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Energy efficiency as a driver of the circular economy and carbon neutrality in selected countries of Southern Europe: a soft computing approach

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Abstract

Background The main goal of the paper is to define the level of energy efficiency in the economies of selected countries in the Balkan region that have opted for the EU Green Deal, a circular economy, and a transition to carbon neutrality. Energy efficiency, as a determinant of carbon neutrality, was selected as an indicator for analysis because it records particularly unfavorable indicators in the region under observation. The research was carried out on a sample of seven Balkan countries and their surrounding areas. An initial qualitative analysis was followed by a quantitative analysis based on a combination of statistical methods and soft computing. Six indicators were selected for the analysis covering a period of 30 years (1990–2020).

Results A significant obstacle to the green transition and the region's transition to a circular economy and carbon neutrality is energy efficiency and energy related pollution—the reliance of most countries on coal-fired thermal power plants for electricity generation. The research results showed the following: (a) the degree of economic development and membership in the European Union are not significantly related to the level of energy efficiency; (b) most of the sampled countries are in the initial stages of introducing activities to achieve carbon neutrality; and (c) only Slovenia has documented consistent indicators and evident advancements in its efforts to achieve carbon neutrality. Based on the research findings, proposals for improvements were made in the direction of policymaking and in a methodological sense.

Conclusions The implementation of circularity and carbon neutrality as a long-term goal of the European Union is not necessarily related to the level of economic development, nor can its trajectory be exclusively ascertained by means of data processing and monitoring. A more precise understanding of a carbon-neutral future can be achieved through the incorporation of qualitative data to a greater extent, a realistic evaluation of historical facts and their repercussions, as well as projections of the effects that reality and global developments after 2022 will have on each country.

Keywords Energy efficiency, Circular economy, Carbon neutrality, Soft computing approach, Fuzzy logic, Bayesian networks

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Background

The European Union has defined its goal of achieving carbon neutrality by 2050 through an extensive collection of documents, regulations, and plans since its inception and has exerted considerable effort to facilitate the financing, implementation, and monitoring of numerous activities within its member states so that the aforementioned could be put into practice. The majority of countries initiated the process with a situation assessment and planning, followed by the enhancement of capacities to facilitate the achievement of carbon neutrality in every country. In this respect, the countries of the European Union have made adequate progress across all domains pertaining to the achievement of carbon neutrality [1], and they persist in implementing measures in this field. It is important to note that although the sustainable development goals defined by the United Nations have not been reached, the countries of the European Union are still making significant progress in this field [2], with a further commitment to achieving full climate neutrality. The above necessitates an adequate monitoring system, yet there remains the continued absence of consensus on how to measure progress toward carbon neutrality [3]. However, the European Union is undoubtedly the leading region in the world in terms of sustainable development and decarbonization. Notwithstanding the commitment to renewable energy sources, member states face challenges in fulfilling their binding targets in this domain [4], and the phase-out of coal as an energy source is not being implemented as anticipated, particularly in the countries of the eastern part of the European Union [5]. Regardless of the difficulties mentioned, the European Union found ways and mechanisms to align its progress with its commitment to achieving carbon neutrality.

Every country that aspired or still aspires to become a member of the European Union is obliged to fulfill a whole set of requirements outlined in the negotiation chapters. Notably, the chapters concerning energy and ecology have frequently proven to be the most difficult when it comes to implementing the changes, which can be considered further complicated in light of the European Union's long-term objective of carbon neutrality [6]. Throughout their development, every candidate country opted for a distinct economic profile in accordance with numerous specificities, and for economic activities to proceed, a reliable energy supply at a reasonable cost is always required [7]. If a country is acceding to the European Union, it should first conduct an exhaustive assessment of its current status concerning basic development indicators as well as interconnections between its economy, energy, and environmental protection, with the aim of reorienting itself toward the gradual elimination of environmentally unacceptable technologies, adapting activities in terms of reduced use of energy sources, and introducing new activities that are carbon-neutral [8]. The aforementioned puts both member states and candidate countries in the position of having to implement substantial changes that will inevitably affect economic activity and the quality of life of their citizens, which imposes the need for meticulous planning [9].

The outbreak of the COVID-19 pandemic (March 2019) precipitated a major global economic crisis, and with the emergence of the crisis in Ukraine (2022), the implementation of activities to achieve carbon neutrality became even more complex because of the resulting changes in geopolitical relations, interruptions of existing economic relations, disruptions in logistics and supply chains [10], as well as inflation and price increases. Disagreements among the great powers on the issue of de-escalating global tensions and the conflict on the territory of Israel (October 2023) further increase general insecurity.

Notwithstanding the aforementioned challenges, the European Union maintains, with the requisite modifications, its course toward the Green Deal, sustainable development, and decarbonization by 2050 [11]. The European Union's response to the COVID-19 pandemic was the EU Recovery Plan, which defined priorities for further development and financing methods [12], according to which the carbon neutrality, circular economy, the position of young people, and the application of digital technologies became one of the main priorities. On the other hand, the conflict in Ukraine is still ongoing. The European Union is implementing specific measures that are urgently needed but still has no clearly defined post-conflict strategy or development mechanisms. Moreover, the planned activities on decarbonization and achievement of full carbon neutrality by 2050 may be jeopardized, and the deadlines may change [13]. Carbon neutrality and energy security emerged as the most significant long-term challenge for the European Union in the aftermath of the crisis in Ukraine; as a result, it has become a priority to save as much energy as possible and utilize it efficiently while implementing climate, carbon and energy policies that are suitable for the new circumstances [14].

In their pursuit of a green energy transition, the Western Balkan countries face numerous problems [15] unique to their circumstances. The countries of the region have opted for membership in the European Union, but due to the varying stages of negotiations and the absence of a clearly defined timeline, they are unable to forecast when they can expect to attain full membership status, which is further complicated by the differing positions of individual members of the European Union on this matter [16]. The experience obtained after numerous Eastern European countries joined the European Union in a short period of time makes accession more challenging [17]. Nevertheless, all the countries of the Balkan region have accepted the Green Agenda for the Western Balkans, which prioritizes carbon neutrality and the circular economy, whereby energy efficiency and efficient consumption of resources are given the utmost priority.

The aforementioned is primarily due to the fact that energy efficiency of the Balkan countries is generally unfavorable [18]. Coal has powered economic growth for decades, but the technologies were energy-intensive and created emissions of carbon dioxide and other pollutants. On the other hand, they facilitated economic development, job creation, and the implementation of all other activities necessary for the functioning of the state and the quality of life of its citizens. The region is rich in coal reserves, natural gas reserves are insignificant, and crude oil reserves are symbolic in nature. The largest amount of electricity (about 60%) is obtained from coal exploitation, and the remaining 40% is from the operation of large hydroelectric power plants [19]. The price of electricity is a social category. Natural gas and crude oil are imported through an infrastructure that has existed for decades, and the degree of environmental pollution, mainly caused by the operation of thermal power plants and traffic, is high and often at a hazardous level [20]. For the reasons mentioned above, changes in the fields of economy, energy, and environmental protection are highly complex and demanding when it comes to the process of joining the European Union, and consideration of the social aspect further complicates the entire process. The European Union-established imperative deadline of 2050 for carbon neutrality also becomes a prerequisite for candidate countries, which are obligated to implement intricate activities and timely define the trajectory towards carbon neutrality over the subsequent decades. Given the complexity of shifting towards a carbon-neutral economy and the wide-ranging ramifications across domains, it is necessary to carefully analyze the current situation and adopt adequate policies and control mechanisms to facilitate efficient governance towards carbon neutrality [21].

Achieving carbon neutrality necessitates transforming the conventional, linear economic model, i.e., substituting it with a circular economy that employs carbon-neutral economic activities. This requires, first and foremost, an analysis of the initial state of countries that are in the early stages of transitioning to carbon neutrality. Using this approach makes it feasible to provide the necessary input parameters for the subsequent definition of a methodology that could assess their existing, i.e., initial capability for circularity [22]. In the case of this study, and in accordance with historical data, the emphasis is on evaluating the level of energy efficiency as a crucial and highly intricate factor that will largely determine the policies and actions that need to be implemented to achieve carbon neutrality by 2050 for all countries in the region.

Methods

The methods were chosen in accordance with the research objective. The study examines an actual problem for which no precise and well-defined mathematical model currently exists (nor is it ever expected to be defined). Therefore, the evaluation of the results requires reasoning, approximate reasoning, and data-based learning to be applied [23, 24]. The linear regression statistical method was applied, and the ANOVA test was performed to assess accuracy.

The linear regression statistical method was applied for analyzing behavior and comparing selected indicators for individual countries over a 30-year period. Initially, an extensive analysis of the behavior of each indicator was conducted on a country-by-country basis. The objective of this analysis is to uncover global (i.e., regional) trends in indicator behavior over a 30-year period. During that timeframe, the majority of the countries under observation experienced substantial instability and underwent profound social and economic transformations. Most of these countries are currently undergoing a transition, and their interdependence in terms of energy security and efficiency remains strong. Therefore, it is not feasible to study them in isolation. With regard to the aforementioned, the authors realize that the covered period remains applicable for decision-making and predicting future developments in the energy efficiency sector for the surveyed countries. The data analysis of six selected indicators demonstrated distinct behavioral patterns that are representative of the region. Countries that have exhibited a *similar* pattern of changes in specific indicators in the past are anticipated to continue experiencing the same trends in the near future [25]. The objective of examining the behavior of indicators on a country level is to acquire pertinent data that will be used for modeling decision support systems founded on fuzzy logic. In order to accomplish this objective, the application ESecFuzzy [26] will be employed. This application enables domain experts to create a model for evaluating the energy efficiency of specific countries based on data gathered from the analysis of various indicators.

In addition to the above, a multiple regression analysis was performed for each country separately in order to analyze trends and reveal possible correlations between individual indicators. The analysis results presented in the following chapters are intended to form an appropriate network model of probabilistic connections between six selected indicators in seven selected countries, representing an approximate system of regional energy efficiency [27]. In order to accomplish this objective, the software tool MSBNx, which facilitates inference modeling based on Bayesian Networks, will be utilized. Previous experiences [28, 29], and [30] provide strong evidence supporting the rationale for using this approach. This model would facilitate the demonstration of the behavior of the whole system of indicators in conjunction with energy efficiency, illustrating how alterations in specific indicators lead to instability in other indicators, ultimately resulting in energy efficiency change.

The ANOVA test was employed to evaluate the significance of the comprehensive data model consisting of six selected indicators for the observed country. Given that the time series of data were used over a respectable time interval (30 years), the ANOVA test coefficients, the *Sum of Square* ratio of Residual to Total, and the *Significance F* values were selected as appropriate for assessing the accuracy of the data model [31]. In other words, the ANOVA test was employed to assess the accuracy of the data model, and it yielded supplementary information essential for modeling the behavior of the System with the six selected indicators. This allowed for the evaluation of reciprocal influences between indicators and their impact on energy efficiency as a (hypothetical) resulting variable at the level of each observed state. By improving the data models, the ANOVA test indirectly enabled more precise modeling of the System based on the distribution of conditional probabilities implemented as a Bayesian network [32]. In this way, the ANOVA test can be presented as part of Bayesian statistics [33].

The research was conducted on a sample comprising seven countries that form a historical, geographical and largely infrastructural entity: Slovenia, Croatia, Bosnia and Herzegovina, the Republic of Serbia, North Macedonia, Albania and Greece. The countries were selected based on their inclusion within the geographical unit. Moreover, due to the interconnected past of the Western Balkan countries, most of them often collaborate on infrastructure projects, and two of them often co-manage energy facilities. Furthermore, it has been prudent to examine whether there are notable disparities in energy efficiency among the countries that have been part of the European Union at different time intervals and the criteria on which these discrepancies are based.

The sample can be separated into two groups based on specific conditions. The first group comprises the non-EU countries in the Western Balkans (Bosnia and Herzegovina, the Republic of Serbia, Montenegro, Albania and North Macedonia), characterized by a shared reliance on coal consumption, which leads to pollution and elevated energy intensity [34]. The second group comprises EU Member States (Slovenia, Croatia, and Greece), which are basically characterized by lower coal consumption, less pollution, and significant incentives for the intensive use of energy from renewable sources [6]. Slovenia is the country that records the most favorable carbon neutrality progress indicators, and it therefore serves as a comparative example in a certain sense.

The selection of indicators invariably poses a certain degree of difficulty. There are a large number of indicators that can be used to assess any phenomenon, including energy efficiency. It is important to consider that the number of indicators used should be neither small nor large. A small number of indicators cannot adequately describe the system under observation; conversely, an excessive number of indicators may result in overfitting or a diminished capacity to detect the pattern. Furthermore, it is important to note that the relevance of energy efficiency indicators varies across countries and that the indicators depend mostly on the availability of energy resources, historical circumstances, determination, and actual prospects for achieving a carbon-neutral future. The indicators used in this research are as follows:

a) GDP pc PPP (which was chosen as the main indicator of economic growth);
b) Net energy imports (which illustrate the extent of energy imports for a specific country, while all countries included in the analysis exhibit a significant reliance on energy imports, resulting in the growth of foreign debt) [35];
c) Production of energy from renewable energy sources (which can be interpreted as a measure of a specific country's preparedness to invest in the green transition, especially in decarbonization) [2];
d) Carbon emission (which represents a general indicator of pollution that has the greatest impact on climate change);
e) Energy intensity (which represents an indicator of energy consumption per unit of GDP, with a very unfavorable historical trend for the countries of the Western Balkans) [36]; and
f) Production of energy from coal (the Western Balkan countries mostly derive their energy from coal combustion, resulting in significant pollution that frequently surpasses harmful levels and extends beyond the geographical boundaries of the area under observation) [37].

It is possible to apply another set of indicators, but the ones provided can be deemed adequate, taking into consideration the particularities of the countries incorporated in the research sample.

Results

The countries in the observed sample have certain similarities but also specificities in terms of energy raw materials, degree of utilization, import of energy sources, energy efficiency, economic development, and numerous other indicators.

Slovenia is a member of the European Union, with a population of 2.1 million inhabitants. The majority of energy requirements are met through oil and nuclear energy, with the remainder comprising natural gas and coal. All energy sources are imported, except for the electricity that is obtained from the operation of the Krško nuclear power plant, which is jointly owned with neighboring Croatia. Slovenia has adopted and implemented all policies of the European Union concerning the green transition; it notes the improvement of energy efficiency in building design and construction [38], whereby the owners of small and medium-sized enterprises are very mindful about energy efficiency [39]. Slovenia has negligible pollution levels and, compared to the other countries in the sample, can be regarded as the country with the most exemplary performance in terms of environmental protection [40].

Croatia, with a population of 3.9 million, is a member of the European Union. The primary sector of its economy is tourism, closely followed by agriculture. With over 75% of its energy requirements being fulfilled by oil and natural gas, Croatia exhibits a significant dependence on energy and is particularly susceptible to disruptions in supply and changes in energy prices. Consequently, this situation adversely affects energy efficiency and economic competitiveness. The most significant progress, as in the case of Slovenia, is recorded in the sector of improving energy efficiency in building design and construction [41] and in the sector of small and medium-sized enterprises [42]. Approximately 10% of Croatia's energy is derived from its own renewable sources, specifically biofuels and waste. However, the lack of adequate watercourses prevents major electricity generation from hydropower [43].

Greece, the sample country that has been a member of the European Union for the longest time, exhibits significant coal consumption, accounting for almost 30% of its energy consumption. Moreover, Greece places considerable emphasis on the green transition, primarily focusing on achieving fairness and advantages for its population of 10.58 million individuals. About 60% of its energy is obtained from the import of oil and natural gas, The production of energy from renewable sources in Greece has made progress, although it has not fully utilized the country's natural potential, particularly in terms of solar energy. The pollution levels in the major cities of Greece are substantial, mainly due to the heavy traffic congestion [44]. The repercussions of the 2008 economic crisis continue to impact this country, impeding the pace of transformations in the energy industry, primarily because the liberalization of the electricity market is incomplete and prices are low (which slows the transition to more energy from renewable sources), which is why the Greek economy is not competitive enough [45].

Bosnia and Herzegovina, a country with a population of 3.27 million, faces significant pollution due to its reliance on coal-fired thermal power plants for 80% of its electricity generation. Oil is imported, and natural gas is available in very small quantities. The history of this country, which went through war in the 1990s, has profoundly impacted its economy and energy sector. In addition to underdeveloped institutions and a complex organizational structure, these factors pose significant challenges to achieving a green transition [46]. Notable advancements have been observed in the domain of building design and construction [47]. However, these advancements mostly have a notable impact on reducing individual expenses rather than making a substantial contribution to total energy efficiency. Hydropower is considered the most promising avenue for enhancing energy efficiency in Bosnia and Herzegovina, with wood biomass residuals as a secondary option. A comprehensive analysis conducted in 2022 indicates that while renewable energy production is potentially feasible [48], it remains too expensive for the country at present and in the foreseeable future, whereby the country is developing opportunities to attract foreign investors [49]. Due to the sudden escalation in the energy security risk on the European continent, Greece is confronted with new geopolitical issues because of its geographical position as the connecting point between Europe and Asia [50].

The economy of the Republic of Serbia, with a population of 6.91 million, relies on resource exploitation and agriculture. Coal accounts for about 60% of electricity production, with hydropower plants producing the remaining 40%. The entirety of oil and natural gas is imported, while energy production from renewable sources is merely symbolic. Due to the extensive use of coal, the Republic of Serbia faces much pollution. The lack of adequate regulation in the financial sector and banking system further exacerbates the position of all economic sectors, hindering the beginning of the transition to carbon neutrality [51]. There is potential for the production of energy from renewable sources. However, the lack of transparency regarding the criteria for issuing permits and the protests of citizens against the construction of small hydropower plants have led to a standstill in this domain [52]. The reliance on outdated and unreliable technologies also slows down the energy transition. Nevertheless, studies indicate a potential for enhancing energy efficiency and emphasize the importance of implementing improved strategies and making more effective decisions [53].

North Macedonia is a country with modest economic indicators. Its 2.08 million inhabitants mostly rely on the metal industry for their livelihood. Additionally, 80% of the country's energy is generated by its coal reserves. All oil and natural gas volumes are imported. The pollution level is elevated, energy generation from renewable sources is moderate, and the regulatory framework in this domain is insufficiently developed [54]. Few studies demonstrate the feasibility of enhancing the energy sector. However, it requires the shutdown of thermal power plants, leading to the country's high dependence on imported electricity, which is a scenario that North Macedonia deems unsustainable [55].

Albania has made significant progress in the domain of sustainable energy development. In the recent past, a total of 2.81 million inhabitants in this country encountered frequent power outages, which caused significant losses and impaired the quality of life. Albania relies solely on its own hydroelectric plants to meet electrical demands. Thermal power plants have not been built in this country, and coal is used exclusively for individual furnaces. The predominant component of the energy composition is oil, which is entirely sourced from imports, while natural gas is utilized in minimal quantities. Electricity prices are covered mainly by state subsidies for citizens and small businesses. In 2022, Albania initiated the necessary administrative procedures to commence the development of the first large-scale solar power facility [56]. However, considering the low price of electricity and bilateral cooperation regarding temporary electricity import and export, along with the social status of citizens, it is not realistic to anticipate substantial shifts towards the extensive use of solar energy, as it involves higher expenses [57].

Value trend by energy efficiency indicators

GDP pc PPP

In the period 1990–2008, all countries under observation reported a positive increase in the *GDP pc PPP*. Since 2008, Greece has reported the biggest decline in this indicator. After one year, Slovenia and Croatia achieved consolidation, whereas the remaining countries experienced modest yet generally positive growth that stalled in 2009. In terms of GDP pc, Slovenia surpassed Greece in 2010, and Croatia drew level with Greece in 2019. The negative trend was repeated in 2020. At that time, similar effects were reported by Greece, Croatia, and Slovenia. The remaining countries recorded stagnation in 2020, as shown in Fig. 1.

Net energy imports

Upon examining the standard deviation of the *Net energy imports* of individual countries, it is observed that this indicator significantly varies in the case of Albania (~ 19), followed by Bosnia and Herzegovina (~ 10). Slovenia and Greece have the smallest variations. Albania recorded a substantial increase in energy imports in the period 1997–2001; subsequently, the figure remained stagnant and has declined since 2009. The sudden growth of this indicator in Bosnia and Herzegovina in 1994 and in the Republic of Serbia in 1996 is interesting. Furthermore, over the past five years, the value of this indicator has

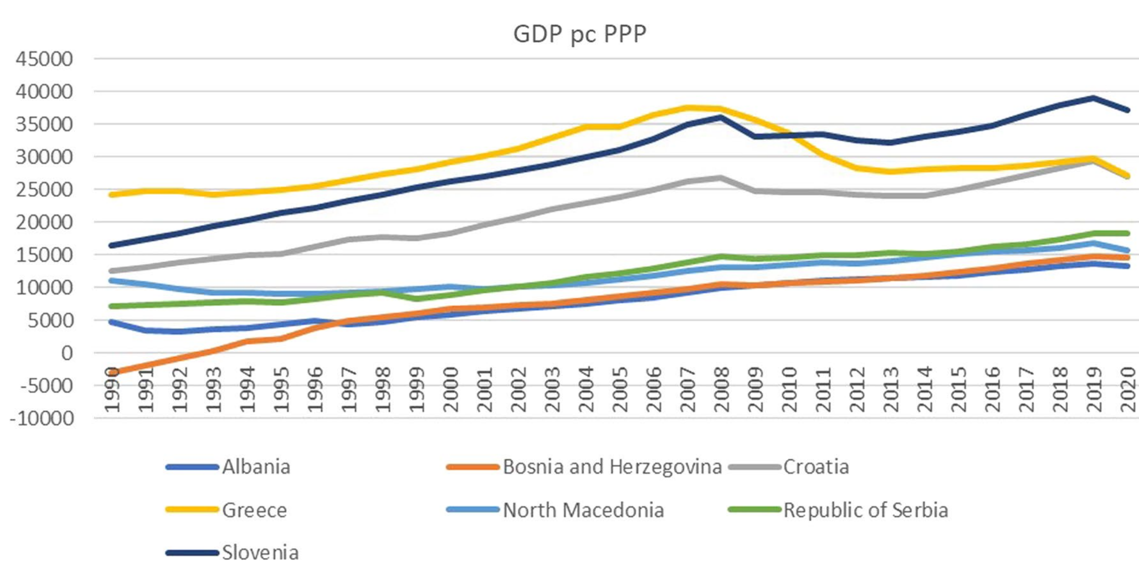

Fig. 1 *GDP pc PPP* values for the Western Balkan countries, Greece, and Slovenia (1990–2020)

increased in North Macedonia and Greece, remained stagnant in Slovenia, and decreased in other countries (Fig. 2).

Production of energy from renewable sources

As shown in Fig. 3, Albania and Bosnia and Herzegovina have similar trends in terms of the *Production of energy from renewable sources*: a sudden increase in the first five years, followed by a permanent decline. Other countries have a slightly positive trend in this regard.

Carbon emission

The *Carbon emission* trends in Albania and Bosnia and Herzegovina follow the trends in the *Production of energy from renewable sources* in these two countries in the period 1990–2004. In the period 2005–2020, all countries reported an increase in this indicator, as shown in Fig. 4.

Energy intensity

With the exception of Bosnia and Herzegovina, the *Energy intensity* in all other countries has a similar downward trend, as shown in Fig. 5.

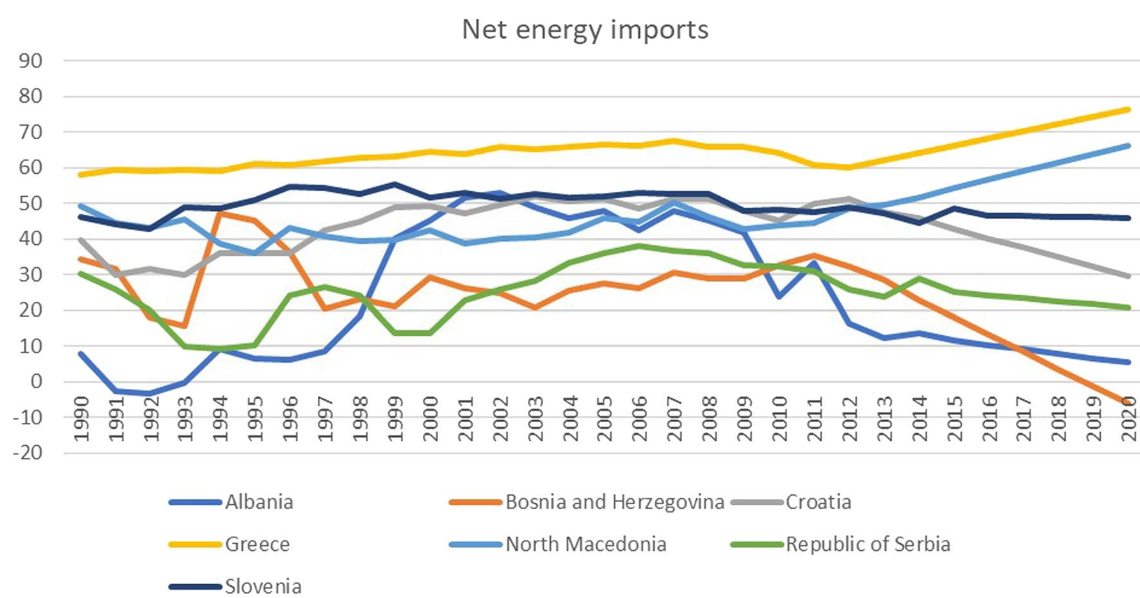

Fig. 2 *Net energy imports* values for the Western Balkan countries, Greece, and Slovenia (1990–2020)

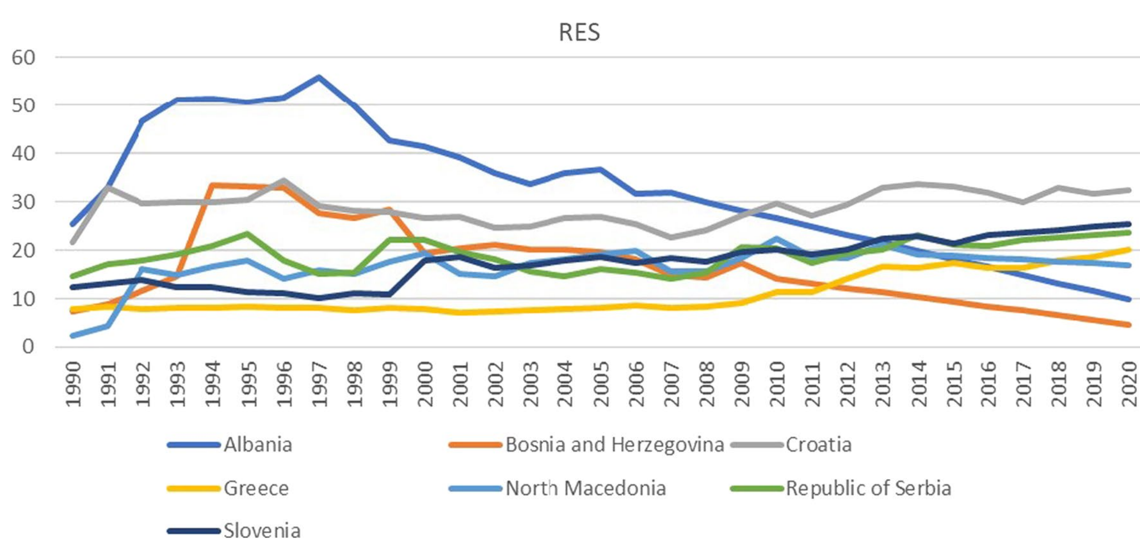

Fig. 3 *Production of energy from renewable sources* values for the Western Balkan countries, Greece, and Slovenia (1990–2020)

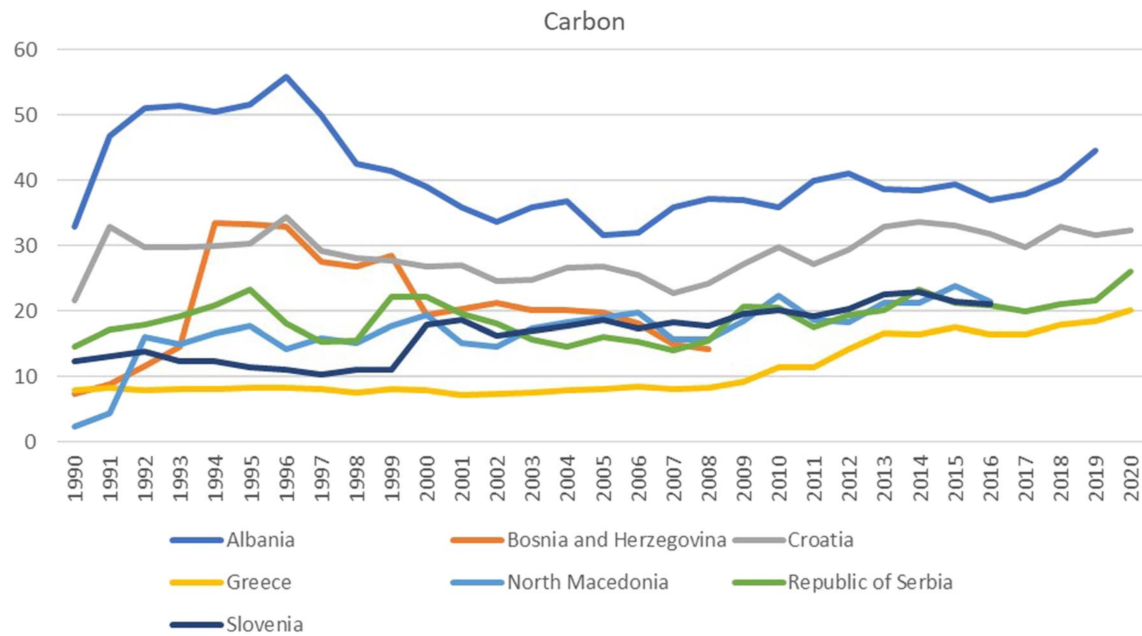

Fig. 4 *Carbon emission* values for the Western Balkan countries, Greece, and Slovenia (1990–2020)

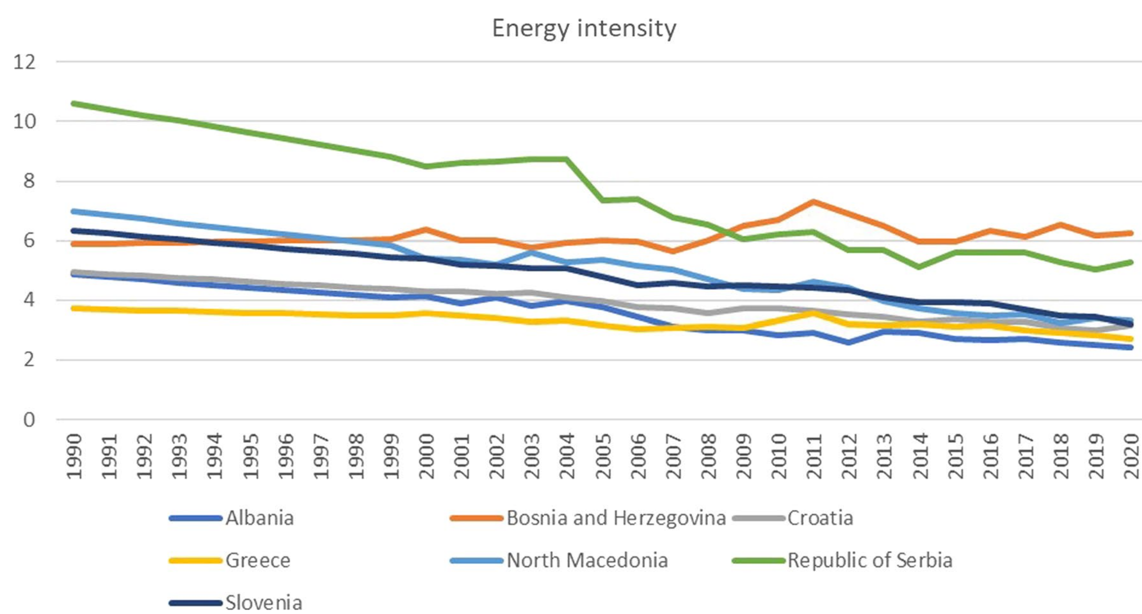

Fig. 5 *Energy intensity* values for the Western Balkan countries, Greece, and Slovenia (1990–2020)

Production of energy from coal

With the exception of Albania, which does not use coal, the trends of this indicator fluctuated in 2015; since then, they have stabilized and recorded stagnation, with a slight increase in the case of Croatia, the Republic of Serbia, and Bosnia and Herzegovina and an equally slight decrease in the case of North Macedonia, Greece, and Slovenia (Fig. 6).

Regression analysis and ANOVA test

To compare the behavior of observed indicators for individual countries, their data are normalized within the range $[-x, +x]$, where the value of x represents the data derived from the statistical *mean* and *standard deviation* values of the sample, indicating the variability of the sample (i.e., how far apart are standard deviations by year from the mean value of the observed sample).

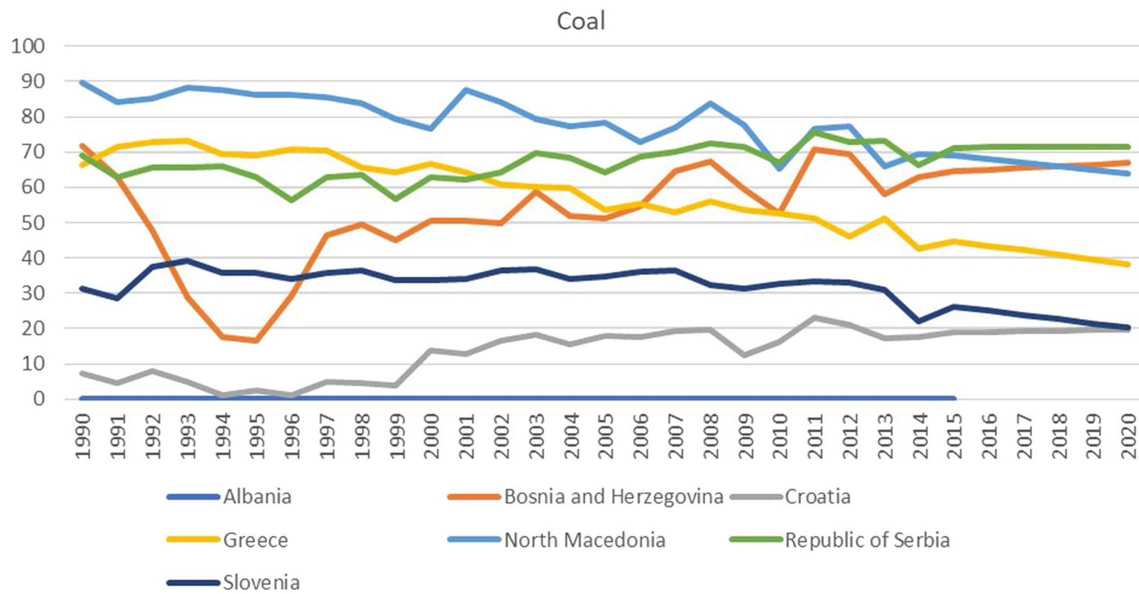

Fig. 6 *Production of energy from coal* values for the Western Balkan countries, Greece, and Slovenia (1990–2020)

Albania

Albania lacks data pertaining to the *Production of energy from coal* indicator due to its complete abstinence from coal utilization. Certain indicators have characteristic trends: on the one hand, there is a permanent increase in the *GDP pc PPP*, and on the other hand, there is an expected permanent decline in the *Energy intensity*. The permanent decline in the *Production of energy from renewable sources* after 1997 was unexpected. Since 1997, the *Carbon emission* has recorded a permanent increase with minor variations in the last ten years. The permanent increase in the *Net energy imports* lasts until 2002 and subsequently declines (with slight variations in 2007 and 2011) until the end of the observed period. The indicators of the *Net energy imports*, the *Energy intensity*, and the *Production of energy from renewable sources* have exhibited a stabilization in their negative trends since 2013. The complete data for this part of the analysis are shown in Fig. 7.

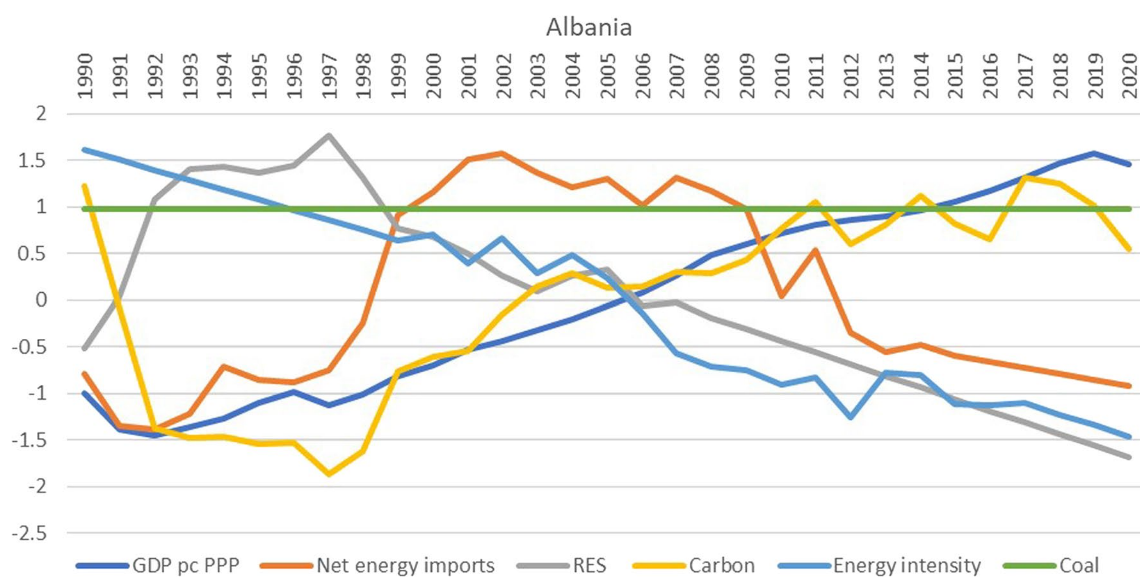

Fig. 7 Values of selected energy efficiency indicators for Albania (1990–2020)

Based on the regression analysis for the *Production of energy from renewable sources* and the *Carbon emission* trends, it can be concluded that they are correlated considering the values of *Multiple R* (> 0.93) and *R Square* (> 0.87), as well as the ANOVA *Sum of Square* good ratio of *Residual* to *Total* (~ 3.6/30) and the *Significance F* values (< < 0.05). The negative coefficient of the regression analysis (-0.93663) indicates a negative correlation between the *Production of energy from renewable sources* and the *Carbon emission* (Table 1).

In addition, the *Energy intensity* and the *GDP pc PPP pc* indicators are also negatively correlated (*GDPpc coefficient* < *0*) considering the values of *Multiple R* (> 0.97) and *R Square* (> 0.95), as well as the ANOVA *Sum of Square* good ratio of *Residual* to *Total* (~ 1.3/30) and the *Significance F* values (< < 0.05), as shown in Table 2.

Regardless of the similarity in general trends (described above), for the other indicators, the analysis of the regression parameters does not suggest a correlation between them.

Bosnia and Herzegovina

A permanent slight increase in *GDP pc* has been observed. The *Production of energy from coal* and the *Carbon emission* indicators have similar trends in the entire observed period. There was a sharp increase in the *Energy intensity* in the period 2007–2011, followed by a subsequent decrease until 2014. In the period 1993–2000,

Table 1 Regression and ANOVA analyses: production of energy from renewable sources and carbon emission for Albania

Regression statistics					
Multiple R					0.93663
R square					0.877277
Standard error					0.356308
ANOVA					
	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	26.3183	26.3183	207.3037	9.61E-15
Residual	29	3.681703	0.126955		
Total	30	30			
					Coefficients
Intercept					9.51E-16
Carbon					− 0.93663

Table 2 Regression and ANOVA analyses: *energy intensity* and *GDP pc PPP* for Albania

Regression statistics					
Multiple R					0.978069
R square					0.95662
Adjusted R square					0.955124
Standard error					0.21184
Observations					31
ANOVA					
	df	***SS***	***MS***	***F***	***Significance F***
Regression	1	28.69859	28.69859	639.5047	2.61E-21
Residual	29	1.301412	0.044876		
Total	30	30			
					Coefficients
Intercept					− 5.5E-16
GDPpc					− 0.97807

the *Production of energy from renewable sources* and the *Net energy imports* reported similar trends (Fig. 8).

Based on the regression analysis for the *Production of energy from renewable sources* and the *Carbon emission* trends, it can be concluded that they are correlated considering the values of *Multiple R* (> 0.92) and *R Square* (> 0.85), as well as the ANOVA *Sum of Square* good ratio of *Residual* to *Total* (~ 4/30) and the *Significance F* values (< < 0.05), as shown in Table 3.

Regardless of the similarity in general trends (described above), for the other indicators, the analysis of the regression parameters does not suggest a correlation between them.

Croatia

The GDP pc PPP reported a decrease in 2008–2014, as well as in 2020. The *Energy intensity* reported a negative trend for almost the entire observation period. The behavior of the *Production of energy from coal* and the *Net energy imports* indicators was similar until 2014, as shown in Fig. 9.

Regression analysis (Table 4) shows the correlation between the *Energy intensity* and the *GDP pc PPP* indicators considering the values of *Multiple R* (~ 0.97) and *R Square* (> 0.91), as well as the ANOVA *Sum of Square* good ratio of *Residual* to *Total* (~ 2.5 /30) and the *Significance F* values (< < 0.05).

The *GDP pc PPP* regression coefficient shows a negative correlation (*-0.95723*). Regardless of the similarity in general trends (described above), for the other indicators, the analysis of the regression parameters does not suggest a correlation between them.

Greece

The *GDP pc PPP* indicator was increasing until 2008; after that, it showed a negative trend. Since 2008, the

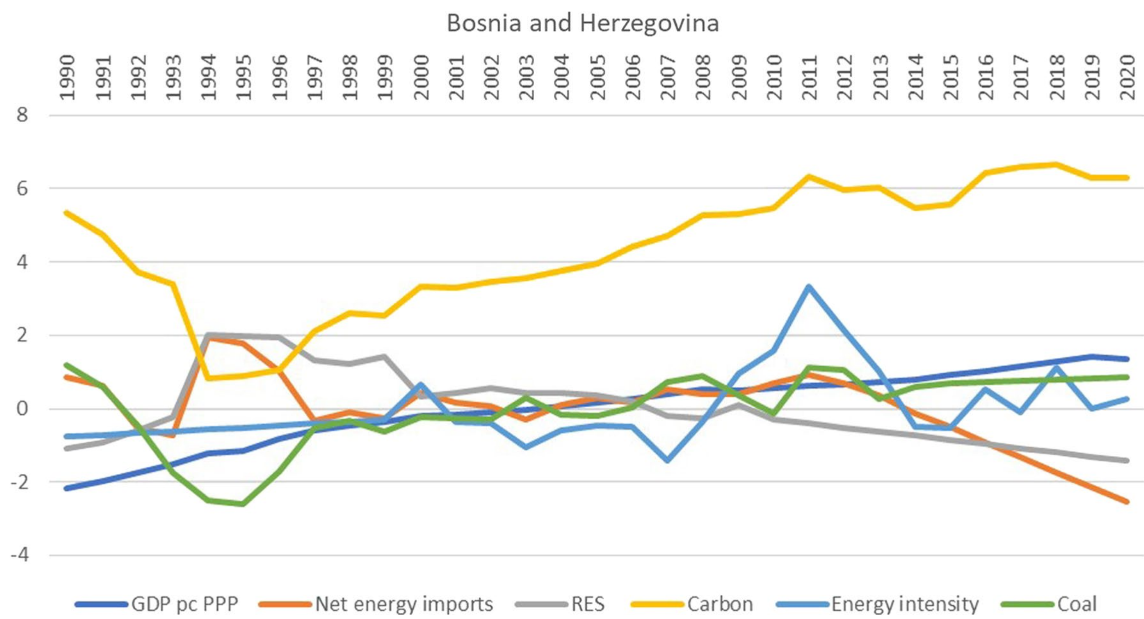

Fig. 8 Values of selected energy efficiency indicators for Bosnia and Herzegovina (1990–2020)

Table 3 Regression and ANOVA analyses: *production of energy from renewable sources* and *carbon emission* for Bosnia and Herzegovina

Regression statistics					
Multiple R					0.927253
R square					0.859799
ANOVA					
	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	25.79397	25.79397	177.8459	6.69E-14
Residual	29	4.206029	0.145035		
Total	30	30			

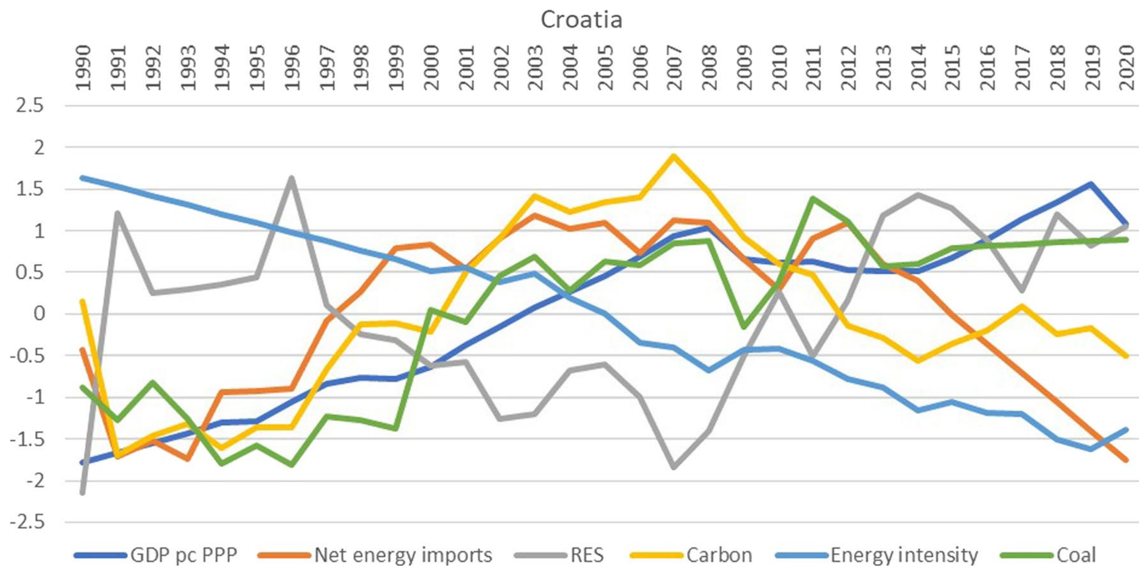

Fig. 9 Values of selected energy efficiency indicators for Croatia (1990–2020)

Table 4 Regression and ANOVA analyses: energy intensity and GDP pc PPP for Bosnia and Herzegovina

Regression statistics					
Multiple R					0.957233
R square					0.916295
Standard error					0.294264
ANOVA					
	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	27.48885	27.48885	317.4541	3.67E-17
Residual	29	2.511155	0.086592		
Total	30	30			
	Coefficients	**Standard error**	**t Stat**	**P-value**	**Lower 95%**
Intercept	− 1.3E-15	0.052851	− 2.5E-14	1	− 0.10809
GDPpc	− 0.95723	0.053725	− 17.8172	3.67E-17	− 1.06711

Carbon emission has been steadily decreasing. The *Production of energy from coal* and the *Energy intensity* indicators had a decreasing trend throughout the observed period, with the *Energy intensity* deviating from this trend in 2011. The *Net energy imports* have had a constant, sharp growth since 2013. The complete data are shown in Fig. 10.

Each of the indicators exhibits a distinct behavior throughout the observed period. Certain indicators exhibit comparable trends, albeit only until 2012. For example, the *Net energy imports* and the *Carbon emission* up to and including 2012 were in direct correlation considering the values of *Multiple R* (~ 0.94) and *R Square* (> 0.88), as well as the ANOVA *Sum of Square* good ratio of *Residual* to *Total* (~ 0.9/8) and the *Significance F* values (< < 0.05), with details of the analysis in Table 5.

Since 2013, the *Net energy imports* and the *Carbon emission* have had reverse trends, but based on the results of the regression analysis, they are no longer correlated. The regression analysis results of other indicators indicate no correlations between them.

North Macedonia

There is a permanent decreasing trend in the *Energy intensity* indicator. After the decline in 1990, followed by stagnation, the *GDP pc PPP* reported a slightly increasing trend from 1997 until 2019. The *Production of energy from renewable sources* and the *Carbon emission*

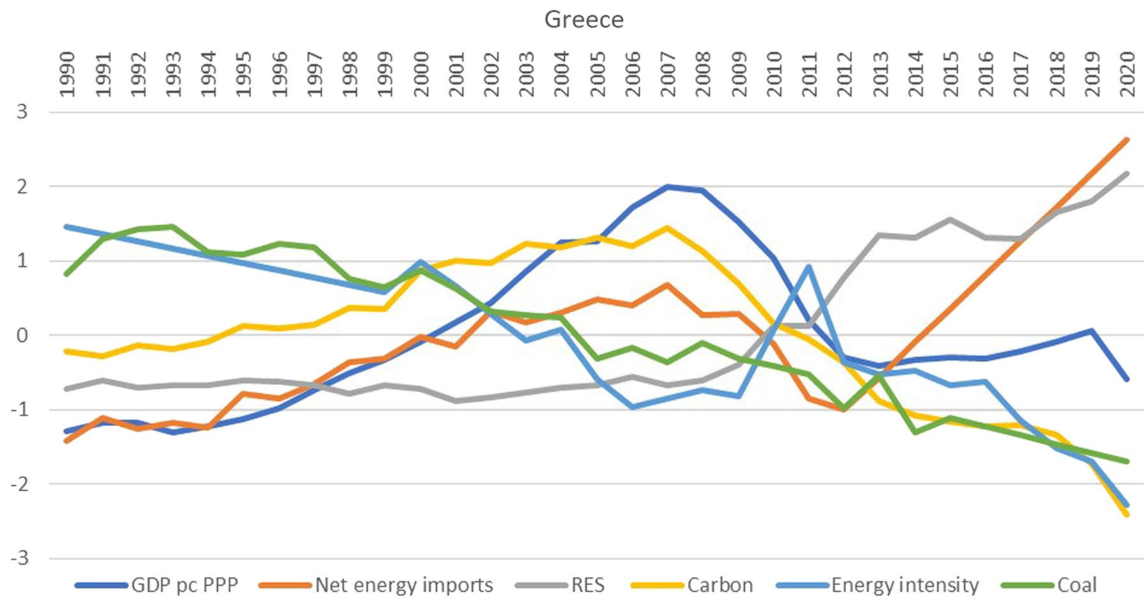

Fig. 10 Values of selected energy efficiency indicators for Greece (1990–2020)

Table 5 Regression and ANOVA analyses: net energy imports and carbon emission for Greece

Regression statistics					
Multiple R					0.940279
R square					0.884124
Standard error					0.210459
Observations					23
ANOVA					
	df	***SS***	***MS***	***F***	***Significance F***
Regression	1	7.096957	7.096957	160.2277	2.7E-11
Residual	21	0.930152	0.044293		
Total	22	8.027109			
Coefficients					
Intercept					0.787711
Net energy imports					0.856928

indicators have very variable trends. The *Production of energy from coal* is on a permanent decline, with significant variations in the period 2000–2013, as shown in Fig. 11.

The *GDP pc PPP* and the *Energy intensity* indicators are strongly correlated considering the values of *Multiple R* (> 0.92) and *R Square* (> 0.85), as well as the ANOVA *Sum of Square* good ratio of *Residual* to *Total* (~ 4.4/30) and the *Significance F* values (< < 0.05). The *Energy intensity* coefficient (*0.92313*) indicates that these two indicators are positively correlated, with a detailed analysis shown in Table 6.

The *Net energy imports* and the *Energy intensity* have similar trends, but the results of the regression analysis (Table 7) show that they are weakly correlated considering the values of *Multiple R* (~ 0.75) and *R Square* (~ 0.56) significantly less than 1, as well as based on the ANOVA *Sum of Square* ratio of *Residual* to *Total* (~ 13.1/30).

Republic of Serbia

The *GDP pc PPP* is permanently increasing, while the *Energy intensity* is permanently decreasing in the observed period. Other indicators vary significantly by year. Since 2013, the changing trends of the indicators

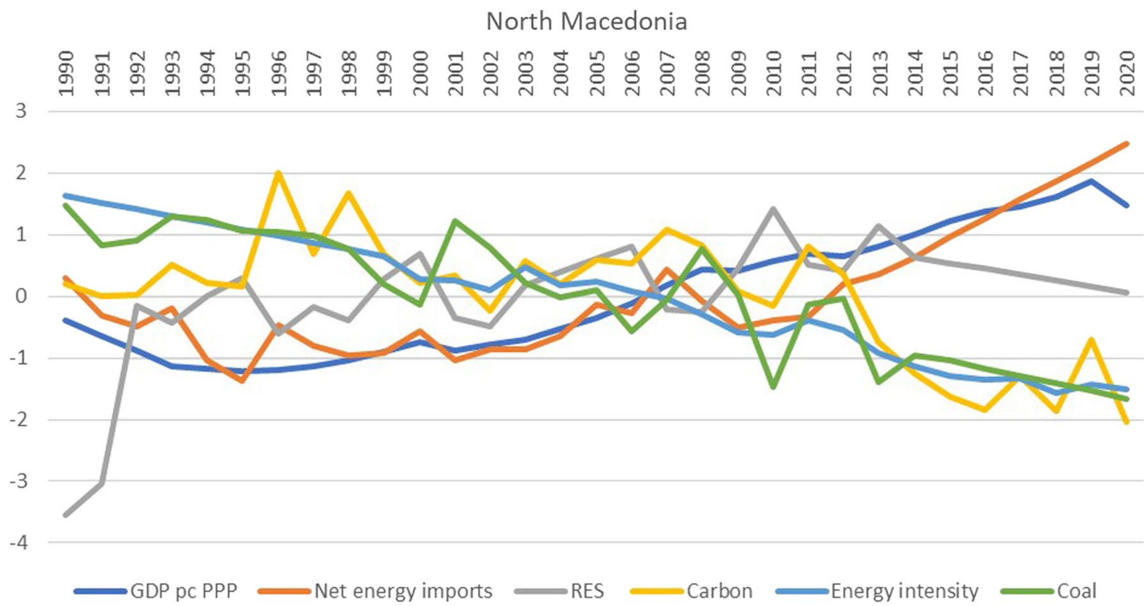

Fig. 11 Values of selected energy efficiency indicators for North Macedonia (1990–2020)

Table 6 Regression and ANOVA analyses: GDP pc PPP and energy intensity for North Macedonia

Regression statistics					
Multiple R					0.923134
R square					0.852177
Standard error					0.391051
ANOVA					
	df	***SS***	***MS***	***F***	***Significance F***
Regression	1	25.5653	25.5653	167.18	1.45E-13
Residual	29	4.434703	0.152921		
Total	30	30			
Coefficients					
Intercept					− 1.4E-15
Energy intensity					− 0.92313

Table 7 Regression and ANOVA analyses: *net energy imports* and *energy intensity* for North Macedonia

Regression statistics					
Multiple R					0.750535
R square					0.563302
Standard error					0.672128
ANOVA					
	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	16.89907	16.89907	37.40747	1.16E-06
Residual	29	13.10093	0.451756		
Total	30	30			

have stabilized: the *Production of energy from renewable sources*, the *Production of energy from coal*, and the *Carbon emission* decreased in 2013, while the *Net energy imports* have followed the *GDP pc PPP* trend of permanent growth since 2010. The trend values of the observed indicators are given in Fig. 12.

The *GDP pc PPP* and the *Energy intensity* indicators are in a very strong correlation considering the values of *Multiple R* (> 0.97) and *R Square* (> 0.94), as well as the ANOVA *Sum of Square* good ratio of *Residual* to *Total* (~ 1.53/30) and the *Significance F* values (<< 0.05). The *Energy intensity* coefficient (*-0.94715*) indicates that these two indicators are negatively correlated (Table 8).

Although there is some doubt about the correlations between the *Carbon emission* and the *Production of energy from renewable sources* indicators, as well as the *Carbon emission* and the *Net energy imports* indicators based on the exploratory analysis, the regression analysis results show a very weak correlation (Table 9). The results in the case of the *Carbon emission* and the *Production of energy from renewable sources* show small values of *Multiple R* (~ 0.70) and *R Square* (~ 0.50), and the ANOVA *Sum of Square* shows a small ratio of *Residual* to *Total* (~ 15.25/30), as presented in Table 9.

The results in the case of the *Carbon emission* and the *Net energy imports* indicators (Table 10) show small

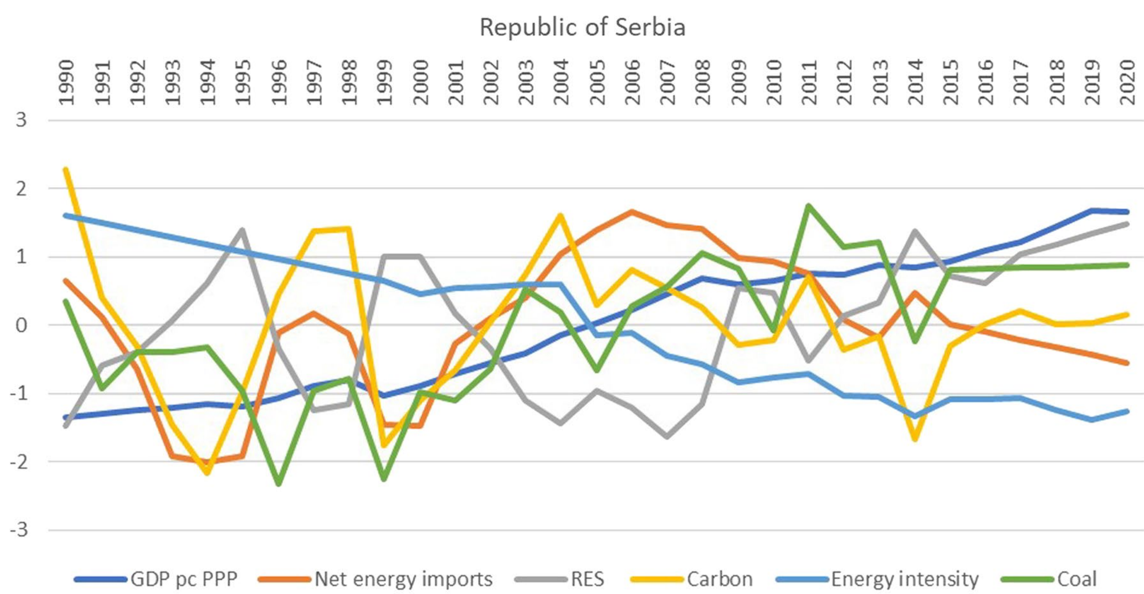

Fig. 12 Values of selected energy efficiency indicators for the Republic of Serbia (1990–2020)

Table 8 Regression and ANOVA analyses: *GDP pc PPP* and *energy intensity* for the Republic of Serbia

Regression statistics					
Multiple R					0.974152
R square					0.948973
Standard error					0.229753
ANOVA					
	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	28.46919	28.46919	539,327	2.76E-20
Residual	29	1.530809	0.052787		
Total	30	30			
Coefficients					
Intercept					4.38E-16
Energy intensity					– 0.97415

Table 9 Regression and ANOVA analyses: carbon emission and production of energy from renewable sources for the Republic of Serbia

Regression statistics					
Multiple R					0.701028
R square					0.49144
Standard error					0.725325
ANOVA					
	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	14.7432	14.7432	28.02376	1.12E-05
Residual	29	15.2568	0.526096		
Total	30	30			

Table 10 Regression and ANOVA analyses: *carbon emission* and *net energy imports* for the Republic of Serbia

Regression statistics					
Multiple R					0.635341
R square					0.403658
Standard error					0.785433
ANOVA					
	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	12.10974	12.10974	19.62981	0.000123
Residual	29	17.89026	0.616906		
Total	30	30			

values of *Multiple R* (~ 0.63) and *R Square* (~ 0.40), and the ANOVA *Sum of Square* shows a small ratio of *Residual* to *Total* (~ 17.9/30).

Slovenia

In the observed period, the *GDP pc PPP* was permanently increasing, while the *Energy intensity* was permanently decreasing, except in the period 2008–2013, when a decline and stagnation of the *GDP pc PPP* were reported. There were significant variations in the trends of other indicators, which were stabilized in the period after 2008. Since then, the *Net energy imports*, the *Energy intensity*, the *Production of energy from coal*, and the *Carbon emission* indicators have been in permanent decline, while the *GDP pc PPP* and the *Production of energy from renewable sources* indicators have been on a permanent increase (Fig. 13).

The *GDP pc PPP* and the *Energy intensity* indicators are in a very strong correlation considering the values of *Multiple R* (> 0.96) and *R Square* (> 0.92), as well as the ANOVA *Sum of Square* good ratio of *Residual* to *Total* (~ 2.21/30) and the *Significance F* values (< < 0.05), as shown in Table 11.

As with most other countries, the Energy intensity coefficient (-0.9623) indicates that these two indicators are negatively correlated.

The trends of other indicators vary significantly by year. Significant similarity in trends exists only in the *Production of energy from coal* and the *Net energy imports* indicators (Table 12), which, based on regression analysis data, are weakly correlated: smaller values of *Multiple R* (~ 0.8) and *R Square* (~ 0.64), as well as the ANOVA *Sum of Square* small ratio of *Residual* to *Total* (~ 1/3).

The *Net energy imports* coefficient (*-0.800862*) indicates that these two indicators are positively correlated.

Regression analysis of the *Production of energy from coal* and the *Production of energy from renewable sources* indicators indicates that they are weakly correlated: small values of *Multiple R* (~ 0.74) and *R Square* (~ 0.55), as well as the ANOVA *Sum of Square* small ratio of *Residual* to *Total* (~ 13.3/30), given in Table 13.

The coefficient obtained for the *Production of energy from coal* (*-0.74544*) indicates that these two indicators are negatively correlated over the entire observed period.

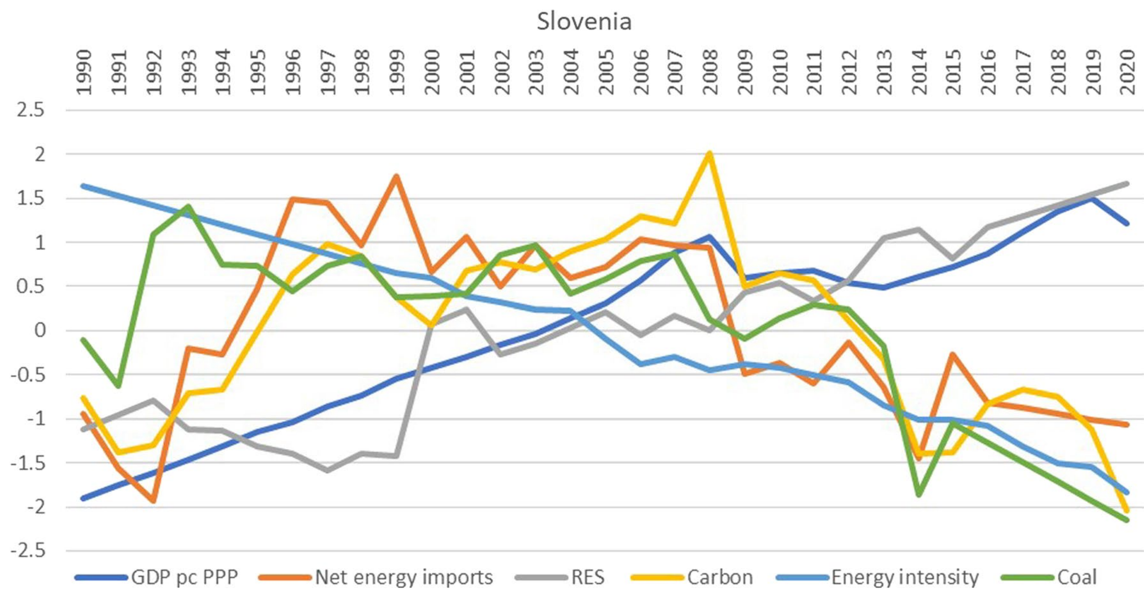

Fig. 13 Values of selected energy efficiency indicators for Slovenia (1990–2020)

Table 11 Regression and ANOVA analyses: *GDP pc PPP* and *energy intensity* for the Republic of Serbia

Regression statistics		
Multiple R		0.962304
R square		0.92603
Standard error		0.276624
ANOVA		
	df	**SS**
Regression	1	27.78089
Residual	29	2.219111
Total	30	30
	Coefficients	**Standard error**
Intercept	3.81E-16	0.049683
Energy intensity	− 0.9623	0.050504

Discussion and recommendations

Analysis of energy efficiency data on a selected group of seven countries over 30 years shows several specificities. The analysis was first performed according to the observed indicators and then according to the countries in the sample.

All sample countries experience continuous economic growth measured by GDP per capita, with the exception of Greece, which experienced a decline following the 2008 financial crisis. The *Net energy imports* indicator significantly varies in all countries except Slovenia, which can be explained by the fact that the economy of Slovenia is not based on energy-intensive technologies and the import of energy products is at a low level. Albania and North Macedonia report the biggest drop in net energy imports. Over the course of three decades, there have been negligible fluctuations in the production of energy from renewable sources. The *Carbon emission* indicator increased during the 1990s, but with the turn of the twenty-first century, the indicator decreased, followed by a gradual increase, without large oscillations. The lowest emissions and the lowest oscillations have been recorded by Greece.

Energy efficiency, measured through indicators of the energy intensity of the economy, has been decreasing over the observed 30 years, but during the entire

Table 12 Regression and ANOVA analyses: production of energy from coal and net energy imports for the Republic of Serbia

Regression statistics		
Multiple R		0.800862
R square		0.64138
Standard error		0.609086
ANOVA		
	df	***SS***
Regression	1	19.2414
Residual	29	10.7586
Total	30	30
	Coefficients	***Standard error***
Intercept	− 7.4E-16	0.109395
Net energy imports	0.800862	0.111203

Table 13 Regression and ANOVA analyses: *production of energy from coal* and *production of energy from renewable sources* for the Republic of Serbia

Regression statistics					
Multiple R					0.745436
R square					0.555674
Standard error					0.677973
ANOVA					
	df	**SS**	**MS**	**F**	**Significance F**
Regression	1	16.67023	16.67023	36.26744	1.5E-06
Residual	29	13.32977	0.459647		
Total	30	30			
Coefficients					
Intercept					− 1.4E-15
Coal					− 0.74544

period, it has been the highest in the Republic of Serbia, and Bosnia and Herzegovina. Greece has recorded the lowest energy consumption per unit of GDP. Notwithstanding the multitude and diversity of phenomena and turbulences that the region has experienced over the past three decades, the production of energy from coal has exhibited neither substantial oscillations nor a significant downward trend, particularly in the Republic of Serbia, North Macedonia, and Bosnia and Herzegovina.

A regression analysis and the ANOVA test were performed for each country in order to analyze the interrelationship of specific indicators. In the case of Albania, the observed indicators do not exhibit a significant degree of correlation, with the exception of the *Energy production from renewable sources* and the *Carbon intensity* indicators, which show a negative correlation. When it comes to the two indicators mentioned, Bosnia and Herzegovina record an inverse correlation, which is positive. Greece records one type of correlation before and after 2012 or 2013. Prior to the aforementioned turning point, the indicators had certain lower correlations, but after this period, the trends changed and the correlations disappeared. North Macedonia records only one important correlation (the *Net energy import* and the *Energy intensity*), but it is also small. In the Republic of Serbia, there is a significant weak correlation between the *Carbon emission* and the *Net energy imports*, i.e., the *Production of energy from renewable sources*. In the case of Slovenia, the analysis showed a significant correlation between the *Production of energy from coal* and the *Net energy imports*.

Following the COVID-19 epidemic, due to armed conflicts and escalating geopolitical tensions worldwide, the Western Balkan region and its neighboring countries have encountered numerous new challenges. Specifically, the post-2022 crisis events have resulted in complex economic, financial, and social issues, with one of the most significant challenges being the disturbances in energy supply. The poor indicators of energy efficiency in the majority of the observed countries may be exacerbated, considering the events occurring on a global scale.

For several decades, the entire region has been importing natural gas and oil from the Russian Federation, which required a suitable infrastructure to be built. Any interruption in the supply of these two energy sources calls into question the functioning of countries and all systems, as well as the welfare of citizens.

The transition to oil supply from other sources is possible because the region has been importing oil from different suppliers until now (although the Russian Federation was dominant in this regard). On the other hand, finding new sources of natural gas supply poses a significant challenge for even the most advanced and prosperous European economies. The aforementioned is quite intricate within the observed region due to several factors. Firstly, the infrastructure for the natural gas supply from the Russian Federation was established. The construction of new gas corridors for supply from other countries is time-consuming and too expensive for the countries in the region. Borrowing on this basis would only further impoverish the countries in the region with already fragile economies.

Secondly, there is the issue of the price of natural gas sourced from alternative locations. An unavoidable surge in natural gas prices would ultimately set off a chain reaction of price increases that would negatively impact not only the economies of the countries involved, but also their citizens. Therefore, the aforementioned factors must undoubtedly be considered when formulating the strategic plan for the green transition of the region. A green transition at too high a price would give rise to problems of a different kind, particularly concerning citizens, given that the majority of the region's inhabitants have had the lowest incomes and purchasing power in Europe for decades. Moreover, it is worth mentioning that natural gas is a scarce resource in high demand (predominantly because of its environmentally friendly quality), so the supply of essential quantities from other regions would be a foreign policy issue rather than only a technical one.

The pollution levels originated for thermal power plants are excessively high, yet the transition to renewable energy sources is too expensive. Although there are facilities in the region for harnessing solar and wind energy to generate electricity, the quantity of energy obtained in this way is negligible and primarily serves the needs of the households that generate it. Equipment installation can be afforded only by the affluent strata of society. On the other hand, coal-generated electricity is inexpensive; cost regulation by the government is a critical imperative in most of the countries in the region, where it is mandatory to maintain prices at a threshold of acceptability among the majority of the population. The social aspect of electricity pricing remains dominant over the market aspect. This can be justified by the need to safeguard citizens against energy poverty, which would likely result in profound and enduring consequences.

The solution lies in enhancing the capacity for energy generation from large hydroelectric power plants (despite the divergent views on their acceptability in terms of sustainable development), and the utilization of nuclear energy may unquestionably be reconsidered. It is highly recommended to enhance efforts in generating energy from waste, as well as in harnessing solar and wind energy. However, all four aforementioned methods of obtaining energy can effectively solve the issue of electricity supply. This is all the less significant due to the small size of the countries in the region and their occasional reliance on electricity imports. Therefore, the change would not be significant in terms of energy security. However, the matter of finding alternative countries to replace the Russian Federation as suppliers of oil and, particularly, natural gas (for transportation and industrial purposes) remains unresolved, and it will pose the biggest challenge for the region in the upcoming decades.

Conclusions

The European Union has made a strategic commitment to implement decarbonization and sustainable development as a continuation of the numerous activities carried out in this region since its inception to improve the quality of the environment. In order to qualify for membership in the European Union, each country must satisfy particular criteria across various domains. In the context of energy policy and ecology, candidate countries are obligated to make the necessary progress and accomplish the established objectives within designated timeframes. Once the country accedes to the European Union, specific indicators in this domain are subject to continuous surveillance by the monitoring system. With the adoption of the Green Deal in 2018 and the decision to decarbonize Europe by 2050, the European Union has unequivocally demonstrated its commitment. Therefore, to achieve the stated objective, significant changes are expected across all domains.

Challenges in the implementation of the decarbonization strategy are to be expected due to the significant upheavals in the global economy, finance, geopolitics, energy security, and supply chains that ensued in the wake of the COVID-19 pandemic and the subsequent

Ukrainian crisis. Nevertheless, the European Union endeavors to stay the defined course and requests that member states and candidate countries adjust to that course. In the case of the last remaining area of Europe that is not a member of the European Union (the Western Balkans), there are several issues in the sectors of energy and environmental protection, as well as in implementing the Green Agenda for the Western Balkans in general. The priorities are clearly outlined in the mentioned documents. Therefore, the Western Balkan countries face the challenge of formulating strategies and policies that facilitate the requisite changes and the attainment of objectives, including those that are novel and essential as a prerequisite for full membership in the European Union.

The Western Balkan countries recognize the circular economy as one of the most important priorities of the Hare Agenda, but their capacity to implement this concept remains uncertain or inadequately understood. Therefore, this study presents an analysis of energy efficiency as an important driver and determinant of the circular economy. An analysis of seven selected indicators yielded data on trends and correlations over the last ten years. For comparison, indicators pertaining to Greece and Slovenia (which are members of the European Union) were used, as these countries share commonalities with the Western Balkan countries in terms of geography, history, and infrastructure.

The main findings of the data analysis show a high degree of variability of the indicators by year, a consistently high degree of use of coal as a dominant energy source, a consistently low level of energy production from renewable sources, and a similar level of energy imports. Disregarding the time span from 1990 to 2000, during which the countries in the region were not formally candidates for membership in the European Union, the aforementioned indicates that even after applying for membership, the observed countries failed to implement activities that would be desirable from the aspect of the green transition.

The main challenge for the countries in the region is reconciling the green agenda with reality after 2022, where the price of the green transition is probably the biggest impediment for now. Given the circumstances, it is reasonable that state authorities are hesitant to enhance energy efficiency at a faster pace and in a more comprehensive manner. The aforementioned further complicates the process of transitioning to a circular economy and establishing a new economic identity; however, it also presents an opportunity for progress since there is significant room for improvement. A more detailed interdisciplinary analysis is required to explain the factors contributing to the values of the indicators presented in this study. Additionally, it is necessary to define the methods that will empower the countries of the Western Balkan region to firmly embark on the path of green transition and European integration.

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Author contributions
ARJ, PŠ and ZB prepared a draft of the study. GŠ implemented data analysis and interpretation of the results. LJK participated in data analysis interpretation. All authors read and approved the final manuscript.

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Availability of data and materials
We do not analyze or generate any datasets, because our work proceeds within a theoretical and statistical approach. One can obtain the relevant materials from the references below.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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