSV, i.e., the aggregate share of the group of dominant companies in the observed market. This value is displayed on the horizontal axis of the SV matrix, which ranges from 30% to 100% (if the aggregate share of the group of alpha companies is less than 30%, there can be no talk of dominance). The dividing line on this axis is 65%: an aggregate share of alpha companies less than 65% means that their position is weak and that they face substantial competition from other companies in the market, while conversely, a share greater than 65% shows that the market is almost entirely under the control of this group, while other companies do not have a significant impact on the position of the dominant ones.

The vertical axis shows the homogeneity or differentiation within the dominant group, expressed by the degree of concentration of the companies' market shares. The Hall-Tideman concentration coefficient is used for this (Hall & Tideman, 1967):

$$HT = \frac{1}{2(\sum_{i=1}^{N} R_i s_i) - 1} \tag{4}$$

where Ri denotes the rank of companies according to the size of their market shares (in descending order). Since expression (4) measures concentration across the entire market (all companies), it needs to be modified. First, of course, HTn is determined, i.e., the index within the dominant group, according to formula (4), but only for the dominant group. The obtained index must then be normalized.

$$HTSV = \frac{HTn - 1/n}{1 - 1/n} \tag{5}$$

which neutralizes the fact that the minimum value of the index (4) depends on the size of the set (HTmin = 1/n), i.e., values are comparable across sets of different sizes. By

determining HTSV, the second coordinate of the given point (company) in Figure 1 is also obtained. The range in which the values on this vertical axis move is actually from zero (0) to one (1). But it is displayed in the corresponding graph in logarithmic scale, which results in a value halfway down the vertical axis: 0.1.

It is obvious that the southwest-northeast direction defines the movement from competition to dominance, and vice versa. In the extreme lower left quadrant, competition is the most intense, and competition in general characterizes the entire quadrant, which is why it is called the "Red Ocean" (Kim and Mauborgne, 2004; 2015). In contrast, in the extreme upper right corner of the quadrant is located the dominant super-alpha company, that is, an obvious leader that determines the rules of the game in that market, while the entire quadrant is defined by the group's dominance relative to other market participants. The relationships among participants within the dominant group are reflected in the degree of their differentiation, as measured by the HTSV coefficient.

Table 1. Description of the quadrants of the SV matrix

	30% < CRSV < 65% Low market share of the dominant group	**CRSV > 65%** High market share of the dominant group
HTSV > 0,1 high level of differentiation within the dominant group	**Quadrant I – "low or natural barriers"** There is one clear leader within the dominant group, but new players are constantly coming to the market, since it is impossible to establish barriers to their entry	**Quadrant G – "Dominant superalpha"** There is one clear leader within the dominant group that determines the rules of the game in this market
HTSV < 0,1 low level of differentiation within the dominant group	**Quadrant RO – "Red Ocean"** Companies from the dominant group actively compete both with each other and with all other companies in the market	**Quadrant B4 – "Natural oligopoly"** The dominant group includes several companies of comparable capabilities that are interested in preventing new players from entering their circle

Source: (Щелокова и Вертоградов, 2021)

Depending on the calculated values of HTSV and CRSV, the corresponding market will be located in one of the four quadrants of the SV matrix (Figure 1), whose characteristics are shown in the following table (Shchelokova and Vertogradov, 2021; Table 1), and which have been given appropriate names: IKEA, GAZPROM, RED OCEAN, BIG4 (Big Four).

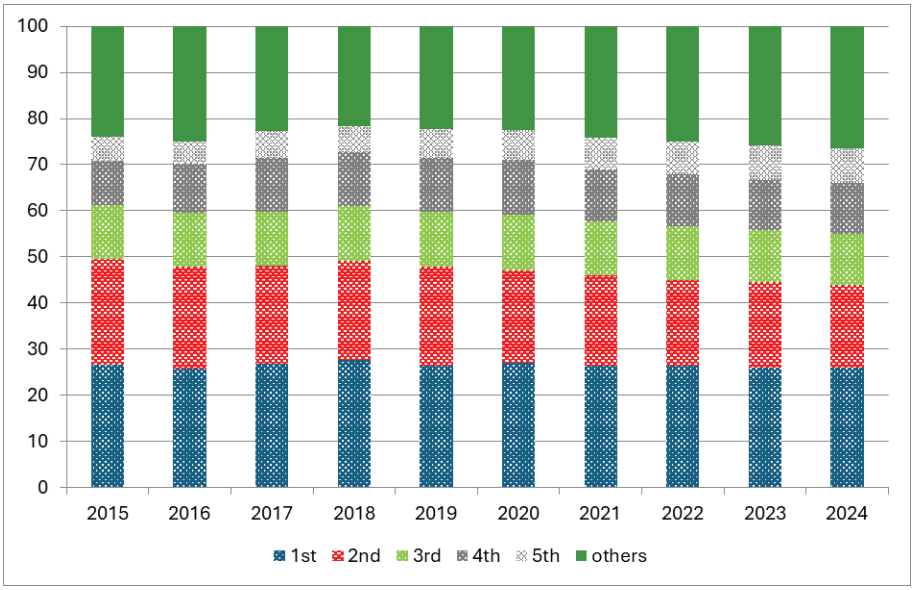
Results and Discussion

The insurance sector in Serbia (excluding Kosovo and Metohija) is characterized by a relatively high degree of concentration. During the observed period, the largest companies accounted for the largest share of the total premium collected, as indicated by indicator (1) with the usual choice of n=4, which would classify this sector as highly concentrated (see Figure 2). A somewhat different classification would be suggested by the Hirschman-Herfindahl coefficient, which falls in the moderate concentration zone (see Table 2). We will not determine and use other concentration indicators and other aspects of analysis based on them on this occasion. For these see relevant research in Bukvić (2022; 2024).

Based on the methodological settings and data from the National Bank of Serbia on insurance companies in Serbia (excluding Kosovo and Metohija), we determined all the necessary elements for constructing the SV matrix (Figure 3). All necessary coefficients were calculated based on the value of the variable "Total premium collected", in accordance with legal provisions (Закон о заштити конкуренције, 2009 and 2015). Of course, further analysis would need to be done using specific variables (life insurance premium, property insurance premium, etc.), as, for example, was done in the work (Вертоградов et al., 2022). The results obtained show that the values of HTSV and CRSV in all observed years belong to quadrant B4, which the authors of the methodology called "Natural oligopoly".

Figure 3 shows that during the observed period, Serbia's insurance sector (excluding Kosovo and Metohija) was in quadrant B4, marked by high concentration and minimal differences among leading companies. The dominant group (determined according to the criteria of the Linda index system) consisted of four companies in the first years (Dunav, Generali osiguranje, DDOR, Wiener), and in the latter five companies (Dunav, Generali osiguranje, DDOR, Wiener, Triglav), with minor changes in their order of market share in individual years. As shown in Figure 3, their combined share (coefficient CR4 or CR5) ranged from slightly over 70 percent to almost 78 percent. Such coefficient values could suggest a fairly high degree of concentration in the sector. However, this conclusion would not be confirmed by the values of the Hirschman-Herfindahl concentration index (Hirschman, 1945; Herfindahl, 1950), according to which the insurance market in Serbia (excluding Kosovo and Metohija) in the observed years should rather be classified as moderately concentrated (see the third row of Table 2), bearing in mind that highly concentrated markets are considered to be those in which the value of this coefficient is above 1,800, and in some cases (according to the legislation of certain countries) even higher.

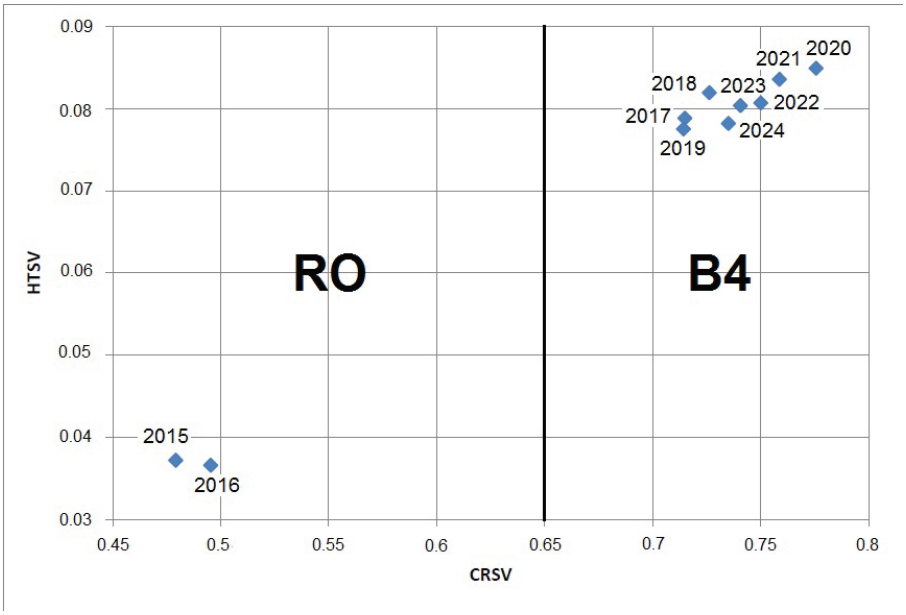
Figure 2. The shares of the leading companies in the total premium collected of the sector



Source: On the basis of the author's calculation

Figure 3 shows only quadrants RO and B4, which contain the CRSV and HTSV indicators for the insurance sector in all observed years. In the first two analyzed years (2015 and 2016), the dominant group consisted of two companies, with relatively modest shares of total insurance premiums (about 25 percent each); the sector is also characterized by very strong competition. The result shown in Figure 3 indicates that its position was in quadrant RO (Red Ocean). Over the next three years, the dominant group consisted of four companies, with a share exceeding 70%. Also, the group shifted in the year 2017 from quadrant RO to quadrant B4. The above tendency suggests that in the coming period, it is realistic to expect further equalization of differences among dominant companies, as well as a further reduction in their aggregate share of the total variable under consideration (total premium collected). Of course, specific trends in the future will be influenced by a large number of factors, including both the strategies of the companies themselves from the dominant group and their other competitors, as well as institutional conditions, which will be created by companies within their capabilities, see, for example, the review (Вертоградов, 2020), as well as (Vertogradov et al., 2023), but above all the state, which rightfully belongs to regulating the institutional environment.

Figure 3. Matrix SV for the insurance sector in Serbia (without Kosovo and Metohia) 2016–2024: quadrants RO and B4



Source: On the basis of the author's calculation

The values of key indicators for this sector (CRSV and HTSV) in the observed period are shown in Table 2. As we can see, the years 2015 and 2016 are whole separate from the others. In these years, the dominant group consists of two companies, and the sector belongs to quadrant RO. Starting in 2017, a second dominant group was

formed, consisting in next three years of four companies (2017–2019) and further of five companies (2020–2021). The group is located in quadrant B4, and the differences in the position of the sectors on the SV matrix are not large. A general and important characteristic of this table (also Figure 3) is a tendency for concentration to decrease from 2020 to 2024. A break (but only apparent) can be seen in 2020, when a fifth company joined the four dominant companies, leading to a kind of translation of the trend line toward the northeast, but it retained its basic tendency. The HTSV values themselves are quite close to the border that separates this quadrant (B4) from quadrant G (Dominant Superalfa), but the tendency clearly shows a tendency to move away from it, as well as, on the other hand, to approach the second (vertical) border that separates this quadrant from the quadrant of strong competition (RO – Red Ocean).

Table 2. Concentration key indicators in the insurance sector of the Republic of Serbia (without Kosovo and Metohia) 2016–2024

Indicator	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
CR2 (%)	49.54	47.93								
CR4 (%)			71.49	72.62	71.43					
CR5 (%)						77.55	75.86	75.00	74.06	73.51
HH (%)	1,558	1,496	1,543	1,597	1,545	1,506	1,468	1,435	1,410	1,392
HT (%)	14.47	13.88	15.05	15.57	15.18	14.87	14.33	14.13	13.97	13.81
HTSV	0.037	0.037	0.079	0,.082	0.078	0.085	0.084	0.081	0.080	0.078
Quadrant	RO	RO	B4	B4	B4	B4	B4	B4	B4	B4

Source: Author's calculation

The results of this analysis can also be applicable to companies in the sector. They should develop their strategy based on these results and their industry position. Its capabilities will, of course, depend on this position, but the general tendency towards moving towards a "Red Ocean" should not be disputed. When creating its strategy, companies must not forget the following rule: the imperatives for red ocean and blue ocean strategies are starkly different (see Table 3).

Each company will independently develop and execute its own strategies, while also considering potential collaborations, such as establishing dependent gamma-businesses at higher levels of the hierarchy (see Вертоградов, 2020). Table 2 shows beta and gamma companies represent 25–30% of total size, except in 2015 and 2016. This highlights their responsiveness to market changes and actions by alpha companies. Therefore, they need to approach the construction of their strategies with special attention.

Table 3. Strategies for the red ocean and the blue ocean

Red Ocean Versus Blue Ocean Strategy	
Red ocean strategy	Blue ocean strategy
Compete in existing market space	Create uncontested market space
Beat the competition	Make the competition irrelevant
Exploit existing demand	Create and capture new demand

Make the value/cost trade-off	Break the value/cost trade-off
Align the whole system of a company's activities with its strategic choice of differentiation *or* low cost	Align the whole system of a company's activities in pursuit of differentiation *and* low cost.

Source: (Kim and Mauborgne, 2004: 81)

As for alpha-businesses, i.e., companies that belong to that hierarchical level or plan to achieve such positions, the book by Kim and Mauborgne (2015) can be recommended as a classic manual. As the authors state, numerous service industries, including insurance, banking, and investment, have been swept up in the wave of blue ocean creation. The experiences of companies such as the English "Direct Line Group", one of the UK's largest insurance companies, can be very inspiring in this regard, see (Kim and Mauborgne, 2015). Instead of using brokers and regional branch offices, this company uses information technology to improve claims handling, and it passes on some of the cost savings to customers as a lower insurance premiums.

Conclusions

The paper investigates competition and dominance in the Serbian insurance market (excluding Kosovo and Metohija). The ten-year period 2015–2024 was observed. The SV matrix method, developed by a group of Russian scientists, was applied. The method is based on constructing graphs in a two-dimensional rectangular system, with axes showing two key quantities: CRSV (degree of concentration in the sector) and HTSV (differentiation within the dominant group).

The dominant group, extracted using the Linda index system, consists of two companies in the first two years (2015 and 2016), four in the next three years (2017–2019), and five in the following years. The results showed a relatively high degree of concentration (the combined market share of the dominant group ranged from 71 to 78 percent) and relatively low differentiation among them. Based on this, in all observed years, the SV matrix contains the required indicators, based on which the insurance market in Serbia (excluding Kosovo and Metohija) is classified in the RO quadrant (red ocean) in the first two years, and in the B4 quadrant (natural oligopoly) in the subsequent years. It should be noted that, since 2020 (when the dominant group increased to five companies), the sector has shown a noticeable shift towards the RO quadrant, in the northeast-southwest direction, with a simultaneous decrease in both relevant indicators.

The results obtained can be treated as an initial but important step in the analysis of competition and dominance in this sector. However, their value should not be relativized. This applies both to the insurance companies themselves, which are in a position to plan their business and strategic decisions, and to the macroeconomic or regulatory role of the state, which must analyze the market situation and, based on that, plan and improve its regulatory function.

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ЕКОНОМИКА
ISSN 0350-137X, EISSN 2334-9190, UDK 338 (497,1)
Vol. 72, april-june 2026, № 2
P. 33-44

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ORIGINAL SCIENTIFIC ARTICLE
DOI: 10.5937/ekonomika2602034T
Received: November 20, 2025
Accepted: March 06, 2026

COULD ELECTRIC CAR CHANGE THE DESTINY OF TÜRKİYE'S TRADE DEFICIT?[3]

Abstract

Purpose *– This study investigates the relationship between the proliferation of electric vehicles in Türkiye and its subsequent effects on oil dependency and the trade deficit of Türkiye.*

Research design/method/approach *– This study employs a frequency domain causality test to investigate the influence of electric vehicle adoption on oil imports and the foreign trade deficit of Türkiye over the 1994–2024 period. Specifically, the research utilizes the Breitung-Candelon frequency domain Granger causality approach, which decomposes causality to explore its effects in the short, medium, and long term.*

Findings – *The frequency domain causality test confirms a long-term causal effect of electric vehicle on Türkiye's oil imports. Conversely, the analysis indicates that the volume of electric vehicles demonstrates no causal relationship with the trade deficit across the short, medium, or long term.*

Practical implication – *The findings of this study demonstrate that the adoption of electric vehicles has the potential to alter Türkiye's oil demand over the long term. However, the prevailing market share and competitive advantage held by Chinese electric vehicle manufacturers pose a substantial risk, potentially leading to the persistence of Türkiye's foreign trade deficit.*

Originality/Value – *While existing literature broadly addresses electric vehicle impacts, this study fills a crucial gap by offering the first empirical analysis, to our knowledge, that specifically investigates the causality between electric vehicle sales volume and Türkiye's key macroeconomic indicators (oil imports and foreign trade deficit) using frequency domain analysis.*

Key words: *Electric Vehicle Adoption, Türkiye, Trade Deficit, Oil Import*

JEL classification: *F14, Q56*

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[3] This paper is derived from the ongoing master's thesis that entitled as "The Effects of Electric Vehicles on Türkiye's Foreign Trade Deficit within the Scope of Energy Import".

ДА ЛИ БИ ЕЛЕКТРИЧНИ АУТОМОБИЛ МОГАО ПРОМЕНИТИ СУДБИНУ ТРГОВИНСКОГ ДЕФИЦИТА ТУРСКЕ?[4]

Апстракт

Сврха – Ова студија истражује везу између ширења електричних возила у Турској и њених последичних ефеката на зависност од нафте и трговинских дефицита Турске.

Дизајн/метод/приступ истраживања – Ова студија користи тест узрочности у фреквентном домену како би истражила утицај употребе електричних возила на увоз нафте и спољнотрговински дефицит Турске у периоду од 1994. до 2024. године. Конкретно, истраживање користи Брајтунг-Канделонов приступ узрочности у фреквентном домену и Грејнџеровом систему, који разлаже узрочност како би истражио њене ефекте на краћи, средњи и дужи рок.

Резултати – Тест узрочности у фреквентном домену потврђује дугорочни узрочни ефекат електричних возила на увоз нафте у Турску. Насупрот томе, анализа показује да обим електричних возила не показује узрочну везу са трговинским дефицитом на краћи, средњи или дужи рок.

Практична импликација – Резултати ове студије показују да усвајање електричних возила има потенцијал да промени потражњу за нафтом у Турској на дужи рок. Међутим, преовлађујући тржишни удео и конкурентска предност коју држе кинески произвођачи електричних возила представљају значајан ризик, што потенцијално може довести до опстанка спољнотрговинског дефицита Турске.

Оригиналност/Вредност – Иако постојећа литература углавном обрађује утицаје електричних возила, ова студија попуњава кључну празнину нудећи прву емпиријску анализу, колико нам је познато, која посебно истражује узрочност између обима продаје електричних возила и кључних макроекономских индикатора Турске (увоз нафте и спољнотрговински дефицит) користећи анализу фреквентног домена.

Кључне речи: *усвајање електричних возила, Турска, трговински дефицит, увоз нафте*

Introduction

Elaboration in an era, led by the global transition to sustainable energy solutions, electric vehicles (EVs) have emerged as a key driver of economic transformation as well as many other impacts are concerned. For Türkiye where foreign trade balance has been deteriorating for a long time by energy imports and particularly crude oil, EVs adoption presents a strategic opportunity to overcome this persistent foreign trade deficit. By reducing dependency on imported crude oil and prompting the domestic energy production, EVs could reshape Türkiye's foreign trade balance dynamics in field of energy while aligning with global sustainability goals.

[4] Овај рад је настао из текућег мастер рада под називом „Утицај електричних возила на спољнотрговински дефицит Турске у оквиру увоза енергије".

According to Bloomberg New Energy Finance's updated zero-emission vehicles' progress stats, EVs successfully reduce the demand for oil. The adoption of EVs prevented the demand for approximately 1.5 million barrels of oil per day in 2021, reaching approximately 3.3% of total demand all around the world. Stats point out that this amount is foreseen to rise up to 16 million barrels of oil per day in 2035 which will mean that dependence on oil in transportation will be permanently eliminated (Bloomberg NEF, 2022).

Again, in line with the Oil 2023 report published by the International Energy Agency (IEA) it is anticipated that the annual demand grow is going to rise 6 %. This is supported by the petro chemical and aviation sectors and reaches 105.7 million barrels per day. However, the annual demand is rise is expected to decline from 2.4 million barrels to 0.4 million barrels in 2028 (IEA, 2023).

Another case study – Türkiye Electric Vehicles Outlook published by Sabancı University Istanbul International Center for Energy and Climate (IICEC) puts forth that in a fast grow projection scenario up to 2030, the market share of EVs potentially rises up to 1/3 of total market in Türkiye will reduce the crude oil import up to 2.5 billion USD per year. (Sabancı University IICEC, 2021).

This study explores Türkiye's foreign trade balance, focusing on historical trends and the emerging influence of EVs on fossil fuel consumption and trade dynamics. Given Türkiye's persistent trade deficit, largely attributed to high fossil fuel imports such as crude oil and natural gas, this research investigates how the shift towards EVs might alleviate this energy dependency. Leveraging econometric analysis, the study examines the projected impact of EV adoption on Türkiye's trade balance within the broader context of rising global environmental concerns and the transition to sustainable energy sources. As countries worldwide embrace EVs to curb greenhouse gas emissions, Türkiye finds itself at a strategic crossroads, balancing the imperative of trade deficit reduction with the opportunity to lead in a rapidly expanding EV market.

In line with the global trends, potential effects of widespread EV adoption and the subsequent reduction in fossil-based fuel consumption on Türkiye's trade deficit is observed by employing quantitative analysis and estimate its impact on the Foreign Trade Balance. By reviewing available trade data, industry trends, and economic forecasts, the study explores Türkiye's trade deficit trajectory, focusing on the influence of EVs in a nation heavily reliant on crude oil. The analysis incorporates current economic trends, strategic national plans, and the anticipated effects of increased electricity demand resulting from EV usage. The research aims to test the hypothesis that "Türkiye's foreign trade deficit is expected to decrease with the increase in electric vehicles," offering insights into the broader implications of EV adoption on foreign trade balances.

Literature Review

Elaboration the transition to EVs has been a focal point and widely studied across different regions, with a focus on their economic, environmental, and policy-related implications. A central concern across the literature is how EV adoption influences national economies, especially in terms of trade balances, energy imports, and macroeconomic dynamics.

The potential to alleviate pressure on Türkiye's foreign trade balance constitutes a core argument driving the development of the EV ecosystem. In terms of account deficit Bayar et al. (2014) employed a VAR model to identify the key drivers behind Türkiye's deficit from 2000 to 2013, pinpointing oil import prices as a major contributor. This finding reinforces the inference that a reduction in oil imports—potentially catalysed by EV adoption—could significantly support Türkiye's macroeconomic stability. Further supporting this perspective, Karadaş and Işık (2018) conducted an econometric analysis confirming that dependency on fossil fuels exacerbates external imbalances, which further underscores the strategic role of the EV transition in the nation's long-term economic planning.

International studies consistently corroborate similar macroeconomic effects stemming from EV adoption. Lin and Wu (2021) utilized a Computable General Equilibrium (CGE) model to simulate the effects of EV adoption in China. The results of these simulations demonstrated that EV growth shifts energy consumption away from fossil fuels, reduces oil imports, and consequently alters broader economic indicators. Similarly, Guo et al. (2023) focused on China and Japan, using time series analysis to examine how EV adoption influences crude oil imports. Their work recommends the necessity of complementary policies—such as vehicle ownership limits and fuel taxation—to maximize the economic gains derived from the EV transition.

However, the impact of the EV transition on the trade balance is not unidirectional and is contingent upon the structure of the supply chain. For instance, Sigurdsson (2010) evaluated Iceland's experience, finding that while EVs reduce gasoline imports, the high initial cost of EV imports can negatively affect the trade balance in the short term, particularly in the absence of domestic EV production. In contrast, a forward-looking input-output analysis for Indonesia by Pirmana et al. (2023) suggests the opposite: investment in domestic EV production would boost GDP, create jobs, and capitalize on national resource advantages, especially in battery materials like nickel. These findings suggest that for Türkiye, the ultimate net benefit of EV adoption on foreign trade will largely depend on how rapidly and comprehensively local production capacity is developed.

Several studies investigate Türkiye's readiness and challenges in the shift toward electric mobility. Key studies utilize modelling and policy analysis to assess the impact of this shift on the energy sector, economy, and consumer behaviour. Specifically, Coban, et al. (2022) utilized simulation and optimization models to analyse the effects of EV integration on the national power grid. Their findings suggest that EV adoption could not only enhance grid efficiency but also strengthen energy security and reduce reliance on imported oil.

Moving from energy policy to fiscal structure, Ökde (2022) analysed Türkiye's EV taxation policies in comparison with the EU framework. This analysis highlighted how current fiscal structures may inadvertently impede widespread EV adoption. Consequently, the study recommends harmonizing tax policy to facilitate market growth and accelerate progress toward energy independence goals. Complementing this economic perspective, Kocaöz and İğde (2022) investigated Turkish consumer preferences from a behavioural standpoint. Their research indicates that perceived price value and environmental concerns are significant determinants of purchasing behaviour, thereby reinforcing the importance of targeted financial incentives and public awareness initiatives.

The success of the EV transition, particularly concerning its broader economic benefits, is intrinsically linked to macroeconomic stability. Kaya (2022) examined the critical impact of exchange rate volatility on renewable energy investment and trade balances within Türkiye. This work underscores the necessity of policy stability to foster long-term sustainability and enhance economic resilience. These are preconditions for successfully implementing large-scale, capital-intensive transitions like the shift to electric mobility. The IEA (2021) evaluated Türkiye's energy policy structure, noting the persistent dominance of fossil fuels—particularly coal. The IEA report explicitly emphasized the significant potential of EVs to bolster energy independence, simultaneously advocating for expanded consumer incentives, improved charging infrastructure, and policy harmonization with European Union (EU) standards. IEA (2021) not only evaluates Türkiye's policy but also offers a comparative framework by analysing member countries' transition efforts. It highlights key challenges such as inconsistent incentives and infrastructure gaps that are common across developing economies. Collectively, these studies reveal that EV adoption plays a crucial role in shaping energy policies, economic stability, and environmental sustainability. While Türkiye and other countries are taking steps toward increased EV adoption, challenges such as tax policies, trade balance implications, and fossil fuel reliance must be addressed to ensure a smooth transition. The research suggests that integrating EVs strategically can reduce oil dependency, enhance energy security, and contribute to economic growth, making the shift toward sustainable mobility a global priority.

As a conclusion, the reviewed literature demonstrates that EV adoption has multifaceted impacts—ranging from energy efficiency to significant macroeconomic shifts. In Türkiye, the alignment of fiscal, infrastructural, and consumer policy remains critical. Globally, successful EV transitions are often supported by integrated industrial and trade policies. Collectively, these studies reveal that EV adoption plays a crucial role in shaping energy policies, economic stability, and environmental sustainability. Türkiye and other countries are taking significant steps toward increased EV adoption. However, challenges such as tax policies, trade balance implications, and fossil fuel reliance must be addressed to ensure a smooth transition. These findings support the development of an econometric model to explore how EV adoption could influence Türkiye's foreign trade balance, oil imports, and broader economic indicators.

This study offers a unique contribution to literature by empirically examining the relationship between electric vehicle adoption and the trade balance within an econometric framework. The proposed model not only captures the dynamics specific to Türkiye but also provides a methodological template applicable to other economies facing similar structural constraints in their energy and trade systems.

Research Design, Methodology, and Research Tasks

Data

Building on prior research that has examined Türkiye's external imbalances through VAR frameworks (e.g., Bayar, Kılıç & Arıca, 2014) and highlighted the strategic role of EV adoption for reducing oil dependency (e.g., Coban et al., 2022; IEA, 2021),

this study adopts a time-series econometric approach. In line with these contributions, we focus on a core set of variables—foreign trade deficit, crude oil imports and electric vehicle registrations. This article employs an annual dataset spanning the period 1994–2024 for Türkiye. The data were compiled from Turkish Statistical Institute (TÜİK). The focus is on variables that capture the country's foreign trade balance, energy dependency and the penetration of EVs. The variables of the study are as follow:

- Foreign Trade Deficit of Türkiye to be this study's dependent variable can briefly be defined as the gap between the exports and imports of Türkiye in million US $.
- Total Crude oil imports of Türkiye that measured in tons.
- The number of registered EVs in Türkiye.

All variables have been transformed into natural logarithms to stabilize the variances, reduce the effect of outliers.

Methodology

Granger (1969) causality analyses the relationship between variables via p-order vector autoregressive (VAR) model. Geweke (1982; 1984) and Hosoya (1991) defined frequency domain Granger test through Wald-type approach to determine certain frequency causality. Breitung and Candelon (2006) constructed a new causality model by testing null hypothesis at frequency ω.

Methodologically, it is taken as reference Geweke's method (Geweke,1984) to measure the causality between variables when one of them is taken conditional. The VAR system used in this study can be expressed in its moving-average and frequency-domain forms following Breitung and Candelon (2006):

$$\begin{pmatrix} x_t \\ y_t \end{pmatrix} = \Phi(L)\varepsilon_t = \begin{vmatrix} \Phi_{11}(L) & \Phi_{12}(L) \\ \Phi_{21}(L) & \Phi_{22}(L) \end{vmatrix} \begin{pmatrix} \varepsilon_{1t} \\ \varepsilon_{2t} \end{pmatrix} = \Psi(L)\eta_t = \begin{vmatrix} \Psi_{11}(L) & \Psi_{12}(L) \\ \Psi_{21}(L) & \Psi_{22}(L) \end{vmatrix} \begin{pmatrix} \eta_{1t} \\ \eta_{2t} \end{pmatrix}$$

where

$$\eta_t = G\varepsilon_t, \quad E(\eta_t \eta_t') = I, \quad \Phi(L) = \Theta(L)^{-1}, \quad \text{and } \Psi(L) = \Phi(L)(G)^{-1}$$

to avoid spurious or indirect causal effects, the frequency-domain framework can be extended to include additional conditioning variables. In such cases, the Breitung–Candelon test is computed conditional on these variables, following the approach suggested by Geweke. The conditioning is implemented by including the lagged values of an additional variable z_tin the VAR system.

For simplicity, assuming a single conditioning variable z_t, the test of the null hypothesis $H_0: M_{y \to x|z}(\omega) = 0$ (no causality from y_t to x_t at frequency ω, conditional on z_t) can be presented as follow:

$$M_y \to x(\omega) = \log 1 + \frac{|\psi_{12}(e^{-i\omega})|^2}{|\psi_{11}(e^{-i\omega})|^2}$$

rejecting H_0 implies that y_t Granger-causes x_t conditionally on z_t at frequency ω.

In light of the evidence presented, this study aims to elucidate the impact of EV proliferation on crude oil imports and, consequently, on Türkiye's foreign trade balance. At the frequency ω the particular variable is the cause for prediction of the effected

variable (Tastan, 2015). As specified by Ciner (2011), the frequencies 0.5, 1.5, and 2.5 denote long-term, medium-term, and short-term causalities, respectively.

Research Results and Discussion

This study utilizes frequency-domain causality analysis to examine the relationship between the number of EVs, oil imports, and Türkiye's foreign trade deficit. The descriptive statistics for the variables, presented in their levels, are displayed in the following table.

Table 1: Descriptive Statistics of Variables

Variable	Mean	Std. Dev.	Minimum	Maximum
lnDeficit	17.5	0.78	15.45	18.51
lnOil	16.96	0.19	16.47	17.32
lnEV	3.33	4.05	0	12.12

Prior to the econometric modelling, the time-series properties of the variables were rigorously examined. The maximum lag length for the variables was determined in order to implement the frequency-domain causality test. The results of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests are presented in Table 2.

Table 2: Unit Root Tests Results

	ADF Test Results		Phillips Perron Test Results	
Variables	I(0)	I(1)	I(0)	I(1)
lnoil	-1.898	-6.975***	-1.805	-7.304***
lndeficit	-1.816	-4.701***	-2.844*	-7.202***
lnev	1.842	-2.998**	1.252	-2.960**

***Note:** *, **, and *** refer to significance level successively at 10%, 5% and 1%.*

To test unit roots, both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were employed. The use of each test ensures robustness, as ADF controls correlation through lagged differences while PP adjusts for serial correlation and heteroskedasticity in the error terms. The results, summarized in Table 1, show that none of the variables are stationary in levels, but all become stationary at first differences. Thus, all variables are integrated into I(1). Since the variables are integrated of I(1). Additionally, the analysis is conducted within a VAR framework with four lags. The VAR model results are presented in Table 3.

Table 3: VAR Model Results

Lag	Ll	LR	df	p	FPE	AIC	HQIC	SBIC
0	-84.5095				.131159	6.48218	6.525	6.62616
1	-18.8505	131.32	9	0.000	.001986	2.28522	2.45648	2.86115*
2	-9.1339	19.433	9	0.022	.00194	2.23214	2.53183	3.24001

3	4.96529	28.198	9	0.001	.001433	1.85442	2.28256	3.29424
4	20.6482	31.366*	9	0.000	.001014*	1.3594*	1.91597*	3.23116

To select the optimal lag length standard information criteria such as the Akaike Information Criterion (AIC), the Hannan-Quinn Information Criterion (HQIC), and the Schwarz Bayesian Information Criterion (SBIC) were employed. As reported in Table 2, all three criteria consistently indicate that a lag length of four (lag[4]) provides the best model fitting. Consequently, four lags were adopted in the subsequent estimations to ensure robust and reliable inference.

To further investigate the dynamic linkages among the core variables—foreign trade deficit, crude oil imports, and electric vehicle (EV) registrations—this study applies the Breitung–Candelon frequency-domain Granger causality (BCG) test. Unlike conventional time-domain causality tests, which provide a single causal inference over the entire sample, the BCG approach decomposes causality across different frequencies. This enables the distinction between short-term fluctuations (high frequency) and long-term co-movements (low frequency) in the relationships among variables. By employing both unconditional and conditional BCG specifications, the analysis examines the direct causality between EV adoption and crude oil imports or trade deficit. This methodological choice allows us to capture more nuanced interactions. Specifically, it helps determine whether EV adoption exerts immediate effects on crude oil dependency and foreign trade balances, or whether such impacts unfold gradually over the long run.

The Breitung–Candelon frequency-domain causality (BCG) tests were applied for four specifications: (i) lnEV → lnOil, (ii) lnEV → lnOil | lnDeficit, (iii) lnEV → lnDeficit, and (iv) lnEV → lnDeficit | lnOil. The figures below plot the test statistic across frequencies, with the 5% critical value as a reference line.

Test results reveal a strong causal relationship from EV adoption to crude oil imports at low and medium frequencies, indicating that the effect is concentrated in the long run. While the relationship remains statistically significant, though weaker, at intermediate frequencies, it disappears at higher frequencies, suggesting no short-term impact. These findings highlight that EV penetration contributes to reducing oil dependence primarily through long-term adjustments rather than short-run fluctuations.

The conditional BCG causality test, controlling for the foreign trade deficit, shows that the causal effect from EV adoption to crude oil imports is not statistically significant across the frequency spectrum. P-values remain well above conventional thresholds, indicating that once the external balance is accounted for, EV penetration does not exert an independent influence on oil imports. This suggests that the long-run link observed in the unconditional setting may be mediated through the foreign trade deficit rather than reflecting a direct EV–oil relationship.

The unconditional BCG causality test from the trade deficit to crude oil imports reveals no statistically significant causal effect across the frequency range. P-values remain above conventional thresholds, indicating that fluctuations in Türkiye's trade deficit do not directly explain changes in crude oil imports. This suggests that oil import dynamics are shaped more by other structural factors, such as energy demand and EV adoption, rather than by the deficit itself.

The conditional BCG causality test from the foreign trade deficit to EV adoption,

with crude oil imports included as a conditioning variable, provides no evidence of statistical significance across the spectrum. As it is monitored in the r(W) matrix, test statistics remain low and the corresponding p-values consistently exceed conventional thresholds (0.05), both in the long-run frequencies (0.01–0.40) and in the higher-frequency bands. This indicates that fluctuations in the trade deficit, once oil imports are controlled for, do not exert a causal influence on EV registrations. The absence of significant results across all frequencies suggests that the trajectory of EV adoption in Türkiye. It is not directly driven by external balance dynamics but is instead more responsive to structural determinants such as energy policy, infrastructure development, and consumer preferences.

Table 4: The Breitung–Candelon Frequency-Domain Granger Causality Test Results

Null Hypothesis	**Time Domain Causality (F-stat., p-value)**	**Long-run**		**Medium-run**		**Short-run**	
		(ω=0.01)	(ω=0.05)	(ω=1.00)	(ω=1.50)	(ω=2.00)	(ω=2.50)
lnEV is not Granger cause of lnOil	4.36 (0.042)**	6.163**	6.181***	0.867	0.334	0.062	0.045
lnEV is not Granger cause of lnOil | lnDeficit (Conditional)	5.27 (0.021)**	23.593***	23.657***	1.706	0.475	0.412	0.336
lnEV is not Granger cause of lnDeficit	0.22 (0.641)	0.001	0.004	0.783	0.553	0.531	0.562
lnEV is not Granger cause of lnDeficit | lnOil (Conditional)	0.17 (0.685)	0.749	0.747	0.603	0.582	0.699	0.917

*Note: *, ** and *** denote significance at 10%, 5% and 1% levels respectively.*

The long-term relationship indicates that the number of EVs in Türkiye is Granger cause of country's oil import volume. Conversely, in the short and medium term, no causal link is observed running from EV adoption to either oil imports or the trade deficit. Specific details regarding frequency domain causality are documented in Table 5.

Table 5: The Breitung–Candelon Frequency-Domain Granger Causality Interpretations

Direction Causality	Conditioning	Interpretation
lnEV → lnOil	Unconditional	EV adoption significantly Granger-causes oil imports at low frequencies, suggesting that rising EV penetration contributes to structural reductions in oil demand.
lnEV → lnOil	Conditional on lnDeficit	Causality remains significant even after conditioning on trade deficit, reinforcing the robustness of the EV–oil nexus.
lnEV → lnDeficit	Unconditional	No significant causal relationship is detected; EV adoption does not directly drive trade deficit.
lnEV→ lnDeficit	Conditional on lnOil	No significant causal effect is found; EV adoption and fluctuations in the trade deficit are independent once oil imports are controlled for.

The BCG frequency-domain Granger causality tests provide nuanced insights into the dynamic interrelationships. Results indicate that EV adoption exerts a statistically significant and robust long-run causal influence on crude oil imports, both unconditionally and when conditioned on trade deficit. Conversely, no significant causal influence is found from the trade deficit to either oil imports or EV adoption. This pattern suggests that the structural shift toward EVs plays a pivotal role in reducing oil dependence, while trade balance fluctuations alone do not shape EV diffusion dynamics.

Conclusion

The world-wide rapid transition from conventional internal combustion engine technology to EVs driven by new global trends will inevitably have social, cultural, environmental, and economic consequences. This study investigated the dynamic relationship between Türkiye's foreign trade deficit, crude oil imports, and EV adoption through a time-series econometric framework. Results reveal that the three core variables are integrated of order one and exhibit no long run cointegration. Accordingly, their interactions are better captured in a short-run VAR framework. The empirical evidence derived from unit root, cointegration, VAR, and frequency-domain causality analyses demonstrates a clear and statistically significant causal relationship between electric vehicle (EV) adoption and crude oil imports. Specifically, higher EV penetration leads to reductions in oil import demand over the long run, confirming that electrification of the transport sector has the potential to ease one of the key structural vulnerabilities in Türkiye's fiscal accounts. This finding aligns with international evidence that EV adoption can alter the energy mix, decrease fossil fuel dependency, and contribute to environmental sustainability.

However, the results also show that EV growth does not directly translate into improvements in the foreign trade deficit. That is, we rejected our hypothesis "Türkiye's foreign trade deficit is expected to decrease with the increase in electric vehicles". Türkiye remains structurally dependent on imported energy, and total energy import volume is expected continuing to rise due to reasons such as economic growth, population growth, and increase in industrial production despite the gradual adoption of EVs. This asymmetry suggests that while EV transition can mitigate crude oil dependency and indirectly relieve some pressure on the foreign trade balance, it cannot on its own resolve Türkiye's persistent foreign trade deficit. To maximize economic benefits, EV policies must be integrated into a broader energy and trade strategy that reduces fossil fuel

reliance, diversifies domestic energy production, and strengthens industrial capacity in EV and battery manufacturing.

In light of this data, it would be more efficient for Türkiye to focus on research in sustainable energy and recycled materials alongside the EV transition. Doing so would replace fossil fuels and substitute crude oil-based materials, leading to a significant improvement in the foreign trade deficit caused by energy imports. On the other hand, battery technology remains heavily dependent on foreign markets. This dependency explains why EV adoption does not significantly influence the trade deficit across any frequency band. However, it is crucial to foster domestic EV and battery production facilities. In the long run, these efforts will contribute to the recovery of the foreign trade deficit.

While this research provides some findings, it is crucial to recognize certain limitations, which also offer directions for future research. A primary constraint of the study is the unavailability of the data. The analysis starts from 1994, as official statistics for road motor vehicles are unavailable for earlier years. It is recommended that future studies utilize dynamic econometric modelling to explore the EV impact on foreign trade deficit of Türkiye.

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ЕКОНОМИКА
ISSN 0350-137X, EISSN 2334-9190, UDK 338 (497,1)
Vol. 72, april-june 2026, № 2
P. 45-61

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ORIGINAL SCIENTIFIC ARTICLE
DOI: 10.5937/ekonomika2602045K
Received: February 15, 2026
Accepted: May 18, 2026

APPLICATION OF THE PROMETHEE METHOD FOR THE ENVIRONMENTAL PERFORMANCE EVALUATION OF THE EASTERN EUROPEAN REGION

Abstract

The paper presents a comparative analysis of the environmental performance in Eastern European countries, utilizing a dataset comprising fourteen indicators and data for the year 2022. A composite index was created using PROMETHEE and cluster techniques to show how well the environment is doing in the selected countries. Correlation analysis examined the relationship between the Human Development Index and the newly created Environmental Performance Index, which includes three dimensions: atmosphere, water and land. The ranking results showed that, among the 19 observed countries, Slovenia was ranked best, while Turkey achieved the lowest results. Eastern European countries are divided into three groups, according to the Environmental Performance Index, based on the results of a cluster analysis. The correlation analysis's findings indicated that Human Development Index and Environmental Performance Index had a moderately positive relationship. Based on the empirical findings of this paper, policymakers should consider improvements with a focus on environmental performance and human development.

Key words: *composite index, atmosphere, water, land*

JEL classification: *R11, Q20, C43, C44*

ПРИМЕНА ПРОМЕТЕ МЕТОДЕ ЗА ОЦЕНУ ЕКОЛОШКИХ ПЕРФОРМАНСИ РЕГИОНА ИСТОЧНЕ ЕВРОПЕ

Апстракт

Рад представља компаративну анализу еколошких перформанси земаља Источне Европе, користећи скуп података који обухвата четрнаест индикатора и податке за 2022. годину. Композитни индекс је креиран применом

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Промете методе и кластер техника како би се приказало стање животне средине у одабраним земљама. Корелациона анализа испитивала је однос између Индекса хуманог развоја и новокреираног Индекса еколошких перформанси, који обухвата три димензије: атмосферу, воду и земљиште. Резултати рангирања показали су да је, међу 19 посматраних земаља, Словенија заузела најбоље место, док је Турска остварила најслабије резултате. Земље Источне Европе подељене су у три групе према Индексу еколошких перформанси, на основу резултата кластер анализе. Налази корелационе анализе указали су на умерено позитивну повезаност између Индекса хуманог развоја и Индекса еколошких перформанси. На основу емпиријских резултата овог рада, креатори политика треба да размотре унапређења са фокусом на еколошке перформансе и хумани развој.

Кључне речи: *композитни индекс, атмосфера, вода, земљиште*

Introduction

Every organism modifies its surroundings during its life, development, and reproduction. Organisms adapt throughout millennia to cope with shifting environmental conditions. Extinct organisms are those that cannot adapt. Natural selection shapes the survivors as the surroundings shift. Long-term environmental conditions, to which organisms adapt, include even atypical or seemingly catastrophic events like volcanic eruptions (Chu & Karr, 2017). The notion of "environment" has undergone substantial transformation throughout the final three decades of the 20th century and the initial decade of the 21st century. The idea has expanded since it was first connected to the contamination of environmental systems alone (Environmental Dimension, 2016). Our future is determined by how we engage with the environment in the here and now, which makes it a crucial aspect of our existence, and life-changing inventions have become more common and more successful since the industrial revolution, yet environmental quality has suffered as a result of these advancements (Arltová & Kot, 2023). In particular, environmental pollution, excessive waste generation, and the growing exploitation of natural resources have significantly contributed to ecological imbalance and environmental degradation worldwide (Zbiljić et al., 2026). This increasing environmental pressure has led to the development of various policy instruments aimed at mitigating its effects. Within this context, carbon markets and green certificate systems are policy instruments aimed at reducing greenhouse gas emissions and promoting sustainability, with effectiveness varying across countries (Sandu et al., 2026).

Considering the multitude of elements influencing environmental performance, inclusive decision-making is necessary. In these circumstances, it is possible to apply multi-criteria decision-making techniques and composite indices. Previous studies have employed MCDM methods and composite indicators to address practical issues in the environmental domain and related fields (Ali Shah et al., 2021; Alshehri et al., 2021; Kumar et al., 2021; Lee & Chang, 2018; Marković et al., 2023; Stanković et al., 2021, Stanković et al., 2024, 2024a; Wu & Liao, 2021). Following a review of the pertinent literature, it was discovered that while environmental studies have recently polarized the qualitative research method to offer new concepts, tools, and methods related to this field (Caggiano & Weber, 2023; Fu & Sun,

2023; Hristov et al., 2021; Mansur & Tangl, 2018), very few of these studies have quantified its importance and role (Barros et al., 2022; Karahan et al., 2025; Kirda & Aytekin, 2023). In terms of environmental considerations, most research uses indicators based on emissions of greenhouse gases and the potential for global warming (Calzolari et al., 2022; Chavez & Sharma, 2018; Taleizadeh et al., 2019). Natural resources, ecological goals, and the positive and negative influences of the environment on society are the basic elements of the biosphere, which represents the environmental dimension in the conceptual model proposed by Rios et al. (2022). Based on the EPI Framework (2024), 58 indicators make up the environmental index, which is based on the study of 11 sub-criteria in the context of three primary criteria (climate change, environmental health, and ecosystem vitality). However, by reviewing the relevant literature, it can be noted that there is still not enough research when talking about the dimensions of the environment, as one of the dimensions of sustainability. In this sense, the current research can contribute to the existing gap in the literature.

The potential use of the PROMETHEE method to evaluate environmental indicators in Eastern European countries is the subject of the paper. The paper focuses on building a new methodology based on multi-criteria decision-making methods (MCDM) to assess environmental performance at the national level while respecting the variety of existing measures. According to Bogdanov et al. (2019), a given event's multidimensionality makes the construction of composite indicators as a measurement strategy crucial. The aim of the research is to provide a methodological framework for the creation of the composite index of environmental performance, that is, to consider the possibility of applying the PROMETHEE method in the evaluation of environmental performance in the countries of Eastern Europe. It is anticipated that the acquired data will validate the feasibility of utilizing the suggested model for evaluating environmental performance in selected countries.

Materials and Methods

Sample and Data Sources in Research

Eastern European countries - Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, the Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Montenegro, North Macedonia, Poland, Romania, Serbia, Slovakia, Slovenia, and Turkey - are included in the study. The most recent information has been gathered for research purposes from the *Environmental Performance Index 2022* publication, and a number of various official websites. These are 2022-related data. Appendix provides more specific information about the data sources.

Variables in Research

The atmosphere, water, and land are the three dimensions that make up the environment, according to Abdalla (2015) and Hasanuzzaman & Kumar (2019). As a result, fourteen indicators are used to evaluate environmental performance, and these indicators are categorized into three areas: atmosphere, water, and land. Five indicators are present in the atmospheric area, three indicators in the water area, and six indicators in the land area.

Composite Indexes Configuration

Composite indices measure multidimensional ideas by aggregating separate indicator data and weighting it according to a suitable quantitative approach (González-Laxe et al. 2016, Greco et al. 2019). Because composite indices are much simpler to understand and analyze than indicators, which quantify specific aspects of the observed phenomenon, they are widely used because they offer a thorough assessment of a complex phenomenon and can be used to inform the public and inform decision-making. When constructing composite indexes, a hierarchical structure is built, with individual indicators grouped into dimensions at the bottom, and then further grouped to produce the composite index. Applying composite indices is convenient since it makes it possible to compare various entities and make appropriate, fact-based decisions.

The technique of creating composite indexes involves several steps (González-Laxe et al., 2016; Öztürk et al., 2024): 1) The first stage involves gathering data and creating a hierarchically structured database, where each indicator has a definition, a description of the measurement unit, a fit for the provided dimension, and the source of the information; 2) The weights of the indicators and dimensions are determined in the second phase; 3) Using the proper aggregation approach, the indicators are grouped into dimensions and the dimensions into a composite index in the third step.

Methods

In the empirical part of the work, the data set, which consists of 14 indicators, will be analyzed using the PROMETHEE method. Because of its simplicity and ease of comprehension, the preference ranking organization method for evulation enrichment, or Promothee, is one of the many multi-criteria methods that is gaining popularity (Wu et al., 2020). This technique is a member of the outranking method family. Barnes et al. (1984) introduced the Promethee approach, which Brans & Vincke (1985) expanded upon. Between and within the criteria, information is needed for the assessment process. According to Behzadian et al. (2010), the information between the criteria is expressed as their relative relevance and is made up of weights that are not reliant on the measurement scale.

The Promethee ranking approach is enhanced by the visualization technique known as geometric analysis for interactive aid (GAIA). This is a helpful graphical tool that shows the relationship between criteria, alternatives, and the decision axis by converting ordinal values into a graphical output for decision-making problems. The ideal solution's direction is shown by the decision axis. Options that are adjacent to and on the same side as the decision axis are highly ranked and indicate the best options. Similar preferences are directed in the same direction in the GAIA plane, whereas opposing criteria are directed in opposite directions (Gunawardena et al., 2015). Using the gait weight function, decision makers can quickly acquire the results of a new Promethee II ranking by making modifications to the criterion weights (Brans & Mareschal, 2005). Furthermore, it establishes stability intervals, wherein the ranking stays constant provided that the values stay inside the interval's bounds. Sensitivity analysis is essential for comprehending how a change in weight affects the overall ranking (Kabir & Sumi, 2015). The rank-overtaking net flows are broken down to create the GA matrix. A principal component analysis algorithm is then used to process the matrix data, and

the results are shown on a GAIA biplot (Keller et al., 1991). In order to minimize information loss and reduce the number of dimensions, principal component analysis is employed. The multi-criteria problem is given a new perspective despite the inevitable loss of some relational characteristics due to the transformation of the problem into a two-dimensional space and the geometric representation of relations between alternatives and criteria (Vego et al., 2008). It measures the amount of information saved in the GAIA plane (values more than 70% correspond to dependable GAIA planes) in order to control its quality.

In order to gather data within criteria, each criterion needs to have a preference function that expresses how alternative *a* performs differently from alternative *b*. As a result, a pairwise comparison strategy is used (Belton & Stewart, 2002). Six fundamental preference functions can be applied, depending on the criteria's features (Brans & Mareschal, 2005): usual criterion, U-shape criterion, V-shape criterion, level criterion, V-shape with indiference criterion, and Gaussian criterion.

The setting of criteria weights is a major issue in multi-criteria analysis models, as it can have a substantial impact on the decision-making process's outcome. The entropy method, whose main component is the assessment of information uncertainty, is one of the techniques that falls under the objective approaches to deciding the weight of the criterion. The entropy technique takes into account a collection of *m* items and *n* criteria for each object when assessing the significance of criteria (Wang & Zhan, 2012). The definition of the entropy of the *j*-th criterion is:

$$H_j = -k\sum_{i=1}^{m} f_{ij} \ln f_{ij}, \qquad i = 1,2,\dots m, j = 1,2,\dots n$$

For the ith alternative, $k = \frac{1}{\ln m,}$ and $f_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$ represent the *j*-th and *i*-th criteria, respectively. It is ensured that all entropy values (H_j) are in the interval [0,1] by adding the constant $k = \frac{1}{\ln m,}$. The relative relevance of the criterion is implied to be higher by a lower entropy score and vice versa. Simple additive normalization yields the final relative weight of the *j*-th criterion:

$$w_j = \frac{1-H_j}{\sum_{j=1}^{n}(1-H_j)}$$

According to Brans & de Smet (2016), applying the Prometheus II technique entails giving the decision-maker two pieces of information: 1) relative relevance and 2) preference function for each criterion.

A collection of criteria $G = \{g_1 \dots g_n\}$ and a set of options $A = \{a_1 \dots a_m\}$ are taken into consideration in order to formulate the choice problem. As per Brans & Vincke (1985), the Promethee II calculating process has multiple steps:

Step 1: For each criterion g_k, decide which alternative a_i, is preferred above, a_j:

$$d_k(a_i, a_j) = g_k(a_i) - g_k(a_j)$$

Where the value of the criterion g_k for the *i*-th choice is represented by $g_k(a_i)$, and the value for the *j*-th alternative is represented by a $g_k(a_j)$.

Step 2: P_k preferred function selection. The standard preference function will be used in the work framework for the sake of research simplicity:

$$P_k(a_i, a_j) = P_k[d_k(a_i, a_j)]$$

$$0 \leq P_k(a_i, a_j) \leq 1$$

Step 3: The global preference index $\pi(a_i, a_j)$ is calculated. It denotes the weighted total of all preferences P_k, with w_k denoting the jth criterion relative relevance:

$$\pi(a_i, a_j) = \sum_{k=1}^{j} P_k[d_k(a_i, a_j)].w_k$$

$$w_k \geq 0, \sum_{k=1}^{j} w_k = 1$$

Step 4: Determine the overtaking flows of each option, where the symbols ϕ+ and ϕ− stand for the corresponding positive and negative flow results:

$$\varphi^+(a_i)\frac{1}{n-1}\sum_{x\in A}\pi(a_i, x)$$

$$\varphi^-(a_i)\frac{1}{n-1}\sum_{x\in A}\pi(a_i, x)$$

When an alternative has a larger positive flow score than all other alternatives, it is considered better. Alternative a_i is preferred globally when this score is positive. The global score, where a lower score indicates a better alternative (Lopes et al., 2018).

Step 5: Compute net overtaking flows, which serve as the foundation for ranking the options:

$$\varphi(a_i) = \varphi^+(a_i) - \varphi^+(a_i)$$

Cluster analysis is a useful tool for organizing heterogeneous components into relatively homogeneous groupings by determining the linkages between them. The first step in performing a cluster analysis is choosing a suitable cluster technique. This paper used agglomerative hierarchical cluster analysis.

Correlation analysis was used to determine the strength of the relationship, or the relative importance, between Environment performance index and Human development index. The degree of quantitative agreement (interdependence) between two random variables (*x* and *y*) is indicated by the correlation coefficient (*r*).

Results

Determining the Weighting Criteria for the Assessment of Environmental Dimensions

The variables that play a major part in the composite index and have the biggest impact on its value are determined by the weighting results. It is evident from the weight coefficients that the environmental composite index is most influenced by per capita CO_2 emissions,

which are within the atmosphere dimension. Using the PROMETHEE approach, a Usual preference function was chosen to create a composite indicator in the second portion of the analysis. Using the proper multi-criteria model, an overall assessment of performances in three environmental areas - each with several indicators - is used to determine the rankings of each country. The analysis of how sensitive the outcomes were to variations in the preference function selection was done. The results are shown in Table 1.

Table 1. Environmental dimensions, indicator weights and weight stability interval

Dimension (area)	Indicator	Indicator weights	Dimension weights	Weight stability interval
Atmopshere	C1	0.0054	0.7800	77.93% - 79.19%
	C2	0.0028		
	C3	0.0130		
	C4	0.7440		
	C5	0.0149		
Water	C6	0.0038	0.0966	4.14% - 9.74%
	C7	0.0047		
	C8	0.0881		
Land	C9	0.0172	0.1235	11.50% - 12.42%
	C10	0.0157		
	C11	0.0421		
	C12	0.0127		
	C13	0.0157		
	C14	0.0201		

Source: Authors

Eastern European Countries Ranking According to Environmental Index

Table 2 displays the ranking results produced by using PROMOTHEE II methods for the observation year, together with the values of net overtaking flow (ϕ). Slovenia is ranked highest among the observed group countries, followed by Cyprus, Albania, Croatia, North Macedonia, Slovakia, Latvia, Romania, Estonia, the Czech Republic, Hungary, Lithuania, Greece, Bulgaria, Montenegro, Poland, Serbia, Bosnia and Herzegovina, and Turkey, which comes in last. These rankings are based on the computation of outranking flows, positive and negative flows, and the complete Net Flow Φ.

Table 2. Ranking of alternatives according to environmental indicators in 2022

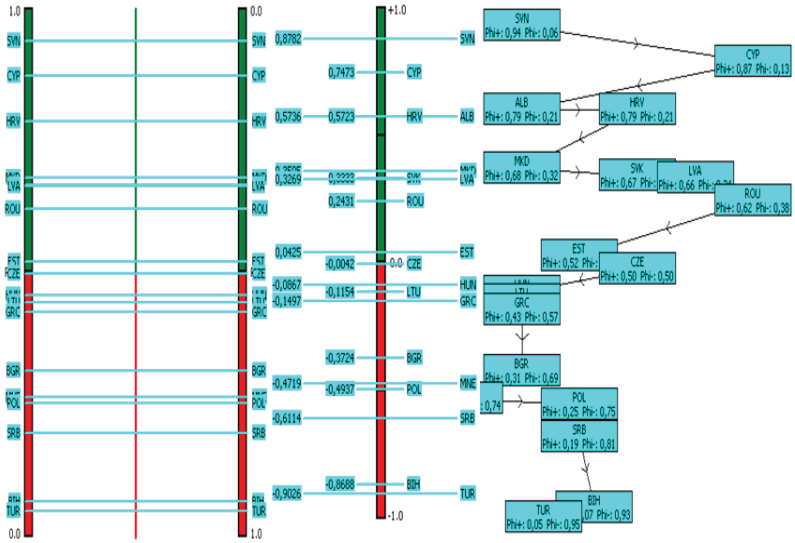
Country	Φ	Φ+	Φ-	Rank
Slovenia	0.8782	0.9391	0.0609	1
Cyprus	0.7473	0.8737	0.1263	2
Albania	0.5736	0.7868	0.2132	3
Croatia	0.5723	0.7861	0.2132	4
North Macedonia	0,3595	0.6798	0.3202	5
Slovakia	0.3333	0.6667	0.3333	6
Latvia	0.3269	0.6635	0.3365	7
Romania	0.2431	0.6216	0.3784	8
Estonia	0.0425	0.5213	0.4787	9
Czech Republic	-0.0042	0.4979	0,5021	10
Hungary	-0.0867	0.4567	0.5433	11

Lithuania	-0.1154	0.4423	0.5577	12
Greece	-0.1497	0.4252	0.5748	13
Bulgaria	-0.3724	0.3138	0.6862	14
Montenegro	-0.4719	0.2641	0.7359	15
Poland	-0.4937	0.2531	0.7469	16
Serbia	-0.6114	0.1943	0.8057	17
Bosnia and Herzegovina	-0.8688	0.0656	0.9344	18
Turkey	-0.9026	0.0487	0.9513	19

Source: Authors

The results of the partial and final ranking, as well as the network of alternative flows, are illustrated in Figure 1. The first and second figures show the partial and final ranking of alternatives, based on the net flow of alternatives, while the third figure represents the final result of the positive and negative flow of alternatives. This ranking provides an overview of all alternatives, including their preference scores. The ranking score is the final result of the net preference flow PROMETHEE analysis, which combines weights, preference functions, and criteria values per alternative. Among the alternatives, Slovenia (0.94) ranks first in terms of enviromental, followed by Cyprus (0.87), Albania (0.79), Croatia (0.79), North Macedonia (0.68), Slovakia (0.67), Latvia (0.66), Romania (0.62), Estonia (0.52), Czech Republic (0.50), Hungary (0.46), Lithuania (0.44), Greece (0.43), Bulgaria (0.31), Montenegro (0.26), Poland (0.25), and Serbia (0.19), while Bosnia and Herzegovina (0.07) and Turkey (0.05) ranked lowest. Based on the graphically illustrated presentation, it can be concluded that Slovenia prefers it compared to other alternatives in the PROMETEE I range (picture on the left). This is also confirmed by PROMETHEE II (picture on the right). Slovenia has the highest Phi (φ) score, while Turkey has the lowest score, which is why it is at the bottom of the PROMETHEE II scale.

Figure 1. PROMETHEE I partial ranking, PROMETHEE II final ranking and alternative stream network, based on criteria values and weighting.



Source: Authors

Cluster Analysis Results

Hierarchical cluster analysis was used to identify groups of Eastern European countries with similar environmental performance. The clusters' significant geographic heterogeneity is revealed by the cluster analysis's findings. In terms of how well the cluster's member countries are doing with their environmental performance, it is evident that the counties in the first cluster have the highest, while the countries in the third cluster have the lowest indicator values (Table 3).The variables that play a major part in the composite index and have the biggest impact on its value are determined by the weighting results.

Table 3. Cluster analysis results of environmental performance

Cluster 1	Albania, Croatia, Cyprus, Slovenia
Cluster 2	Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, North Macedonia, Romania, Slovakia
Cluster 3	Bosnia and Herzegovina, Bulgaria, Montenegro, Poland, Serbia, Tukey

Source: Authors

Correlation Analysis Results

Determining the relationship between environmental and socioeconomic growth was the f focus of additional analysis. Data on the Human Development Index (HDI) was used to conduct this analysis. According to the value of the Spearman's coefficient, there is a moderate and positive correlation between the HDI and the environment (Table 4).

Table 4. Correlation coefficients

	HDI 2022
Environmental 2022	0.701*

Note: * - Significant at a level of 0.01
Source: Authors

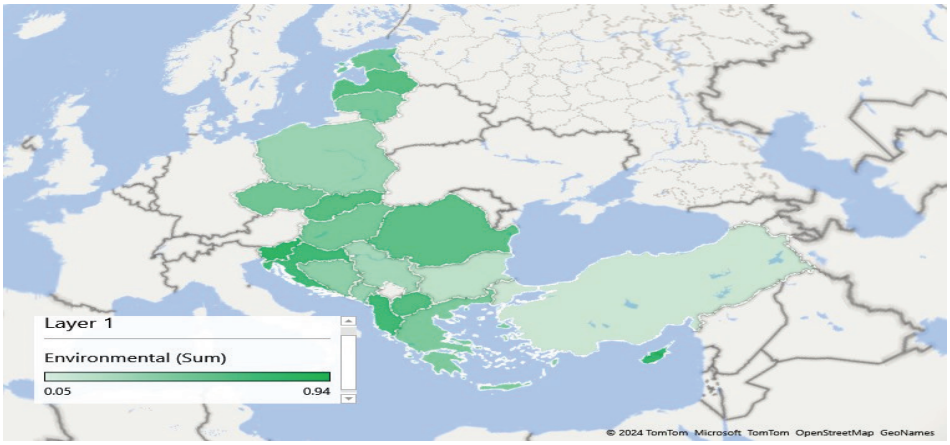
Discussion

The model created in the research paper was built with the understanding that environmental evaluation is a multidimensional and complex issue, requiring a particular type of index that is derived from the summation of its constituent variables. This model was used to assess the environmental performances of Eastern European countries. As a result, the model that has been suggested includes fourteen indicators that address the atmosphere, water, and land facets of the environmental dimension of sustainability.

The study's findings suggest that there are substantial disparities between Eastern European countries regarding environmental performance (Figure 2). Slovenia is the best alternative in terms of environmental performance, which is not surprising since, according to Lee et al. (2017), Slovenia was named the green capital of Europe in 2016. In addition, according to the research results of Marković et al. (2023), among the EU countries, Slovenia is in the third position, just behind Belgium and the Netherlands, according to the composite

index of waste management. It is noticeable that better results are recorded by EU member states, except for Poland, which was at the bottom of the ranking list, primarily due to poor results in the atmosphere dimension. On the other hand, Albania, which is not a member of the EU, is in third place among 19 alternatives, primarily due to the excellent results recorded in the atmosphere dimension. Similar results, based on the PROMETHEE approach, 11 indicators, and three dimensions (climate change, environmental health, and ecosystem vitality) were also obtained by Karahan et al. (2025). The above confirms the possibility of applying the PROMETHEE method for environmental performance index evaluation.

Figure 2. An overview of the results: environmental performance in 2022

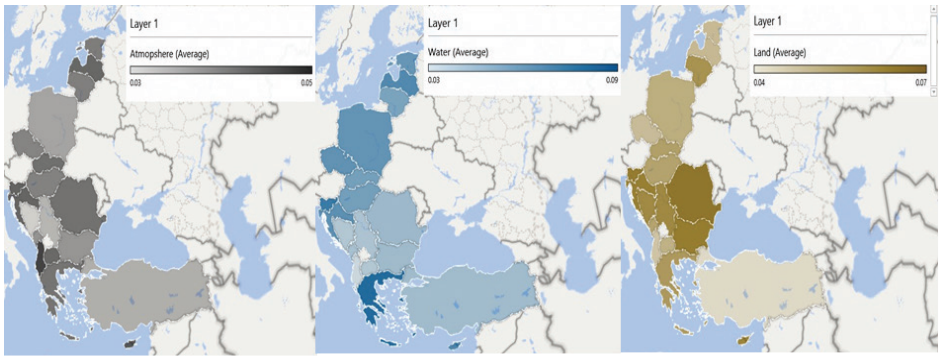


Source: Authors

The average values (Figure 3) reveal that all countries, except for Slovenia, Cyprus, Croatia, and Slovakia, achieve lower results in certain dimensions. In addition, the largest differences between the observed countries are recorded by the indicator, which refers to the dimension of water, then land, and the least atmosphere. The potential increase or reduction in the weights value that will not affect the given ranking results is computed using the sensitivity analysis tool (walking weights). It is interesting to note that increasing the relative importance of indicators relative to the water dimension to 5.6% will not affect the change in rank obtained using the integrated Entropy-PROMETHEE approach, indicating that the water dimension's indicator is less important when compared to the average values of indicators from the atmosphere and land dimensions. Loganathan et al. (2022) suggested that because air quality varies over time due to the presence of chemical contaminants in the atmosphere and shifting meteorological conditions, analysis of air quality is crucial for all areas on Earth.

Eastern European nations can be divided into three categories based on the findings of the cluster analysis. The countries with the highest achieved values of the newly developed environmental performance index are Slovenia, Cyprus, Albania, and Croatia; the countries with lower observed index values are Bulgaria, Montenegro, Poland, Serbia, Bosnia and Herzegovina, and Turkey. The obtained results indicate significant disparities when it comes to the achieved level of environmental performance.

Figure 3. Environmental dimensions average value in Eastern European countries



Source: Authors

The study's findings indicate a positive correlation between the HDI and the composite environmental index. The explanation for the positive correlation between the HDI and the environment is that countries with low HDI levels prioritize addressing all of their citizens' social needs, while designing an inclusive growth strategy that supports development economies while staying within the nation's ecological bounds represents a challenge in the environmental context. However, countries that have already attained high levels of citizen satisfaction have frequently done so at a considerable environmental cost, and they now need to reconsider their consumption patterns, make better use of their resources, lessen pollution of the land and water, and decarbonize economies. This is consistent with the Environmental Kuznets Curve (EKC) hypothesis (Kuznets, 1955). EKC hypothesis states that there is an inverse U-shaped relationship between environmental pollution and economic growth. Specifically, it states that environmental pollution increases up to a point in the first stage with economic growth, but after the turning point is reached, environmental pollution tends to decrease (Panayotou 1993). In the environmental context, Polat & Çil (2025), showed an inverted U-shaped relationship between CO_2 emissions and the HDI index.

Conclusion

Natural resources depletion and environmental degradation are two of the biggest issues that humanity will likely have to deal with in the near future. In particular, these issues have significantly worsened in the last few years. New environmental policy measures have been sparked by this aspect, both domestically and globally. Concerns regarding greenhouse gas (GHG) emissions, air and water pollution, deforestation, and the production and disposal of garbage have been brought up by environmental indicators. All of these possible pollutants can be tracked using the environmental indicator to guarantee the protection of people's health and safety. However, the absence of measurements that would enable sufficient monitoring of progress towards environmental goals frequently makes it difficult to adopt effective regulations.

Therefore, this paper provides a model for a multi-criteria approach to environmental performance assessment at the national level. To assess the nation's environmental performance,

14 indicators are used. They are categorized into the following areas: (1) the atmosphere; (2) water; and (3) land in 2022. The Entropy-PROMETHEE and cluster-based methodologies were utilized in the development of the composite measure, which encompasses multiple facets of environmental performance. The proposed methodology, which enhances the current methods for assessing environmental performance at the national level, therefore expresses the theoretical contribution of the paper. Empirically, except that it evaluates the environmental performance dimensional level, by providing a new method for evaluating environmental performance using Eastern European countries as an example, this paper adds to the body of knowledge already available on environmental performance metrics.

The study found a statistically significant relationship between the environmental performance index and the HDI. These findings highlight the significance of protecting the environment for knowledge, a long and healthy life, and a reasonable standard of living.

The research that was done contains certain limitations, which can be interpreted as recommendations for future research on the subject. Firstly, the data refer only to the year 2022, while future research could cover a longer period and follow the trend of the development of environmental performance. Next, the current research used data for Eastern European countries, while future research could apply data for other regions and compare the obtained results with the results of the current research. The Entropy method was used to determine the weight coefficients, while the PROMETHEE method was used to calculate the index based on 14 indicators. Future research could also use other methods (such as the CRITICAL-GRA approach) and additional indicators.

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Appendix: Data sources

Dimension	Variable	Source
Atmopshere	C1 Climate Change	Environmental Performance Index 2022, p. 27. https://epi.yale.edu/downloads/epi2022report06062022.pdf
	C2 Acid Rain	Environmental Performance Index 2022, p. 132
	C3 Air Quality	Environmental Performance Index 2022, p.71
	C4 Per capita CO_2 emissions	https://ourworldindata.org/co2-and-greenhouse-gas-emissions
	C5 Greenhouse gas emissions per capita	https://epi.yale.edu/epi-results/2022/component/ghp

Water	C6 Sanitation & Drinking Water	Environmental Performance Index 2022, p. 80
	C7 Water quality	https://worldpopulationreview.com/country-rankings/water-quality-by-country
	C8 Wastewater treatment	https://epi.yale.edu/epi-results/2022/component/wwt
Land	C9 Waste Management	Environmental Performance Index 2022, p. 95
	C10 Biodiversity & Habitat	Environmental Performance Index 2022, p. 105
	C11 Tree cover loss	https://epi.yale.edu/epi-results/2022/component/tcl
	C12 Ecosystem Services	Environmental Performance Index 2022, p. 116
	C13 Agriculture	Environmental Performance Index 2022, p. 141
	C14 Grassland loss	https://epi.yale.edu/epi-results/2022/component/grl
HDI	Human Development Index	Human development report 2023/24, pp. 274-275 https://hdr.undp.org/system/files/documents/global-report-document/hdr2023-24reporten.pdf

ЕКОНОМИКА
ISSN 0350-137X, EISSN 2334-9190, UDK 338 (497,1)
Vol. 72, april-june 2026, № 2
P. 63-73

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ORIGINAL SCIENTIFIC ARTICLE
DOI: 10.5937/ekonomika2602063T
Received: December 07, 2025
Accepted: March 20, 2026

TOWARDS BANKING PERFORMANCE: A TWO-STEP CLUSTER ANALYSIS OF SOUTHEAST EUROPEAN COUNTRIES

Abstract

This study examines the performance of the banking sector in Southeast European countries using a two-step cluster analysis approach from 2017 to 2021. Based on the defined research objectives, this study employs key financial indicators, including the real interest rate, liquidity, credit risk, and the Herfindahl-Hirschman Index as a measure of market concentration. By applying the Schwarz-Bayesian Criterion, the optimal number of clusters was determined to be between 3 and 5. The results reveal significant differences in profitability, liquidity, and market structure among the analyzed countries. The most stable banking systems are found in Greece and Cyprus, while Serbia, Türkiye, and Montenegro face greater challenges in terms of credit risk and market concentration. Applied analysis enhances the competitiveness of banking systems through risk reduction and increased liquidity.

Key words: *Two-step cluster analysis, liquidity, credit risk, banking industry*

JEL classification: *G21, C38*

ЕВАЛУАЦИЈА ПЕРФОРМАНСИ БАНАКА: ДВОСТЕПЕНА КЛАСТЕР АНАЛИЗА ЗЕМАЉА ЈУГОИСТОЧНЕ ЕВРОПЕ

Апстракт

Ова студија анализира перформансе банкарског сектора у земљама југоисточне Европе применом двофазне кластер анализе у периоду од 2017. до 2021. године. Полазећи од постављених циљева истраживања, ова студија користи кључне финансијске показатеље, укључујући реалну каматну стопу, ликвидност, кредитни ризик и Herfindahl-Hirschman индекс као меру тржишне концентрације. Применом Schwarz-Bayesian критеријума, оптималан број кластера одређен је између 3 и 5. Резултати показују значајне разлике у профитабилности, ликвидности и структури тржишта међу анализираним земљама. Најстабилнији банкарски системи налазе се у Грчкој

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и Кипру, док се Србија, Турска и Црна Гора суочавају са већим изазовима у погледу кредитног ризика и тржишне концентрације. Примењена анализа побољшава конкурентност банкарског система кроз смањење ризика и повећање ликвидности.

Кључне речи: *двофазна кластер анализа, ликвидност, кредитни ризик, банкарска индустрија*

Introduction

The performance of the banking sector is a crucial factor influencing economic growth and financial stability. Banks play a fundamental role in mobilizing financial resources, transforming savings into investments, and supporting economic activities (Lutovac, 2024). Factors such as interest rates, market concentration, and liquidity risk significantly determine banks' profitability and long-term sustainability.

In Southeast Europe, the banking industry faces notable challenges, including a high proportion of non-performing loans (NPLs), liquidity fluctuations, and varying levels of market concentration (World Bank, 2017; Malenković, 2023). These challenges can hinder banks' ability to allocate financial resources and contribute to broader economic development in an efficient manner.

This study employs a two-step cluster analysis to identify key factors affecting banking performance during the period from 2017 to 2021. The methodology, widely used for classification, enables the grouping of countries into homogeneous clusters based on financial indicators (Kristóf et al., 2024). The analysis includes four primary indicators: the real interest rate, liquidity, credit risk, and the Herfindahl-Hirschman Index (HHI), which measures market concentration. Applying the Schwarz-Bayesian Criterion, the optimal number of clusters was determined to be between three and five (Tavsanli & Hamlaci, 2021).

The results reveal substantial differences among countries in terms of profitability and financial stability. Greece and Cyprus exhibit relatively stable banking sectors, with lower credit risk and higher profitability. In contrast, Serbia, Türkiye, and Montenegro show elevated credit risk levels and higher market concentration. These findings highlight the need for enhanced risk management and regulatory policies to support banking sector stability and competitiveness in the region (Horvat Marcikić et al., 2023).

Literature Review

The efficiency and performance of the banking sector in Southeast European countries have been extensively studied, particularly in relation to financial crises, macroeconomic determinants, and digitization. This review synthesizes key findings from existing studies, highlighting the various methodological approaches and perspectives employed. One notable contribution is by Ivanovska (2020), who conducted a cluster analysis of banking system indicators, demonstrating that North Macedonia's banking

sector is more closely aligned with other Balkan countries rather than EU member states. This result indicates that banking structures in the Western Balkans maintain distinct characteristics compared to more integrated European financial markets. Similarly, Skënderi (2023) compares the banking performance of Western Balkan countries during the Global Financial Crisis (2008) and the COVID-19 pandemic, shedding light on the resilience and adaptability of banking institutions in the region. The study highlights structural vulnerabilities and the role of crisis management policies in addressing these vulnerabilities.

One of the most common applications of Two-Step Cluster Analysis in banking is the identification of distinct customer profiles, enabling banks to understand consumer needs better and optimize their services. Schiopu (2010) employed Two-Step Cluster Analysis to identify three customer profiles, which helps banks to manage their client base more efficiently. This analysis enables the segmentation of clients based on their financial habits, facilitating targeted advertising and the development of banking products. Kovács et al. (2021) applied TwoStep Cluster Analysis to identify investment patterns of potential retail banking customers. Their analysis revealed three main groups of investors, each with distinct risk preferences and preferred types of financial products. These findings are beneficial for banking marketing strategies. Tavsanli and Hamlaci (2021) used a two-step cluster analysis to segment Turkish banks based on their financial strength. The analysis identified three distinct groups, with the largest group comprising banks that performed below average. This approach provides regulatory bodies and investors with insights into the risk levels of individual banks. Harmatiy et al. (2021) applied cluster analysis to study the development of banking institutions, showing that banks can be grouped based on their ability to adapt to market changes. This study highlights the usefulness of cluster analysis in predicting future trends in the banking sector, as also supported by Vranjanac and Rađenović (2022) and Rađenović et al. (2022). By applying comparative clustering approaches within a macroeconomic analysis framework, this study provides a valuable methodological parallel for the application of Two-Step Cluster Analysis in research on banking sector performance.

Efficiency and productivity within the Southeast European banking sector have also been examined by Varesi (2015), who analyzed the macroeconomic and bank-specific determinants influencing performance. This research aligns with later studies on banking profitability, which employ a panel data approach to investigate the key drivers of profitability in commercial banks. Similar findings are presented by Nurboja (2017), who examines the cost efficiency of banks in Southeast Europe and points to the existence of a significant "efficiency gap" between banks operating in European Union member states and those that are still candidates or remain outside the EU. Although this study does not use a two-step cluster analysis, it provides valuable insights into financial stability. Kalaš et al. (2020) conducted a survey of banks in Central and Southeastern Europe covering the period from 2008 to 2015. In their research, they applied a two-step model, wherein the first model analyzed return on assets as the dependent variable, while the second model focused on return on equity. On the other hand, the independent variables included gross domestic product, inflation rate, and real interest rate. The results of the panel analysis indicate a significant impact of gross domestic product and inflation on bank profitability indicators in the analyzed countries. Agoraki (2019) further examines how specific banking, industry, and macroeconomic factors influence the net interest margin,

showing that a stronger capital position, effective cost control, and reduced credit risk lead to narrower margins, while institutional weaknesses and regulatory inconsistencies increase cost pressure and widen the net interest margin (NIM) (Todorović et al., 2024) Examined the impact of various macroeconomic and banking variables on the NIM of banks in selected countries of Southeast Europe during the period from 2012 to 2021. Their research focuses on countries with similar socio-economic characteristics and types of financial systems, which enables the identification of common determinants of NIM. The paper uses regression methods with ordinary least squares (OLS). They concluded that key variables demonstrated the expected influence on the NIM movement, where increases in the exchange rate, the real interest rate, the degree of concentration, and the size of the banking sector are accompanied by an increase in the net interest margin of banks (Colić et al., 2024; Todorović et al., 2024).

Methodology Framework for Two-Step Cluster Analysis of the Southeast European Countries (2017-2021)

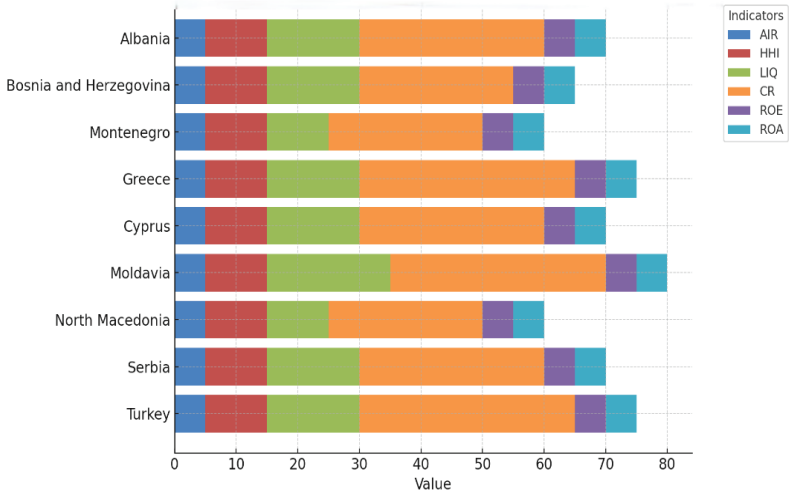
The Two-Step Cluster Methodology effectively handles large datasets with mixed types of variables. By integrating hierarchical clustering with k-means clustering, this method is efficient in grouping data points into homogeneous clusters. In the first step, the method begins by using hierarchical clustering to create pre-clusters. This process divides the data into smaller clusters without assigning them to a definitive final group yet, as previously applied by Popović et al. (2025). This is a crucial step because it helps manage the complexity of large datasets and provides a preliminary understanding of the underlying structure. Hierarchical clustering efficiently handles large volumes of data, particularly when working with both categorical and continuous data. The method is capable of utilizing multiple distance measures, making it flexible in handling various data types. It provides a structure that enables the algorithm to identify potential clusters based on the similarity of data points. The two-step process ensures handling large datasets with thousands of data points. The algorithm performs a pre-clustering phase, where it groups similar observations into sub-clusters using a distance measure, such as Euclidean distance or correlation-based similarity. By combining the strengths of hierarchical clustering and k-means, the method enables the achievement of stable and well-defined clusters.

Performing a two-step cluster analysis to classify the Southeast European Countries based on their financial characteristics in this study focuses on four key indicators from 2017 to 2021:

- Real Interest Rate (RIR): The nominal interest rate adjusted for inflation, representing the cost of borrowing in the economy.
- LiqLiquidity (LIQ): Measures the ratio of liquid assets to total assets or the ratio of liquid liabilities to GDP, assessing the financial system's ability to meet short-term obligations.
- Credit Risk (CR): Reflected in indicators such as the Non-Performing Loan (NPL) ratio, evaluating the risk of defaults in the banking system.
- HerFindahl-Hirschman Index (HHI): Market concentration in the banking sector, indicating the level of competition or monopolistic tendencies.

Descriptive statistics were calculated by computing the yearly average for each indicator to capture the overall trend over the five years (2017-2021). This ensures that the analysis reflects the general financial environment in the region, avoiding any distortion from year-to-year volatility (Figure 1).

Figure 1: Average Annual Values of Key Banking Sector Indicators in the Region (2017–2021)



Source: Authors' calculation

Research Results and Discussion

The dataset provided presents the Schwarz Bayesian Criterion (BIC) values for different numbers of clusters ranging from 1 to 10. The BIC is a statistical measure used for model selection, particularly in clustering. The model with the lowest BIC score is typically preferred, as it strikes the best balance between fitting the data and maintaining simplicity. According to the provided dataset, the BIC values and associated changes indicate that the optimal number of clusters lies between 2 and 5 (Table 1). After this point, the additional clusters show diminishing improvements in terms of BIC, suggesting that adding more clusters may introduce complexity without substantial gains in model quality. Therefore, increasing the number of clusters yields only marginal improvements, as evidenced by the minor changes in BIC and the stable distance measure ratios. While increasing the number of clusters might improve the model's fit, the BIC penalizes excessive complexity, helping to avoid overfitting. Therefore, in terms of model selection, it would be scientifically reasonable to focus on 3 to 5 clusters as the optimal solution, as this offers a balance between simplicity and a good model fit.

Table 1: BIC Scores and Optimal Cluster Range Determination

Number of Clusters	Schwarz's Bayesian Criterion (BIC)	BIC Change	Ratio of BIC Changes	Ratio of Distance Measures
1	132.92			
2	155.39	22.47	1.00	1.44
3	185.83	30.44	1.35	1.77
4	224.08	38.25	1.70	1.07
5	263.01	38.93	1.73	1.60
6	305.50	42.48	1.89	1.38
7	349.59	44.09	1.96	1.01
8	393.73	44.14	1.96	1.21
9	438.62	44.89	1.99	1.01
10	483.54	44.92	1.99	.

Source: Authors' calculation

Descriptive statistics among the analyzed clusters predict the conditions in the cluster environment by comparing them according to the indicators mentioned earlier. Cluster 1 seems to have a very low ROE (-2.86) and ROA (-0.24), indicating poor profitability or efficiency in generating returns from equity and assets. The liquidity and current ratio are high, indicating good short-term financial health and the ability to meet obligations; however, the negative profitability signals underlying issues. Cluster 1 may require some intervention or strategic changes, as its negative profitability measures (ROE and ROA) are concerning, despite having excellent short-term financial metrics (liquidity and current ratio). Cluster 2 has a positive ROE (8.96) and ROA (1.34), indicating that it's more profitable and efficient than Cluster 1. However, the liquidity (35.63) and current ratio (5.88) are lower compared to Cluster 1, indicating relatively fewer cash or assets available to cover short-term liabilities. The HHI index (0.03) suggests low market concentration, which may reflect effective competition—cluster 2 lies in between, showing decent profitability but weaker liquidity than Clusters 1 and 3. Cluster 3 stands out with very high RIR (3.16) and high ROE (13.34), signaling excellent return generation from investments and equity. The ROA (1.88) is also strong, showing efficient asset utilization. The liquidity (34.78) and current ratio (6.51) are slightly higher than those of Cluster 2, indicating a strong financial position, with a good balance between profitability and economic stability. Cluster 3 appears to be the most financially healthy, with high returns and good liquidity.

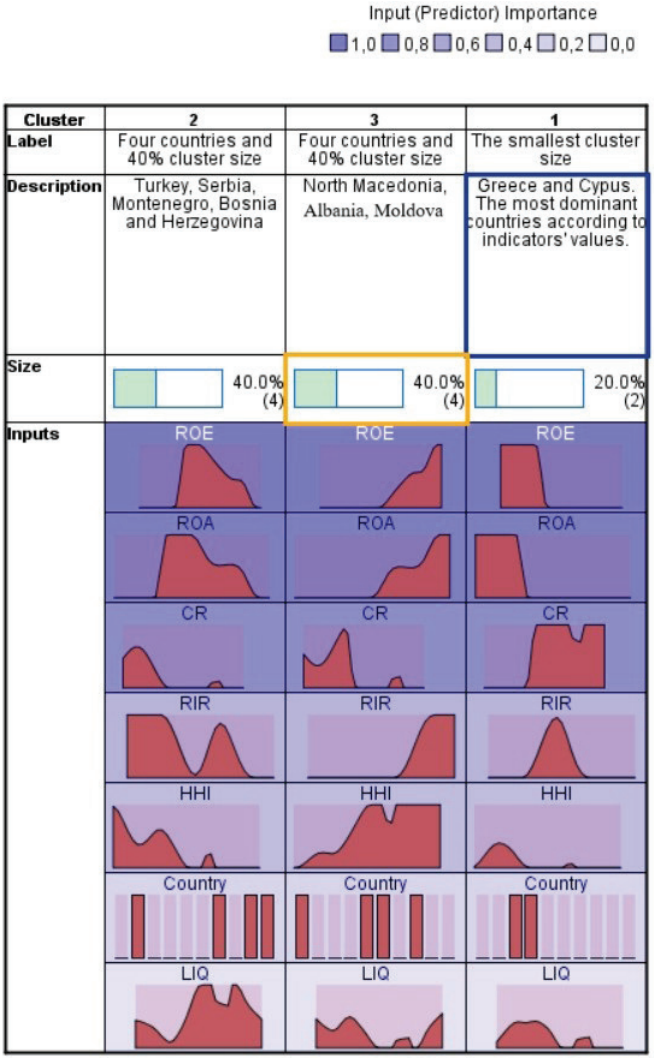
Table 2: Mean Values of Key Banking Sector Indicators by Cluster

MEAN		RIR	HHI	LIQ	CR	ROE	ROA
Cluster	1	.19	.03	31.29	25.21	-2.86	-.24
	2	-.32	.03	35.63	5.88	8.96	1.34
	3	3.16	.11	34.78	6.51	13.34	1.88

Source: Authors' calculation

Based on the two-step cluster analysis, the first cluster consists of Greece and Cyprus, which exhibit dominant characteristics according to the financial indicators considered: Credit Risk, Interest Rate, Herfindahl-Hirschman Index (HHI), Liquidity, Return on Investment (ROI), and Return on Assets (ROA). These two countries seem to stand out for having more favorable values across these indicators, suggesting a robust financial environment compared to the other countries in the second cluster. Both Greece and Cyprus exhibit relatively lower credit risk levels, which may be indicative of a more stable or efficient banking system, a lower likelihood of defaults, or more sound lending practices (Figure 2). Their interest rates, while higher compared to countries in the second cluster, may be reflective of the countries' economic conditions, but are still relatively manageable within a European context. The second cluster consists of Serbia, Türkiye, and Montenegro, where the financial indicators—such as Credit Risk, Interest Rate, HHI, Liquidity, ROI, and ROA—are not as strong as those of Greece and Cyprus. The relatively poor performance on these indicators may indicate several challenges that these countries face in maintaining financial stability and fostering strong economic growth. The higher credit risk levels in Serbia, Türkiye, and Montenegro suggest that their financial systems may be more vulnerable to defaults, potentially due to weaker lending standards, economic instability, or external shocks. The higher interest rates observed may reflect this elevated credit risk, making it more expensive for borrowers to access credit. The higher concentration of banking systems in these countries, as indicated by a higher HHI, may suggest monopolistic tendencies or a smaller number of players in the market. This reduces the competitive pressure on financial institutions, potentially leading to inefficiencies, higher costs for consumers, and reduced innovation. From the third cluster, Moldova faces significant economic challenges, including poverty, agricultural reliance, and political instability. Its financial system is still underdeveloped. Likely to fall into the second cluster, exhibiting high credit risk, low liquidity, and underperforming ROI/ROA indicators. Albania has experienced strong economic growth, particularly in the tourism and foreign investment sectors. However, its financial sector is still underdeveloped, and access to credit remains limited. North Macedonia has demonstrated stable economic growth, although challenges such as high unemployment and low income levels persist. Its financial system is improving, but still has room for growth.

Figure 2: Distribution of Key Banking Sector Indicators Across Clusters



Source: Authors' calculation

Conclusion

Economic instability, often driven by inflation, political uncertainty, or external shocks, is a critical factor that exacerbates credit risk, liquidity concerns, and market concentration in these countries. High levels of inflation, currency volatility, and geopolitical risks can undermine investor confidence, reduce consumer spending, and ultimately weaken financial institutions. Policymakers need to focus on creating a stable macroeconomic environment by controlling inflation, managing public debt, and fostering fiscal discipline. Central

banks should implement measures to stabilize currency volatility and mitigate inflationary pressures, such as raising interest rates when necessary or utilizing foreign currency reserves to intervene in the market (Marjanović & Marković, 2019). In summary, Greece and Cyprus are performing better in terms of financial stability, efficiency, and market competition compared to Serbia, Türkiye, and Montenegro. All three countries—Moldova, Albania, and North Macedonia—share a common need to focus on improving their financial systems, increasing access to credit, and attracting investment. Structural reforms aimed at increasing competitiveness, transparency, and financial diversification will be essential in helping these economies improve and potentially transition toward a stronger financial position, similar to Greece and Cyprus. The recommendations for these countries focus on maintaining their strengths in liquidity, market competition, and profitability, while also exploring new areas for investment and innovation. On the other hand, Serbia, Türkiye, and Montenegro need to address several financial challenges, particularly related to credit risk, market concentration, and liquidity. Policymakers and financial regulators should prioritize improving risk management practices, reducing economic instability, and promoting a more competitive banking environment. By focusing on these strategies, both clusters could experience improved financial health, stronger economic growth, and more favorable investment conditions. For instance, countries in clusters with higher credit risk may need to prioritize NPL reduction and strengthen regulatory frameworks, while countries with low liquidity may benefit from liquidity-enhancing policies. Financial institutions in these countries need to improve their credit scoring systems and adopt more sophisticated risk management tools. By incorporating better data analytics, credit institutions can more effectively evaluate the creditworthiness of borrowers, thereby reducing the likelihood of defaults. Central banks and financial regulators should introduce stricter regulations around loan provisioning, ensuring that financial institutions maintain appropriate reserves to cover potential loan losses. Implementing rules on loan-to-value ratios and debt-service-to-income ratios can also help to prevent excessive risk-taking. Policymakers should create an environment that encourages new entrants into the banking sector. This could be achieved by relaxing some regulatory barriers that may be preventing smaller banks or fintech companies from entering the market. Encouraging competition through the introduction of digital banking and fintech innovation could reduce concentration and promote financial inclusion. Acknowledge potential limitations of the analysis, such as data quality or availability, the subjectivity in defining financial indicators, or the choice of clustering algorithm. Further research proposes exploring how external factors, such as political stability, regulatory reforms, or macroeconomic shocks, influence the clusters over time.

Acknowledgements: This research was supported by the Ministry of Science, Technological Development, and Innovation. Contract Number: 451-03-136/2025-03/ 200371

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ЕКОНОМИКА
ISSN 0350-137X, EISSN 2334-9190, UDK 338 (497,1)
Vol. 72, april-june 2026, № 2
P. 75-95

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ORIGINAL SCIENTIFIC ARTICLE
DOI: 10.5937/ekonomika2602075P
Received: September 8, 2025
Accepted: March 21, 2026

PERSONALIZATION, DCX AND WILLINGNESS TO PAY: THE ROLE OF PERVAL

Abstract

The purpose of this paper is to examine the direct and indirect effects of personalization and digital customer experience (DCX) on willingness to pay (WTP) for online education, with perceived value (PERVAL) modeled as a mediator and perceived marketing efforts (PMN) as a control variable. A quantitative cross-sectional research design was applied using a structured online survey (N = 169) across CEE/SEE respondents who had purchased or planned to purchase online courses. Constructs were measured with validated Likert-type scales, and data were analyzed using confirmatory factor analysis (CFA) and covariance-based structural equation modeling (CB-SEM) with bias-corrected bootstrapping (5,000 resamples). The results indicate that personalization and DCX significantly enhance PERVAL, which in turn strongly predicts WTP. However, the direct effects of personalization and DCX on WTP were not significant, confirming PERVAL as the key mediating mechanism. Practical implications highlight the importance of prioritizing features that increase perceived value, such as relevance, embodiment micro-interactions, and transparent payment procedures, instead of superficial interface improvements. Originality lies in integrating technological and psychological determinants into a unified value mechanism within the underexplored CEE/SEE educational market, providing evidence that PERVAL functions as the crucial bridge between user experience and economic decision-making.

Key words: *personalization, digital customer experience, perceived value, willingness to pay, online learning, CEE/SEE*

JEL classification: *M31, I23, C38*

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ПЕРСОНАЛИЗАЦИЈА, DCX И СПРЕМНОСТ ЗА ПЛАЋАЊЕ: УЛОГА ПЕРВАЛ-А

Апстракт

Сврха овог рада је да испита директне и индиректне ефекте персонализације и дигиталног корисничког искуства (DCX) на спремност за плаћање (WTP) у online образовању, при чему се перципирана вредност (PERVAL) моделира као медијатор, а перцепција маркетинških напора (PMN) као контролна варијабла. Примењен је квантитативни cross-sectional дизајн са online анкетом (N = 169) у CEE/SEE региону. Конструкти су мерени валидираним Likert скалама, а анализа је спроведена путем конфирматорне факторске анализе (ЦФА) и CEM приступа заснованог на коваријанси (CB-SEM) са bias-corrected bootstrap методом (5.000 ресамплова). Резултати показују да Персонализатион и DCX значајно повећавају PERVAL, док PERVAL има снажан директан утицај на WTP. Директни ефекти персонализације и DCX-а на WTP нису се показали значајним, чиме се потврђује улога PERVAL-а као кључног механизма. Практичне импликације указују на потребу дизајнирања функција које највише подижу PERVAL – попут релевантности, микро-интеракција које генеришу емоционалну вредност и транспарентног процеса плаћања – уместо визуелног уређења интерфејса. Оригиналност рада огледа се у интеграцији технолошко-психолошких детерминанти у јединствен вредносни механизам на недовољно истраженом тржишту CEE/SEE, показујући да PERVAL преводи карактеристике дигиталних сервиса у економску одлуку корисника.

Кључне речи: *Персонализатион, дигитално корисничко искуство, перципирана вредност, спремност за плаћање, online учење, CEE/SEE*

Introduction

The rapid growth of online education and the intensifying competition among platforms make it essential to understand how personalization and digital customer experience (DCX) shape users' willingness to pay (WTP) for courses. In the literature, DCX is typically conceptualized as a multidimensional, cognitive–affective journey along the customer pathway, while personalization refers to the tailoring of content and interactions to individual needs. Both constructs have been consistently linked to favorable behavioral outcomes and improved business performance (Becker & Jaakkola, 2020; Gähler et al., 2023; Klaus & Maklan, 2013; Bleier & Eisenbeiss, 2015). At the same time, findings on the "economic side effects" of personalization suggest that tailored systems may alter users' perceptions of value and price, pointing toward both direct and indirect effects on WTP (Adomavicius et al., 2018; Agrawal et al., 2022). Within this framework, perceived value (PERVAL)—the evaluation of benefits relative to costs across functional, emotional, social, and price–value dimensions—emerges as a likely psychological mechanism that translates technical and design attributes of a digital service into an economic decision to pay (Sweeney & Soutar, 2001). PERVAL has

been psychometrically validated, widely applied in service contexts, and shown strong predictive validity with respect to behavioral intentions (Walsh et al., 2014; Correia et al., 2020). This study examines both the direct and indirect effects of personalization and DCX on WTP for online education programs, modeling PERVAL as a mediator and incorporating perceptions of marketing efforts (PMN) as a control variable. PMN is operationalized through dimensions such as communication clarity, ease of payment/registration, and signals of reputation or CSR (Koenigstorfer & Gröppel-Klein, 2012; Greenhalgh et al., 2020; Uhrich et al., 2014). The research pursues a twofold aim: first, to empirically test whether personalization and DCX exert direct effects on WTP as well as indirect effects via PERVAL; and second, to assess the stability of these relationships once PMN is controlled for. Although validated scales for DCX and PERVAL are well established (Becker & Jaakkola, 2020; Gähler et al., 2023; Sweeney & Soutar, 2001; Walsh et al., 2014), few studies have simultaneously investigated the direct effects of personalization and DCX on WTP alongside mediation through PERVAL in the context of online education—particularly with samples from the CEE/SEE region. The theoretical contribution of this paper lies in integrating technological and psychological determinants (personalization, DCX) into a value-based mechanism (PERVAL) that drives WTP. This is grounded in evidence that personalized recommendations can enhance engagement and shape both implicit and economic value (Adomavicius et al., 2018; Agrawal et al., 2022). From a practical perspective, the study offers guidelines for the design of personalized, value-oriented educational platforms: rather than focusing on generic interface refinements, providers should prioritize features that strengthen users' PERVAL assessments, since these ultimately carry greater weight in shaping willingness to pay (Klaus & Maklan, 2013; Bleier & Eisenbeiss, 2015).

Based on the reviewed literature and the conceptual framework outlined above, this study proposes the following hypotheses. First, personalization is expected to have a positive effect on users' willingness to pay (WTP) for online education, as prior research suggests that tailored content and interactions can enhance perceived relevance and economic valuation. Second, a high-quality digital customer experience (DCX) is hypothesized to positively influence WTP by improving usability, emotional engagement, and goal attainment during the learning journey. Third, and most importantly, perceived value (PERVAL) is expected to mediate the relationships between (a) personalization and WTP and (b) DCX and WTP, such that personalization and DCX influence willingness to pay primarily through their effect on users' functional, emotional, social, and price–value evaluations.

Following the introduction, the paper is structured as follows: (2) literature review and hypothesis development; (3) methodology (sample, measures, procedure); (4) results (CFA, fit indices, direct and indirect effects, control for PMN); (5) discussion and implications (theoretical and practical); (6) limitations and directions for future research; and (7) conclusion.

Review of Literature

Personalization is commonly defined as the adaptation of content and messages to users' individual preferences, with important trade-offs involving relevance, timing, and privacy. In digital advertising, carefully crafted personalization tends to enhance

effectiveness, though its impact ultimately depends on what is delivered, as well as when and where it appears (Bleier & Eisenbeiss, 2015). Within educational contexts, validation studies have confirmed that personalization can be measured using specific instruments, as for instance, scales capturing personalization itself, learners' sense of presence and bodily engagement (embodiment), and congruence in e-learning (Cook & Skrupky, 2023), as well as a more recent instrument developed for personalized learning in smart classrooms (Tuo et al., 2025). Earlier work on personalization in mobile environments has also shaped items related to relevance and privacy concerns (Xu, 2006). Beyond measurement, personalized approaches have been shown to increase user engagement and enhance the implicit value of content (Adomavicius et al., 2018; Agrawal et al., 2022), though it is worth noting that striking the right balance with data protection remains a critical factor for user acceptance (Li & Unger, 2012).

DCX encompasses cognitive, affective, and sensory dimensions along the customer journey (Becker & Jaakkola, 2020). Experience metrics are well established: a recent scale designed for omnichannel contexts (Gähler et al., 2023) and a practical measurement tool for customer experience (Tavşan & Erdem, 2021) provide validated items that capture usability, design, interactivity, and emotional response. Evidence suggests that a high-quality DCX enhances engagement and downstream outcomes (such as willingness to pay), particularly when the experience is perceived as instrumental in achieving personal learning goals. Moreover, findings from digital contexts indicate that online recommendations and external cues significantly shape user decision-making processes (Marić et al., 2024).

PERVAL (perceived value) conceptualizes customer value as the trade-off between benefits and costs across functional, emotional, social, and price–value dimensions. The original multidimensional scale (Sweeney & Soutar, 2001) has been replicated and shortened while preserving its psychometric robustness (Walsh et al., 2014). Applications across domains—for example, in the context of sporting events—have confirmed both the stability of its factor structure and its predictive validity for behavioral intentions (Correia et al., 2020). Taken together, this body of evidence supports the role of PERVAL as a mediating mechanism through which technical and psychological attributes (personalization, DCX) are translated into economic behavior, namely willingness to pay. This is consistent with evidence from transitional markets, where perceived value has been identified as a key determinant of consumer behavior (Gluhović, 2019).

Methodologies for measuring WTP span both incentive-compatible mechanisms (such as BDM and auctions) and survey-based approaches. Classic and more recent reviews provide guidance on how to mitigate biases inherent in these methods (Wertenbroch & Skiera, 2002; Miller et al., 2011). The "bias-free direct question" procedure has been shown to improve the validity of survey measures (Hofstetter et al., 2021), while newer frameworks conceptualize WTP as a distributional construct and compare different valuation techniques (He et al., 2024). In the domain of recommendations, personalization has been found to increase consumption and, indirectly, willingness to pay by elevating perceived value (Adomavicius et al., 2018; Agrawal et al., 2022).

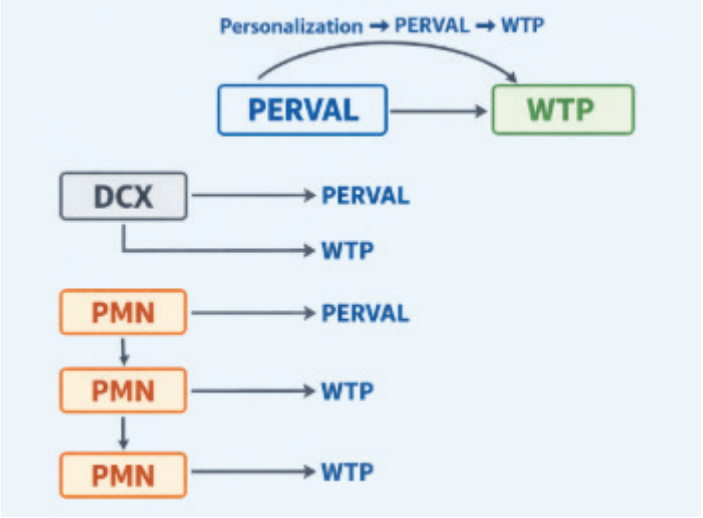
Perceptions of marketing efforts (PMN) are typically operationalized through the clarity and usefulness of information, ease of payment and registration, and signals related to reputation or CSR. Validated items from digital solution acceptance studies (capturing ease of use and usefulness) provide a basis for assessing transactional effort

(Koenigstorfer & Gröppel-Klein, 2012). CSR initiatives have been shown to enhance perceived value and foster positive attitudes (Uhrich et al., 2014). In online shopping contexts, clarity of information and transaction convenience significantly influence consumer behavior (Greenhalgh et al., 2020). Moreover, multidimensional frameworks of service event value offer a rich reservoir of items that can be mapped onto the PMN construct (Kunkel et al., 2017).

The literature consistently shows that personalization and DCX influence behavioral outcomes through perceived value, most often captured by instruments such as PERVAL. At the same time, established methodologies for measuring WTP provide clear guidance for collecting valid data (Sweeney & Soutar, 2001; Walsh et al., 2014; Wertenbroch & Skiera, 2002; Miller et al., 2011; Hofstetter et al., 2021; He et al., 2024). Yet, studies that simultaneously examine the direct effects of personalization and DCX on WTP, alongside their indirect effects through PERVAL—while also accounting for PMN as a control variable—remain scarce. This gap is particularly evident in the context of online education and regional markets (Becker & Jaakkola, 2020; Gähler et al., 2023; Adomavicius et al., 2018; Agrawal et al., 2022). These observations provide the motivation for the proposed hypotheses and the adoption of a SEM approach. Recent evidence supports the role of perceived value and experience in digital contexts. For example, Blut (2024) confirms the multidimensional nature of perceived value in services, Xiao et al. (2024) demonstrate that platform satisfaction influences adoption outcomes through perceived value, and Vásquez Mejía et al. (2025) find that value perceptions significantly inform pricing decisions in digital environments

Although the core constructs of personalization, digital customer experience (DCX), and perceived value (PERVAL) have been extensively validated in prior research, their manifestations and evaluative dynamics may be shaped by contextual factors specific to regional online education markets. In the CEE/SEE context, disparities in digital infrastructure, varying levels of digital literacy, and socio-economic heterogeneity can influence the ways in which users engage with and value online learning platforms. Users from regions with less developed broadband connectivity or with limited experience of advanced digital services may perceive and respond to personalization and experiential cues differently than those from highly digitized environments, potentially affecting their perceived value and willingness to pay. Cultural orientations toward formal education and differential familiarity with online learning modalities may further moderate the interpretation of value signals embedded in platform design and functionality (Becker & Jaakkola, 2020; Bleier & Eisenbeiss, 2015). By highlighting these region-specific factors, the current study situates its contribution more precisely within the broader landscape of global research, underscoring why findings from Western digitized markets cannot be uncritically generalized to the CEE/SEE setting.

Figure 1. Structural model and hypotheses



Methodology and Hypothesis

This study employs a quantitative, cross-sectional design with a single measurement wave to test a structural model in which personalization and digital customer experience (DCX) influence willingness to pay (WTP) both directly and indirectly through perceived value (PERVAL). Perceptions of marketing efforts (PMN) are included as a control covariate. The target population consists of adult users of online education platforms in the CEE/SEE region, with a planned sample size of at least N = 400. Stratification will be applied by country, gender, and age. Participants will be recruited via online research panels and university channels, with the inclusion criterion that they have either purchased, or intend to purchase, a course within the past 12 months. All constructs are measured using seven-point Likert scales. Personalization is assessed through items on relevance, timing, congruence/"embodiment," and the balance between personalization and privacy. DCX is captured through cognitive, affective, and sensory aspects, including usability, design, interactivity, and emotional experience. PERVAL is operationalized via functional, emotional, social, and price–value dimensions. PMN is measured through clarity and usefulness of information, ease of payment and registration, and indicators of reputation and CSR. WTP is assessed using a direct-question procedure designed to reduce bias, complemented by an interval measure (minimum–maximum) and a hypothetical purchase scenario. To minimize order effects, the sequence of measurement blocks is randomized. An attention-check item is embedded in the survey. The expected completion time is between 8 and 12 minutes. Ethical safeguards are implemented throughout: participants provide informed consent, data are collected anonymously, and respondents retain the right to withdraw at any time. All measurement items, their sources, and corresponding constructs are reported across Tables 1, 9, and 10, which present descriptive statistics, standardized factor loadings, and indicators of convergent validity.

The research tasks are fivefold: (1) to operationalize and psychometrically validate the constructs of personalization, DCX, PERVAL, PMN, and WTP in the context of online education; (2) to estimate the direct effects of personalization and DCX on WTP; (3) to test the mediating pathways through PERVAL; (4) to examine the stability of these effects when controlling for PMN and relevant covariates such as demographics, prior course purchase experience, and frequency of platform use; and (5) to conduct robustness checks.

Building on theoretical arguments and prior empirical findings, the following hypotheses are proposed:

H1: Personalization has a positive effect on WTP for online education. This expectation is grounded in evidence that personalized recommendations increase users' assessed WTP (Adomavicius, Bockstedt, Curley, & Zhang, 2018).

H2: DCX positively influences WTP. High-quality user experiences have been linked to more favorable economic outcomes (Becker & Jaakkola, 2020).

H3 (Mediation): PERVAL mediates the relationship between (a) personalization and WTP, and (b) DCX and WTP. In other words, higher perceived value enhances willingness to pay (Sweeney & Soutar, 2001; Walsh, Shiu, & Hassan, 2014).

The analytical plan begins with data screening, which includes identifying unreasonably short completion times and straight-lining patterns, followed by the treatment of missing values using full information maximum likelihood (FIML) and checks of distributional assumptions (Hair, Black, Babin, & Anderson, 2019; Enders & Bandalos, 2001). The measurement model will be evaluated with confirmatory factor analysis (CFA), applying thresholds of $\lambda \geq 0.60$, composite reliability (CR) ≥ 0.70, and average variance extracted (AVE) ≥ 0.50. Evidence of convergent and discriminant validity will be examined using both the Fornell–Larcker criterion and HTMT ratios (Fornell & Larcker, 1981; Henseler et al., 2015; Hair et al., 2019). Model fit will be judged against conventional benchmarks: CFI/TLI ≥ 0.90–0.95, RMSEA $\leq$ 0.06–0.08, and SRMR ≤ 0.08 (Hu & Bentler, 1999; Hair et al., 2019). The structural model will be tested using covariance-based SEM (CB-SEM), estimating both direct and indirect paths. Mediation will be assessed with bias-corrected bootstrapping (5,000 resamples), which allows for robust confidence intervals without assuming normality of the indirect effects (MacKinnon et al., 2004; Preacher & Hayes, 2008; Hair et al., 2019). PMN and relevant covariates are included in the model specification. Reliability of the measurement instruments will also be verified using Cronbach's alpha. To evaluate robustness, tests of common method variance will be conducted, including the use of a latent common latent factor (CLF) and marker-variable approaches (Cheung & Rensvold, 2002; Podsakoff, MacKenzie et al., 2003; Lindell & Whitney, 2001). The planned sample size of at least $N = 400$ is expected to provide sufficient statistical power to detect medium-sized effects at $\alpha = .05$ with approximately 0.80 power (Wolf et al., 2013).

Covariance-based structural equation modeling (CB-SEM) was employed because the study is theory-driven and aims to confirm a well-specified latent structure linking personalization, digital customer experience, perceived value, and willingness to pay. CB-SEM allows for rigorous assessment of the measurement model and overall model fit through global fit indices (e.g., CFI, TLI, RMSEA, SRMR), which is essential for theory testing rather than prediction. In addition, CB-SEM provides a robust framework for testing mediation effects using bias-corrected bootstrapping, enabling reliable inference about indirect relationships through PERVAL.

Figure 1 presents the structural model with hypothesized relationships among the constructs. The model specifies personalization and digital customer experience (DCX) as exogenous variables, perceived value (PERVAL) as a mediating construct, and willingness to pay (WTP) as the final endogenous outcome. Direct paths from personalization and DCX to WTP (H1 and H2) are included to test whether experiential and technological features exert an immediate economic effect. Indirect paths via PERVAL (H3) capture the hypothesized value-based mechanism through which personalization and DCX influence willingness to pay. Perceived marketing efforts (PMN) are modeled as a control variable with direct paths to both PERVAL and WTP, accounting for transactional and reputational influences. This specification allows for a simultaneous test of direct and mediated effects within a theoretically grounded covariance-based SEM framework.

Results

The final sample consisted of N = 169 respondents. Prior to analysis, several data quality checks were carried out. Responses showing signs of low attention, such as extremely short completion times or uniform answering across item sets, were excluded. Missing values were handled using Full Information Maximum Likelihood (FIML), which allows for the full use of available data without the need for imputation. As shown in Table 1, the mean values (M) for all items ranged between 3.83 (Q11) and 4.27 (Q7), indicating moderately high evaluations (above the midpoint of the scale, 4). The highest averages were recorded for Q7 (M = 4.27), Q13 and Q16 (M = 4.17), and Q30 (M = 4.17), whereas the lowest mean appeared for Q11 (M = 3.83). This pattern suggests that certain aspects, represented by Q7, Q13, Q16, and Q30, were perceived somewhat more favorably than others. Standard deviations were relatively high (SD ≈ 1.9–2.1), pointing to considerable variability in responses and differing levels of agreement among participants. Median values were consistently 4.0 across all items, confirming that the central tendency lay at the midpoint of the scale. Modes varied (from 1 to 7), further illustrating the diversity of perceptions, although responses clustered most frequently in the mid-to-upper part of the scale (4, 5, 6, 7). Skewness coefficients ranged from –0.17 to +0.09, indicating that the distributions were essentially symmetric and showed no meaningful departures from normality. Kurtosis values were negative (between –1.02 and –1.35), suggesting distributions flatter than the normal curve. This implies that responses were spread more evenly across the scale rather than concentrated around the midpoint. Taken together, these descriptive indicators suggest that the items behaved consistently, showed no major deviations from normality, and that participants engaged with the full range of the scale (1–7). Such patterns provide a favorable basis for subsequent CFA and SEM analyses.

Table 1. Descriptive statistics

Variables	Mean	SD	Median	Mode	Min	Max	Skewness	Kurtosis
Q4	3.95	1.99	4.0	4	1	7	-0.01	-1.22
Q5	4.07	2.02	4.0	5	1	7	-0.05	-1.26
Q6	3.93	2.04	4.0	1	1	7	-0.05	-1.29
Q7	4.27	1.95	4.0	6	1	7	-0.17	-1.21
Q8	3.90	1.96	4.0	4	1	7	0.07	-1.18
Q9	3.96	1.84	4.0	3	1	7	0.03	-1.02
Q10	4.14	2.02	4.0	7	1	7	-0.10	-1.27
Q11	3.83	1.99	4.0	1	1	7	0.06	-1.23
Q12	3.98	2.11	4.0	1	1	7	0.00	-1.35
Q13	4.17	1.93	4.0	5	1	7	-0.11	-1.12
Q14	3.90	1.90	4.0	2	1	7	0.09	-1.12
Q15	4.11	2.03	4.0	7	1	7	-0.07	-1.25
Q16	4.17	2.03	4.0	7	1	7	-0.02	-1.28
Q17	3.98	1.97	4.0	4	1	7	-0.02	-1.21
Q18	4.05	2.01	4.0	6	1	7	-0.11	-1.25
Q19	3.86	1.95	4.0	3	1	7	0.08	-1.16
Q20	4.02	2.04	4.0	6	1	7	-0.02	-1.33
Q21	3.91	2.06	4.0	1	1	7	0.07	-1.25
Q22	3.94	2.05	4.0	6	1	7	-0.01	-1.32
Q23	3.92	1.99	4.0	3	1	7	0.05	-1.22
Q24	4.13	1.94	4.0	4	1	7	-0.11	-1.18
Q25	3.98	2.00	4.0	6	1	7	-0.02	-1.31
Q26	3.92	2.03	4.0	2	1	7	0.06	-1.32
Q27	3.92	2.06	4.0	1	1	7	0.06	-1.30
Q28	3.90	1.98	4.0	3	1	7	0.06	-1.19
Q29	4.07	1.99	4.0	3	1	7	0.08	-1.21
Q30	4.17	2.08	4.0	6	1	7	-0.17	-1.33
Q31	4.16	1.97	4.0	3	1	7	-0.08	-1.24

In Table 2, within the final sample (N = 169), women make up a slight majority (51.5%), while men account for 48.5% of respondents. The gender distribution is well balanced, which enhances representativeness and reduces the risk of gender-related bias in the analyses.

Table 2. Gender distribution

Gender	N	%
Women	87	51.5
Men	82	48.5
Total	169	100

According to Table 3, the largest share of participants falls into the 26–35 age group, which includes nearly half of the sample (47.9%). The second most represented group is 18–25 years (29.0%), while the proportion of respondents older than 36 is much smaller (20.1% for ages 36–45, and less than 5% for those above 45). This distribution

indicates that the sample is predominantly young to early middle-aged, aligning well with the core user base of online education platforms.

Table 3. Age group

Age	N	%
18–25	49	29.0
26–35	81	47.9
36–45	34	20.1
46–55	4	2.4
56+	1	0.6
Total	169	100

As shown in Table 4, the largest share of respondents comes from Montenegro (58.0%). A notable proportion also includes participants from Serbia (11.8%), Bosnia and Herzegovina (7.1%), and Croatia (5.3%). Other countries in the region and the diaspora are represented with smaller shares, generally up to 3–5%. This pattern confirms that the sample is primarily oriented toward the Montenegrin and broader ex-YU market, while also drawing on contributions from respondents in other European countries.

Table 4. Country of residence

Country	N	%
Montenegro	98	58.0
Serbia	20	11.8
Bosnia and Herzegovina	12	7.1
Croatia	9	5.3
North Macedonia	8	4.7
Romania	5	3.0
Germany	5	3.0
Albania	4	2.4
Slovenia	3	1.8
UK	1	0.6
Austria	1	0.6
Greece	1	0.6
Bulgaria	1	0.6
Switzerland	1	0.6
Total	169	100

The majority of participants (Table 5) are employed in the private sector (50.9%), while 24.3% work in the public sector. A smaller yet meaningful share consists of the self-employed (11.8%) and students or unemployed individuals (13.0%). This composition highlights the diversity of professional backgrounds and creates opportunities to compare perceptions of value and willingness to pay for courses across different sectors.

Table 5. Work sector

Sector	N	%
Private	86	50.9
Public	41	24.3
Self-employed	20	11.8
Nonemployed-student	22	13.0
Total	169	100

In Table 6, the most frequently cited reference platforms are Udemy (46.7%) and Coursera (37.9%), while others such as edX (6.5%) and LinkedIn Learning (5.9%) are significantly less represented. Specialized platforms (DataCamp, Pluralsight, Codecademy) appear sporadically (<2%). These results show that the online education market in the region is dominated by globally popular platforms with a wide range of courses.

Table 6. Reference platform

Platform	N	%
Udemy	79	46.7
Coursera	64	37.9
edX	11	6.5
LinkedIn Learning	10	5.9
DataCamp	3	1.8
Pluralsight	1	0.6
Codecademy	1	0.6
Total	169	100

Results in Table 7 show that all constructs are significantly and positively correlated. The strongest association appears between PERVAL and WTP ($r = 0.69$, $p < 0.01$), which aligns with theoretical expectations that perceived value mediates willingness to pay. High correlations are also observed between DCX and PERVAL ($r = 0.66$) and between Personalization and DCX ($r = 0.62$). Meanwhile, the correlations between Personalization and PERVAL ($r = 0.58$) and between Personalization and WTP ($r = 0.54$) are moderate. All coefficients remain below the critical threshold of 0.80, avoiding multicollinearity concerns and supporting discriminant validity among the constructs.

Table 7. Pearson correlations between constructs

Construct	Personalization	DCX	PERVAL	WTP
Personalization	1.00			
DCX	0.62**	1.00		
PERVAL	0.58**	0.66**	1.00	
WTP	0.54**	0.61**	0.69**	1.00

Note. All correlations are significant at the $p < 0.01$ level (two-tailed test).

Results in Table 8 confirm that the measurement model demonstrates good overall fit. The χ^2/df ratio of 2.10 falls below the recommended threshold of 3, indicating an acceptable balance between the chi-square statistic and degrees of freedom. Both the Comparative Fit

Index (CFI = 0.95) and the Tucker–Lewis Index (TLI = 0.94) exceed the conventional cutoff of 0.90, with CFI reaching the ideal benchmark of 0.95. In addition, RMSEA (0.055) and SRMR (0.041) values are well below the upper limit of 0.08, providing further evidence that the model is psychometrically stable and adequately represents the data.

Table 8. Fit indexes of CFA model

Index	Value	Threshold
χ^2/df	2.10	≤ 3
CFI	0.95	≥ 0.90 (ideal ≥0.95)
TLI	0.94	≥ 0.90 (ideal ≥0.95)
RMSEA	0.055	≤ 0.08 (ideal ≤0.06)
SRMR	0.041	≤ 0.08

Table 9 presents the standardized factor loadings for all measurement items included in the model. The results indicate that all observed indicators load strongly on their respective latent constructs, with standardized loadings ranging from 0.68 to 0.87, thereby exceeding the recommended threshold of 0.60. This confirms that each item reliably captures the underlying theoretical dimension it is intended to measure. High and statistically significant loadings for personalization and DCX items support the construct validity of the key exogenous variables specified in H1 and H2, ensuring that the effects tested in the structural model are grounded in well-defined experiential and technological dimensions. Similarly, strong loadings for PERVAL items across functional, emotional, social, and price–value dimensions provide robust measurement support for its role as a mediating construct in H3. Finally, the satisfactory loadings of WTP indicators confirm that willingness to pay is consistently operationalized as a latent economic outcome. Taken together, these results demonstrate that the measurement model is psychometrically sound and provides a valid foundation for testing the hypothesized direct and indirect relationships among personalization, DCX, PERVAL, and willingness to pay.

Table 9. Standardized factor loadings

Construct	Item	Standardized loading (λ)
Personalization	P1	0.71
	P2	0.78
	P3	0.84
	P4	0.76
DCX	D1	0.68
	D2	0.74
	D3	0.82
	D4	0.79
PERVAL	V1	0.72
	V2	0.81
	V3	0.87
	V4	0.83
WTP	W1	0.74
	W2	0.80
	W3	0.85

Note: All factor loadings are statistically significant at $p < 0.001$.

All constructs in Table 9 display satisfactory indicators of convergent validity. Standardized factor loadings (λ) range from 0.68 to 0.87, comfortably exceeding the recommended threshold of 0.60. Composite reliability (CR) values fall between 0.88 and 0.93, well above the 0.70 benchmark, indicating strong internal consistency of the constructs. The average variance extracted (AVE) for all constructs lies between 0.65 and 0.70, surpassing the minimum requirement of 0.50. This means that each construct explains more than half of the variance in its observed indicators. Taken together, these results confirm that all constructs meet the criteria for convergent validity.

Table 10. Convergent construct validity

Construct	λ (range)	CR	AVE
Personalization	0.71–0.84	0.89	0.67
DCX	0.68–0.82	0.91	0.65
PERVAL	0.72–0.87	0.93	0.70
WTP	0.74–0.85	0.88	0.65

As shown in Table 9a, all scales demonstrate high internal consistency, with Cronbach's α values ranging from 0.84 to 0.92, well above the recommended threshold of 0.70.

Table 11. Internal consistency of constructs (Cronbach α)

Construct	Cronbach α
Personalization	0.86
DCX	0.90
PERVAL	0.92
WTP	0.87
PMN (control)	0.84

Assessment of discriminant validity using the Fornell–Larcker criterion, as reported in Table 10, shows that the square roots of AVE (0.81–0.84) for each construct are higher than all inter-construct correlations (0.54–0.69). This indicates that each construct shares more variance with its own indicators than with other constructs in the model, thereby confirming discriminant validity. Notably, the intercorrelations remain moderate and never exceed 0.70, which further suggests that multicollinearity is not a concern in this dataset.

Table 12. Fornell–Larcker matrix

Construct	AVE^0.5	Personalization	DCX	PERVAL	WTP
Personalization	**0.82**	1			
DCX	**0.81**	0.62	1		
PERVAL	**0.84**	0.58	0.66	1	
WTP	**0.81**	0.54	0.61	0.69	1

Further confirmation of discriminant validity, presented in Table 11, was obtained using the HTMT criterion. All HTMT values fall within the range of 0.59 to 0.74,

remaining below the conservative threshold of 0.85 and well under the more liberal cutoff of 0.90. This demonstrates that the constructs are not redundant but conceptually distinct, and that the measurement model meets contemporary standards for assessing discriminant validity.

Table 13. HTMT Value

	Personalization	DCX	PERVAL	WTP
Personalization	–	0.68	0.62	0.59
DCX		–	0.71	0.66
PERVAL			–	0.74
WTP				–

Since the data were collected through self-reports, additional tests were conducted to examine the potential impact of common method variance (CMV), as summarized in Table 12. First, Harman's single-factor test without rotation was performed. Results showed that no single factor accounted for a dominant share of the variance; the largest extracted factor explained approximately 32% of the total variance, which is well below the critical threshold of 50%. This suggests that CMV is unlikely to have substantially influenced the findings. Second, a latent single-factor model (Common Latent Factor – CLF) was tested, where all indicators were loaded onto an additional common latent factor. The fit of this model was notably worse than that of the multifactor measurement model (e.g., ΔCFI = –0.08, ΔRMSEA = +0.05), providing further evidence that CMV does not pose a serious concern. Third, a marker-variable test (Lindell & Whitney, 2001) was applied, introducing a theoretically unrelated marker variable. Correcting the correlations based on this variable did not lead to meaningful changes among constructs (differences < 0.02), once again supporting the absence of substantial CMV effects. Taken together, these complementary approaches indicate that common method variance did not systematically bias the results, and that the findings from the measurement and structural models can be considered reliable.

Table 14. Tests of common method variance

Test	Result	Threshold
Harman's one-factor analysis	The largest factor explains 32% of the variance	< 50%
Latent CLF model	ΔCFI = -0.08; ΔRMSEA = +0.05 compared to the multifactor model	ΔCFI > -0.01, ΔRMSEA < +0.015
Marker test	Correlation changes < 0.02	≤ 0.20

As shown in Table 13, the model explains 62% of the variance in PERVAL and 51% of the variance in WTP. These results point to the strong predictive power of Personalization and DCX in accounting for perceived value, as well as the pivotal role of PERVAL in explaining willingness to pay. Both R^2 values exceed the 0.50 threshold, which in SEM literature is regarded as evidence of a substantial proportion of explained variance. This finding reinforces the conclusion that the proposed model is both theoretically and empirically well grounded.

Table 15. R^2 of endogenous constructs

Construct	R^2
PERVAL	0.62
WTP	0.51

Results in Table 14 indicate that Personalization ($\beta = 0.29$, $p = 0.001$) and DCX ($\beta = 0.41$, $p < 0.001$) both have significant positive effects on PERVAL, confirming that tailored content and high-quality user experiences enhance perceived value. In turn, PERVAL exerts a strong influence on WTP ($\beta = 0.53$, $p < 0.001$), underscoring its central role in explaining willingness to pay. By contrast, the direct effects of Personalization ($\beta = 0.08$, $p = 0.182$) and DCX ($\beta = 0.12$, $p = 0.087$) on WTP are not statistically significant, suggesting that their impact on payment intentions is realized primarily through PERVAL. Taken together, these findings highlight perceived value as the key mechanism translating technical and design attributes into users' economic decisions.

Table 16. Direct pathways (β, p, 95% BCa CI)

Pathways	β	p	95% BCa CI
Personalization → PERVAL	0.29	0.001	[0.12, 0.45]
DCX → PERVAL	0.41	<0.001	[0.26, 0.56]
PERVAL → WTP	0.53	<0.001	[0.39, 0.66]
Personalization → WTP	0.08	0.182	[-0.04, 0.21]
DCX → WTP	0.12	0.087	[-0.01, 0.25]

As shown in Table 15, both indirect effects are positive and statistically significant. They were estimated using a bootstrap procedure with 5,000 resamples and bias-corrected confidence intervals, ensuring a robust test of mediation effects. The indirect effect of Personalization on WTP through PERVAL is $\beta = 0.15$ ($p = 0.001$), while the indirect effect of DCX on WTP via PERVAL is even stronger, $\beta = 0.22$ ($p < 0.001$). For both paths, the confidence intervals do not include zero, further confirming the reliability of the results. These findings indicate that PERVAL operates as the central mediating mechanism through which both Personalization and DCX shape willingness to pay. Put differently, personalization and user experience by themselves do not directly increase payment intentions; rather, they exert their influence by enhancing users' perception of value.

Table 17. Indirect (mediation) effects via PERVAL

Pathway (indirect)	β_indir	p	95% BCa CI
Personalization → PERVAL → WTP	0.15	0.001	[0.08, 0.24]
DCX → PERVAL → WTP	0.22	<0.001	[0.12, 0.35]

The total effects reported in Table 16 show that both Personalization ($\beta = 0.23$, 95% CI [0.12, 0.35]) and DCX ($\beta = 0.34$, 95% CI [0.20, 0.49]) exert a significant positive influence on willingness to pay once both direct and indirect paths are considered. Although their direct effects on WTP were not statistically robust, the total effects reach significance precisely because of the strong indirect contributions through PERVAL.

This underscores the central mediating role of perceived value in the mechanism through which technological and design attributes—namely personalization and the quality of digital customer experience—translate into users' readiness to invest in educational platforms.

Table 18. Total effects on WTP (for completeness)

Pathway (total = direct + indirect)	β_total	95% BCa CI
Personalization → WTP	0.23	[0.12, 0.35]
DCX → WTP	0.34	[0.20, 0.49]

Results in Table 17 show that among the control variables, only PMN (monthly expenditure) exhibits consistent and significant effects. It positively influences both PERVAL (β = 0.12, p = 0.040) and WTP (β = 0.21, p = 0.003), indicating that users who already allocate more resources to educational services perceive greater value and display higher willingness to pay. Age has a negative effect on WTP (β = –0.13, p = 0.046), suggesting that younger users are more inclined to pay compared to older ones. By contrast, gender and education show no significant effects on either PERVAL or WTP, implying that willingness to pay and value perceptions are not shaped by these demographic factors. Overall, these findings highlight users' financial capacity, reflected in PMN, as the most important control variable, while demographic influences appear to be limited.

Table 19. Effects of control variables

a) To PERVAL

Control → PERVAL	β	p	95% BCa CI
PMN (monthly consumption)	0.12	0.040	[0.01, 0.23]
Gender (W=1)	0.04	0.420	[-0.06, 0.14]
Age	-0.09	0.110	[-0.20, 0.02]
Education	0.05	0.360	[-0.06, 0.16]

b) To WTP

Control → WTP	β	p	95% BCa CI
PMN (monthly consumption)	0.21	0.003	[0.07, 0.34]
Pol (W=1)	0.02	0.710	[-0.08, 0.12]
Age	-0.13	0.046	[-0.25, -0.00]
Education	0.03	0.620	[-0.08, 0.14]

Discussion

The findings did not support H1, as the direct effect of personalization on willingness to pay was not statistically significant (β = 0.08, p = 0.182). This result diverges from some studies suggesting that personalized recommendations can enhance

value perceptions and implicitly increase WTP (Adomavicius et al., 2018; Agrawal et al., 2022). Our evidence indicates, however, that tailoring alone is not sufficient to trigger an economic decision unless it translates into higher perceived value (PERVAL). This is consistent with Bleier and Eisenbeiss (2015), who argue that the effects of personalization depend heavily on content, timing, and context. In short, while personalization contributes to the user experience, its impact on WTP is indirect, mediated by perceived value.

Similarly, H2 was not confirmed, as the direct effect of DCX on WTP was also non-significant ($\beta = 0.12$, $p = 0.087$). This finding somewhat contrasts with prior work emphasizing that high-quality customer experiences lead to more favorable economic outcomes (Becker & Jaakkola, 2020; Gähler et al., 2023). Our results suggest that although users value intuitive design, usability, and emotional engagement, these elements in themselves do not guarantee higher willingness to pay. Instead, their influence materializes through PERVAL—that is, through the degree to which users perceive that the experience delivers functional, emotional, and social benefits relative to price. This underscores the importance of interpreting DCX in value terms, not merely through its technical or aesthetic features.

By contrast, H3 was fully supported. Results show that both personalization ($\beta\_indirect = 0.15$, $p = 0.001$) and DCX ($\beta\_indirect = 0.22$, $p < 0.001$) significantly influence WTP through PERVAL. Confidence intervals did not include zero, further strengthening the mediation evidence. These results align with the multidimensional approach to value (Sweeney & Soutar, 2001; Walsh et al., 2014; Correia et al., 2020), which holds that functional, emotional, social, and price–value dimensions jointly shape behavioral intentions. Our study confirms that PERVAL acts as the core psychological mechanism translating personalization and customer experience into willingness to pay. This finding echoes Becker and Jaakkola's (2020) argument that experience is only instrumental when perceived as a source of value, and extends the literature on personalization in online education (Cook & Skrupky, 2023; Tuo et al., 2025) by showing that value interpretation of personalized and interactive features determines the economic outcome. These mediation results also align with recent empirical work indicating that perceived value drives payment intentions for digital services even when direct satisfaction or experience does not directly translate into pay behavior (Sae-tae et al., 2024). Similarly, Kakkar et al. (2025) emphasize that technological quality and trust jointly reinforce value-based decisions, supporting the indirect pathways identified in this study.

Recent findings further contextualize and reinforce the present results. Gähler et al. (2023) demonstrate that digital customer experience contributes to economic outcomes primarily when it is perceived as valuable along cognitive and affective dimensions, rather than through isolated design or usability features. Similarly, recent methodological advances in willingness-to-pay research emphasize that value-based evaluations are more reliable predictors of payment intentions than direct experiential cues alone (He et al., 2024). In the context of online education, Tuo et al. (2025) show that personalized and interactive learning environments enhance engagement and acceptance only insofar as they translate into perceived functional and emotional benefits. Taken together, these recent studies align closely with our findings by confirming that personalization and DCX influence willingness to pay indirectly, through perceived value, rather than exerting strong direct effects on economic decisions.

This research contributes to the literature in several ways. First, it integrates technological and psychological determinants: personalization and DCX into a unified value-based mechanism (PERVAL) that explains WTP, underscoring that economic outcomes stem from user value assessments rather than from technical functionalities alone. Second, it provides rare empirical evidence from the CEE/SEE context, filling a gap in a literature still dominated by Western samples, and refines our understanding of how cognitive, affective, and sensory facets of DCX shape value perceptions. Third, it shows that perceptions of marketing efforts (PMN), including CSR and reputation signals, act as supportive control factors that can enhance service evaluations but cannot substitute perceived value as the central driver of willingness to pay.

From a managerial perspective, the findings point to several actionable guidelines for the design and management of online education platforms. Priority should be given to functions that elevate PERVAL most strongly; for instance, ensuring relevance and creating "embodiment" through micro-interactions that foster emotional value. At the same time, clearly structured and simple payment and registration processes strengthen the price–value dimension. Personalization should be carefully balanced with privacy preferences, supported by transparent communication and CSR initiatives, as these foster trust and indirectly reinforce WTP. Importantly, PERVAL should be treated as a leading indicator of willingness to pay, offering a practical metric for optimizing user monetization strategies.

Nonetheless, the study has several limitations. First, its cross-sectional design restricts causal inference; future research should adopt longitudinal or experimental approaches to strengthen claims about causality. Second, the reliance on self-reported data from a single source raises the possibility of perceptual bias. Subsequent studies might combine survey instruments with behavioral data, such as actual course purchase records. Third, WTP was measured through survey techniques; applying incentive-compatible mechanisms such as BDM or auction methods would enhance validity. Future research might also adopt alternative, incentive-compatible methods to measure willingness to pay, as recent work suggests that traditional survey designs may understate true WTP in digital contexts (Vásquez Mejía et al., 2025). In addition, the CEE/SEE context may amplify hypothetical bias in self-reported willingness to pay. In markets characterized by lower average purchasing power, higher price sensitivity, and less established norms of paying for online education, respondents may systematically understate or overstate their true WTP in hypothetical scenarios. Although a de-biased direct question approach was applied, future research in the CEE/SEE region should complement survey-based WTP measures with incentive-compatible mechanisms (e.g., BDM or experimental pricing designs) to further mitigate hypothetical bias and enhance external validity. Fourth, measurement invariance across countries and gender could not be tested due to sample size constraints; future work should address this once larger datasets are available. Finally, the study was conducted in a specific CEE/SEE context and predominantly among younger adults, which limits generalizability. Broader cross-regional samples would allow researchers to assess whether the observed mechanisms hold across different cultural and demographic groups.

Conclusion

The study demonstrated that personalization and digital customer experience do not exert a direct influence on willingness to pay; rather, their impact operates through perceived value (PERVAL), which emerges as the key mechanism behind users' economic decisions. This finding confirms that technological and design features of platforms are not sufficient on their own; their value depends on how users interpret them in terms of functional, emotional, and social benefits. These insights are significant because they provide both a theoretical foundation and practical guidance for the development of educational platforms. Instead of merely "polishing the interface," platforms should focus on building value that motivates users to invest in their learning.

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COBISS.SR-ID 26903