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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.

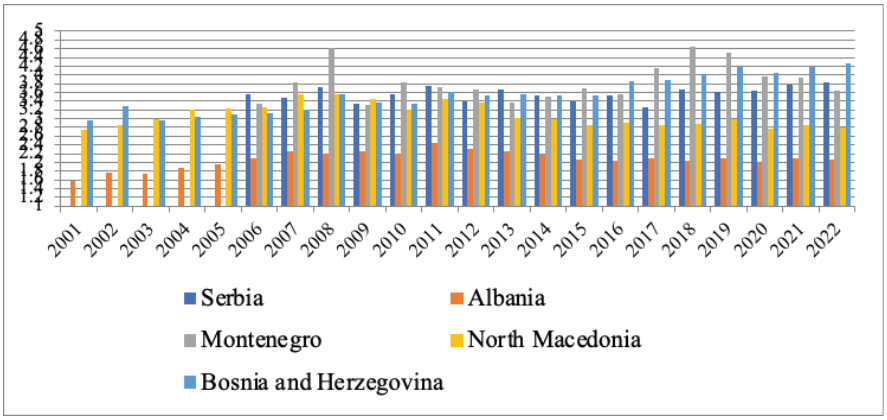
Research Results and Discussion

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.

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