



HOW CAN INNOVATION ECOSYSTEMS ACCELERATE DECARBONIZATION AND GREEN GROWTH?

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ABSTRACT

Eco-innovation, as a new business approach that promotes sustainability throughout the product life cycle, is shaping the green transition and the pace of growth. Green growth and decarbonization are strategic imperatives aiming for a high-income economy. To achieve long-term goals, it is necessary to establish a stimulating innovation ecosystem, supported by a developed infrastructure, which can accelerate decarbonization and green growth. European Union countries have made significant progress in shaping the eco-innovation environment, measured by the Eco-innovation Index, which can be a landmark for the countries of the Western Balkans. In this regard, the focus of the paper is on the analysis of the situation in the countries of the Western Balkans. Decisions taken today influence the Western Balkan ability to meet decarbonization and green growth. The authors investigate how far the Western Balkan countries are along the road to decarbonization, and what remains to be done in the innovation ecosystem in the strategic framework and policy recommendations. The paper will investigate whether Western Balkan countries that have more developed innovation ecosystem measured by the AI Preparedness Index (AIPI) published by International Monetary Fund, achieve greater Green Growth and lower Global Greenhouse Gas (GHG) total emissions and GHG per GDP emissions. The results obtained from the comparative analysis could be the basis for creating strategic priorities and convergence policies in selected countries in the coming period.

Keywords: *Catch up effect, Green Growth, Decarbonization, AI Preparedness Index, Eco-innovation Index*

1. INTRODUCTION

Climate change at the global level and the energy crisis have contributed to the formation of a new global energy economy that will be based on a green transition towards the use of non-fossil sources, technologically advanced technologies and the process of green energy production. Green technological innovations are considered the most necessary instrument for the green transition. Therefore, green technologies are necessary for global energy transformation in accordance with the observance of the Paris Agreement, but they should be implemented at significantly faster rates and on a larger scale. As stated in a report by the International Energy

Agency (IEA, 2023), the arrival of a new era of clean technology industries is the most significant indicator of this transition. The inevitability of low-carbon energy production becomes functionally the focus of achieving net-zero ambitions. That is why green technological innovation (GTI) is an effective way to truly solve environmental problems.

From the aspect of global digital and green development, it is necessary to build climate-neutral economies by looking at global indices. Urgently overcoming climate challenges and achieving “net zero” emissions, the role of digital transformation in this process is very important. That is why the convergence of green and digital economic development is necessary.

Advances in the digital economy could offer a new mechanism for achieving carbon emission targets and neutrality. The application of the digital economy, such as smart energy management, intelligent transport systems and digital agricultural technologies, would significantly reduce carbon emissions by optimizing the use of resources, reducing energy waste and improving production efficiency.

Eco-innovation promises to achieve environmental goals while supporting economic well-being. That’s why this idea is attractive to policy makers, because it solves the trade-off between environmental quality and economic prosperity. Eco-innovation policy aims to stimulate the development and application of innovations that reduce pressure on the environment. To achieve this, these policies rely on the identification of such innovation ex ante. However, it is not always easy to identify the environmental consequences due to the numerous risks. Detailed assessments of the indirect effects of specific innovations, over the life cycle and including various economic feedback, can help to avoid such unintended consequences. The environmental consequences arising from the spread of a specific innovation depend in part on broader political conditions. Strong environmental policies, including regulations and emission pricing policies, can limit the risk that indirect effects result in poor environmental outcomes. Therefore, the integration of eco-innovation policy and environmental protection policy effectively contributes to the improvement of the environment.

The goal of the paper is to investigate how an innovative environment can accelerate the decarbonization of the economy and green economic growth. Although there are many studies that apparently confirm this thesis in developed countries, the challenge remains to examine the existence and nature of this relationship in the less developed countries of the Western Balkans. After the theoretical background and explanation of the basic relationships between the variables.

The paper is structured as follows: after the Introduction, the first part of the paper refers to environmental quality in developing countries and the need to introduce green innovations, decarbonization and green growth, as well as the influence of digital innovation ecosystems on low-carbon economic development. The second section is devoted to theoretical background, which emphasizes green innovations, green growth and decarbonization of the economy, and describes the role of digital economy in green transition. The third section explains methodology, while the fourth section reveals research results and discussion. The paper ends with the Conclusion section.

2. ENVIRONMENTAL QUALITY IN DEVELOPING COUNTRIES AND THE NEED TO INTRODUCE GREEN INNOVATIONS, DECARBONIZATION AND GREEN GROWTH

Carbon dioxide (CO₂) emissions are the primary contributor to GHG emissions, accounting for about 75% of total emissions (Diffenbaugh, 2020, Pattak et al., 2023). Emissions reductions of 25% and 55%, respectively, must be achieved to meet the climate change reduction target by 2030 (UNEP, 2019, Raihan et al., 2022).

The motivation to examine the relationship between green technology innovation (GTI), green growth (GG), and ecological sustainability (ES) in emerging economies is very significant considering the fact that these countries have recorded the fastest economic growth in the last three decades, which is almost 60% of the world GDP growth (Lin & Wang, 2019). However, the accelerated growth of these economies was based on increased energy consumption and depletion of natural resources (Ozturk & Uddin, 2012; Khattak et al., 2020; Nurgaliuly & Smagulova, 2025). Also, little progress in resource efficiency and productivity and increasing environmental conflicts due to resource-based economic activities have challenged the progress of GG and ES in emerging economies (Capozza & Samson, 2019).

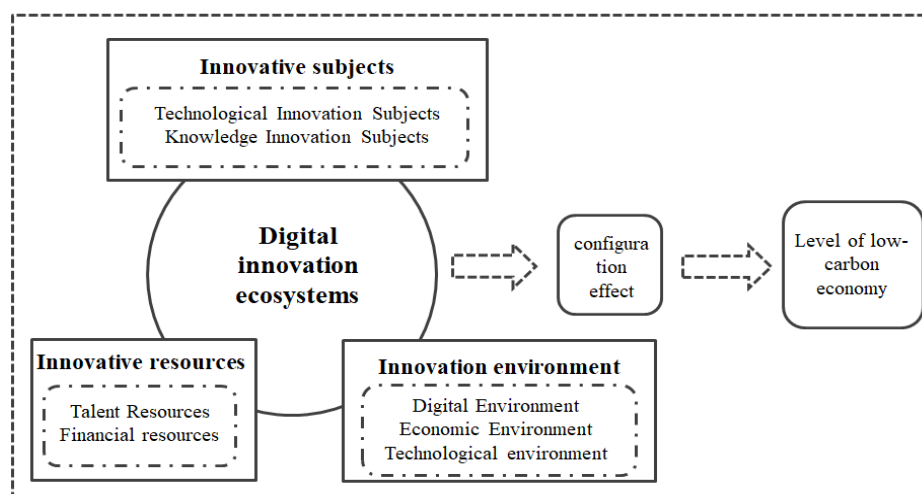
The emerging economies largely contribute to the increase in carbon emissions. They contributed 49.5% of CO₂ emissions for the last three decades (Borojo et al., 2023). In addition, some of these countries (China, India, Russia, Turkey, Indonesia, and Saudi Arabia) are among the most polluting economies (Huang et al., 2022a), and some of them are rapidly increasing greenhouse gas emissions (Wolf et al., 2022). These countries consume more than one third of the world's energy (IEA, 2023) with a limited percentage share of renewable energy consumption (19.37%). Also, foreign direct investments in developing countries has increased significantly from around 5% in 2000 to almost 19% in 2020, which is above the world average of FDI inflows (Xie & Sun, 2020), so the GTI growth rates in emerging economies have also significantly improved compared to the rest of the world (Borojo et al., 2023).

3. THE INFLUENCE OF DIGITAL INNOVATION ECOSYSTEMS ON LOW-CARBON ECONOMIC DEVELOPMENT

The innovative environment has three aspects: digital, economic, and technological environment. First, the digital environment is vital for the green transformation of the economy and society. According to endogenous growth theory and new growth theory, technological innovation and progress are the endogenous energy of economic growth. On the one hand, digital technology develops time and space barriers in traditional production and promotes the optimal allocation of resources between regions. On the other hand, digital technology facilitates the innovation and diffusion of green technology through knowledge spillover effects and thus enables traditional industries to engage in clean energy production. At the same time, the government and companies can use digital technology to establish an environmental monitoring system. Thus, real-time dynamic detection of pollutant emissions and environmental quality can be realized, and the government's environmental management efficiency can be improved.

Second, a stable and sustainable economic environment is an important guarantee for the growth and expansion of a low-carbon economy, as it triggers the development of ecosystems from the market demand side (Xu et al., 2022), strengthens international cooperation, and enables the sharing of low-carbon technology and management experience. Increasing environmental regulations facilitate the green transition of the economy in a low-carbon and environmentally friendly direction (Mahdhi & Belgaroui, 2025).

Figure 1. Analytical framework for digital innovation ecosystems affecting low-carbon economic development



Source: Zhang et al., 2024a, p. 5.

Finally, a favorable technological environment strengthens the information links within the ecosystem, which is a necessary condition for the efficient generation of digital innovations. GHG emissions can be effectively reduced through the development and implementation of clean energy technologies, technologies to improve energy efficiency, and technologies for carbon capture and storage. This will lead to industrial modernization, the construction of a green financial system that will attract investments in low-carbon technologies and lead to the promotion of the transformation of green consumption and new patterns of production in society. An analytical framework for a digital innovation ecosystem influencing low-carbon economic development is given in Figure 1 (Zhang et al., 2024a).

4. THEORETICAL BACKGROUND

4. 1. GREEN INNOVATIONS, GREEN GROWTH AND DECARBONIZATION OF THE ECONOMY

Some studies consider that green technological innovation (GTI) directly contributes to green growth (GG) and ecological sustainability (ES). The green revolution by promoting new technologies and business models has a positive impact on the environment and society (Fernandes et al., 2021; Meiling et al., 2020; Sohag et al., 2021; Nosheen et al., 2021; Jamal et al., 2024). Moreover, GDI affects the efficient use of energy and thus indirectly affects GG and ES (Fisher-Vanden et al., 2006). In this way, GDI affects the energy intensity and indirectly the energy conservation effect (Zhang & Lin, 2012) and improves energy efficiency (Wang et al., 2019). GTI can moderate the relationship between foreign direct investment (FDI), GG, and productivity (Xu & Li, 2021), because countries that promote GTI can attract new FDI, direct existing investments to environmental business and minimize the pollution haven effects of FDI inflow in less advanced countries (Lin & Chen, 2018).

Vargas-Hernández et al. (2021) believe that green innovation is directly related to environmental sustainability and urban ecosystems, which includes the management and use of natural resources, energy minimization, material reduction and pollution prevention.

GTI is an essential technology pathway to support green development (Yi et al. 2019). GTI provides a combination of economic growth with improved environmental management (Sharif et al. 2023; Kocak 2023). By efficiently allocating and using energy resources, advancing green innovation will increase production and ultimately reduce carbon emissions (Sharif et al. 2022).

GTI is the key to solving the economy-environment problem due to it improves operational efficiency while simultaneously reducing harmful impacts on the environment (Li et al. 2021). The main factors influencing GTI are the promotion of the use of renewable energy, environmental taxes and foreign direct investments, i.e. all factors that affect intensive environmental pollution can be driving forces of GTI. Also, one of the clearest indicators of change in GTI is the share of energy from renewable sources (Molchanova & Kovtoniuk, 2023). GTI can improve energy technologies, processes and products and help reduce waste of raw materials and environmental degradation. It becomes a motivation to promote and implement ways for sustainable economic development (Huang et al., 2022b).

Hu (2023) argues that the effects of technical innovation and improving energy efficiency are powerful mechanisms. The success of the method when heterogeneous groups of variables affecting environmental technology patents are taken into account is crucial in the selection of the target group of countries. According to Aghion et al. (2022), in EU countries where there are many environmental technology patents, the methodology used allows comparing quantiles made by categorizing heterogeneous groups among themselves, which is a significant advantage. In this way, it will be possible to determine whether the determinants of environmental technology patents differ between quantiles. You et al. (2022) proved that environmental innovation and international cooperation in environmental technologies reduce CO₂ emissions. Ding et al. (2021) suggests that eco-innovations are among the factors influencing CO₂ emissions in G7 countries.

Qamruzzaman & Karim (2024) found that technological innovation significantly affects green growth in OECD countries. Innovation shocks affect green growth, which emphasizes the adoption and diffusion of green technology that affects the improvement of sustainable development and the minimization of environmental damage (Wang et al., 2024). Similarly, clean energy adoption plays a key role in fostering green growth, with positive links observed between renewable energy consumption and green growth in the short and long term. Environmental innovation is also positively correlated with green growth, highlighting the importance of developing new products and services to manage environmental challenges. In addition, political stability is a critical determinant of green growth, as a stable political environment fosters investor confidence and long-term sustainable investment. The study highlights the complex interplay between these factors, highlighting the bidirectional causal relationships observed between clean energy adoption, political stability, innovation and urbanization. This highlights the need for integrated policies to promote the green growth agenda.

Khattak and Ahmad (2022c) found that positive shocks of sustainable technological innovation reduce CO₂ emissions in OECD countries, and negative shocks increase them, which is in line with the findings of Weimin et al. (2022), who investigated the impact of innovation on environmental quality in a panel of countries.

The study of Borojo et al. (2023) examines the effects of green technological innovation on green growth and ecological sustainability for 25 emerging economies from 1990 to 2018 and they found that there were positive effects. Also, the findings imply that foreign direct investment and energy intensity have negative effects on green growth and ecological sustainability, but they diminish compared to the increase in green technological innovation. This means that they consider green technological innovation to be a vital factor for green revolution in emerging economies because promotion of green technological innovation minimizes the pollution effects of foreign direct investment and mitigates the negative effect of energy intensity.

Study results Rahman et al. (2024) indicate that carbon taxation, green innovation, energy transition, digital infrastructure, sustainable mineral exploitation and gross domestic product sig-

nificantly influence carbon neutrality. Moreover, carbon taxation, energy transition and green innovation significantly help to achieve carbon neutrality in the long term. They therefore suggest that governments encourage the use of green energy solutions through subsidies and support for technology that reduces carbon emissions. This study contributes to a new policy framework for carbon taxation and green innovation for carbon neutralization in the Global South (China, India and Pakistan).

Udeagha & Ngepah (2023) concluded, based on regression analysis, that strict environmental protection policies, green innovation and renewable energy research and development help reduce CO₂ emissions in the long term, while the composite risk index and GDP intensify emissions in the BRICS countries during the period 1960-2020. Although the acceptance of the Paris Agreement requires the decarbonization of the economy, this goal is difficult to achieve because less developed countries accelerate economic growth at the expense of the use of fossil fuels and environmental degradation. Based on their findings, they recommend tightening environmental policies, promoting green innovation and renewable energy R&D spending, maintaining political stability and institutional quality, and adopting clean economic growth strategies to enable the BRICS countries to reduce sectoral risks, create a sustainable environment, and decarbonize their economies.

Koval et al. (2022) analyze the innovative component of regional and national economic development for the implementation of decarbonization and green energy transition on the example of Ukraine in view of the growing threat to energy security. The results of the analysis based on several international indices of ecological efficiency and innovative activity enable a synergistic effect of the development of innovative regions and industries.

In contrast, there are studies that claim that GTI negatively affects GG and ES by increasing carbon emissions and depleting environmental resources (**Santra, 2017**), also through the technological or energy rebound effect (**Wang & Wei, 2020**). GTI have high initial costs, and the application will be limited by the level of economic size (**Liu et al., 2020**).

Sahoo et al. (2022) used relevant data from 14 developing countries in Asia from 1990 to 2018 to examine the potential impact of environmental innovation, measured by the number of environmental technology patents, on CO₂ emissions with control variables such as globalization, urbanization, and economic growth. The results showed that the consumption of renewable energy and globalization have a significant impact on reducing CO₂ emissions, while environmental technological innovations play a weak role in reducing emissions and only when economic growth supports such investments. They also found that urbanization, oil consumption and economic growth are harmful to the environment, which is consistent with many studies. Therefore, the authors recommend that countries should invest in renewable energy sources and environmental innovations that are consistent with economic growth to reduce GHG emissions.

Thus, there is no clear consensus among authors on the impact of GTI on GG and ES due to differences in econometric methods and models, time horizon, sample of countries and regions.

Cutcu et al. (2024) examine the determinants of green technology innovation (GTI) for 15 EU countries in the period 2003-2018 and the results showed that the determinants of GTI are heterogeneous in EU countries. While green growth (GG) has a negative effect on GTI in countries with medium and high GTI, the effect of ecological footprint on GTI is positive in countries with the highest GTI. Also, positive effects of financial development on GTI were found in all countries, environmental taxes have a negative and positive impact on GTI in countries with the lowest and highest quantiles, respectively, and renewable energy sources and greenfield foreign direct investments have no impact on GTI. Therefore, their recommendations are that governments should promote GTI by providing financial resources to companies engaged in green technology projects, as well as environmental taxes.

Khattak et al. (2022a) have found using a panel of G7 countries that positive shocks in environmental technological innovation moderate CO₂ emissions during economic booms. They further applied this analysis **Khattak and Ahmad (2022b)** on BRICS economies and the findings showed that the relationship between green and sustainable technology and CO₂ emissions was counter-cyclical during economic expansion and contraction. These findings support the evidence **Xin et al. (2021)** and **Ahmad and Zheng (2021)**, who found consistent results in the US and BRICS economies.

In the emerging countries, such as the countries of the Western Balkans, the challenges for the green transition are significantly greater due to the deficit of adequate resources, such as knowledge, technologies, financial resources and public support (**Đorić, 2021**). In most countries of the Western Balkans, the main source of primary energy production was solid fuels, they are less dependent on energy imports compared to the EU-27, they have high energy intensity (especially Serbia, Kosovo* and Bosnia and Herzegovina), the contribution of renewable sources to electricity consumption was higher in half of the countries of the Western Balkans compared to the EU-27. In the future period, Western Balkan countries need to work intensively on the implementation of the Green Agenda, which has been imposed as a new development strategy for the region based on the European Green Agenda, where digital transformation will play a key role. It is essential to reduce greenhouse gas emissions and increase resistance to the impact of climate change, bearing in mind that this region is highly dependent on coal, so the transition to cleaner and renewable energy sources is essential.

4. 2. THE ROLE OF DIGITAL ECONOMY IN GREEN TRANSITION

The global economy has been transformed by the digital economy. **Study by Xu (2024)** which synthesizes the literature investigating the relationship between the development of the digital economy and its impact on carbon emissions, came to the conclusion that the digital economy and carbon emissions are not linear, but have an inverted U-shaped curve. These findings are explained by the fact that data centers and network infrastructure have increased energy consumption, resulting in carbon emissions from the initial growth of the digital sector. After reaching a certain threshold, the digital economy helps reduce carbon emissions (**Xie et al., 2023**). Also, there are disparities in the spatial impact of the digital economy on carbon emissions due to the spatial spillover effect of carbon emissions through the diffusion of technological progress and cooperation among regional governments. Therefore, a balanced approach to the development of the digital economy is necessary, which means that digital technology should be fully utilized to promote sustainable economic growth.

Study of **Maksymova (2024)** based on the analysis of global indices, such as the Green Future Index, Climate Change Index, Energy Trilemma Index, Global Digital Competitiveness Index, Digital Economy and Society Index and Digital Quality of Life Index, shows significant differences between countries and individual regions in the degree of digital and green development. Countries with a high level of digital competitiveness are usually leaders in implementing green initiatives, confirming the synergy between digital transformation and environmental sustainability. At the same time, there is a significant gap between developed and underdeveloped countries in progress towards climate neutrality, which highlights the need for additional targeted support, investments, increased technological potential and international cooperation.

Ridwan et al. (2024) emphasize that the dynamics of ecological sustainability of the G7 region are affected by changes in economic activities, progress in artificial intelligence, digital technology, urbanization and financial expansion. Also, the authors make recommendations for policies that support both green development, technology and urban infrastructure improvements, and a healthy environment in the regions.

Research by [Chen et al. \(2024b\)](#) found that the digital economy can significantly reduce carbon emissions, with green technological innovation and industrial transformation being key factors. This paper has deepened the understanding of the drivers of low-carbon growth and the importance, mechanisms and regional disparities of the decarbonization effects of the digital economy, such as the spatial spillover effect of decarbonization in neighboring counties in China.

A review of the relevant literature reveals that digital technologies and innovation ecosystems can directly and indirectly influence the development of a low-carbon economy, and this influence also has significant spatial effects. The digital economy can reduce carbon emissions through direct effects ([Li & Wang, 2022](#)) or indirectly, for example by improving energy efficiency ([Zhang et al., 2022](#)). Some authors found a non-linear relationship between the digital economy and carbon emissions, and pointed out that when China's digital economy develops to a higher level, the effect of reducing emissions will be more obvious. ([Han et al., 2022](#)). Moreover, there is complexity and diversity in the relationship between the digital economy and carbon emissions, and this heterogeneity is reflected in different regions, industries and stages of growth of the digital economy ([Yi et al., 2022](#); [Pan et al., 2020](#)).

4. 3. GREEN INNOVATION ECOSYSTEM AND ARTIFICIAL INTELLIGENCE (AI) IN FACING CHALLENGES GREEN DEVELOPMENT AND CLIMATE CHANGE

[Zhang et al. \(2024b\)](#) believe that the essence of the evolution of green innovation systems is the process by which the positive strategy of green innovation spreads into a complex network. They presented the Object-Technology-Environment-Management-Culture (OETMC) structure paradigm of innovation ecosystems. According to their results:

1. the complexity of ecological green innovation networks has been significantly improved, but numerous empty links remain, which are the key limitations of this structural evolution;
2. many long-range connections weakens geographical distance constraints, but hinders network joining in the environment;
3. the existence of preferences and a strong distribution law of the ecological network of green innovations leads to an incomplete approach to a positive strategy of green innovations from some initial strategy;
4. the default rate of costs and taxes on pollution ensures the motivation of green innovation actors to seek cooperation in innovation by increasing opportunity costs, thus accelerating the formation and reconstruction of the ecological network of green innovations. These conclusions can help in the decision-making process by authorities to encourage green innovation entities to formulate targeted policies.

[Meszaros et al. \(2024\)](#) investigate the development of a sustainable innovation ecosystem and propose the construction of energy ecosystems in which the amount of energy used is considered and the efficiency of energy transformation is measured in order to calculate the net energy productivity of the ecosystem. A good innovation ecosystem depends on the integration of state-of-the-art technical solutions and effective cooperation between different stakeholders in order to improve operational efficiency, reduce environmental impact and promote an innovative and creative culture.

The literature on the factors influencing the low-carbon transition of the economy is mainly from an institutional and economic perspective, and less from the perspective of the innovation ecosystem. [Li et al. \(2024\)](#) from a systemic level, explained how the symbiosis of the innovation ecosystem drives the green transformation of the economy.

The implementation of systems based on artificial intelligence (AI) results in carbon emis-

sions, so it is necessary to determine the carbon footprint of artificial intelligence. This has led in recent years to the emergence of research into the environmental sustainability of artificial intelligence, referred to as green AI (Milićević et al., 2024). The literature on green artificial intelligence has been growing significantly since 2020 and considers AI footprint tracking, hyperparameter tuning to improve model viability or benchmarking models. Most of the works focus on the training phase or study algorithms and neural networks using image data. Reported green AI energy savings go up to 115%, with savings of over 50% being quite common. The authors conclude that green AI research results have reached a significant level of maturity and that it is an opportune time to adopt other green AI research strategies and transfer the results into industrial practice (Verdecchia et al., 2023).

In a study by Dannouni et al. (2023) states that artificial intelligence (AI) is just beginning to be applied in climate change mitigation, and the application has the following three dimensions:

- a) information: artificial intelligence provides sources of information that are useful to countries in shaping their climate strategies;
- b) prediction: artificial intelligence can predict the occurrence of situations that may have harmful consequences; and
- c) optimization: AI applications enable businesses to determine and reduce their carbon footprints.

Policymakers have a key oversight role in maximizing the benefits of AI-driven climate action while minimizing its risks. The key outcomes of such a policy are: enabling artificial intelligence to achieve climate progress by encouraging data sharing, ensuring affordable access to technology, raising awareness and investing in talent, accelerating the deployment of artificial intelligence for climate by defining public and private sector priorities, shifting to public sector use and encouraging private sector action, promoting environmentally and socially responsible application of AI.

Barrie et al. (2024) have provided an overview addressing the multiple roles of artificial intelligence in climate change mitigation, highlighting its potential in several critical areas:

- AI predictive climate modeling provides more accurate forecasts and simulations enabling better informed policies and decision-making processes;
- AI optimizes energy systems through smart grid management, demand forecasting and renewable energy integration, thereby increasing energy efficiency and reducing fossil fuel use;
- AI advances carbon capture and storage technology and thus improves the identification of optimal locations and process efficiency.

Environmental monitoring using AI enables the collection and processing of environmental data in real time and increases the level of efficiency. Also, the adoption of AI in this domain is not without challenges, such as data privacy, algorithmic transparency, and ethical implications of applying artificial intelligence (Barrie et al., 2024; Baltezarević & Baltezarević, 2024).

On one hand, Chen et al. (2024a) measures the green value of artificial intelligence and concluded that:

1. there is a significant inverted U shape in the impact of AI on green development;
2. capital-intensive and technology-intensive areas have a stimulating effect on green development;
3. AI affects not only directly, but also indirectly green development by promoting green technology innovation and optimizing industrial structures;
4. AI has a significant U-shaped spatial spillover effect on green development, and the development of local AI has an impact on the green development of spatially connected areas.

The results of this study can serve to formulate regional AI applications and green development policies. On the other hand, [Doran et al. \(2024\)](#) examined how the adoption of artificial intelligence affects GHG emissions in European countries in the period 2012-2022. Their findings reveal intriguing trends, such as a downward trajectory in GHG emissions correlated with increased levels of investment in artificial intelligence and the use of industrial robots, meaning that larger companies and higher levels of investment potentially contribute to lower emissions. These conclusions provide valuable insights to policymakers for developing strategies to mitigate GHG emissions while harnessing the potential of AI technologies for sustainable development through financial incentives, investment in research and development, stricter environmental regulations and standards for AI and automation industries, etc. In addition, education and training programs for workers on energy-efficient technologies and raising awareness of the impact of industrial processes on the environment, cooperation through public-private partnerships, the implementation of carbon pricing mechanisms and the encouragement of international cooperation are recommendations addressed to all stakeholders in order to use the potential of artificial intelligence and automation for the transition to a low-carbon economy in order to mitigate the adverse effects of climate change.

Model of [Mondal et al. \(2024\)](#) covers various aspects of AI-enabled policy, including technology adoption, policy frameworks, digital literacy and public engagement based on survey data collected from key actors in climate policy, technology sectors and local communities from developing countries. The findings showed that AI-based methodologies have significant potential to achieve a net zero carbon economy in emerging markets and identify four scenarios:

- high predictability AI helps in climate modeling and warning systems in preparation for climate challenges;
- artificial intelligence can help improve energy efficiency and automate the monitoring of carbon emissions;
- data-driven and technology-enabled decision-making makes policy formulation and implementation more resilient to advances in analytics;
- artificial intelligence offers multidirectional solutions for their rapid transfer and adaptation in other environments, which is useful for emerging economies that can bypass the stages of development while maintaining sustainability.

Although progress in solving climate problems lies in the application of artificial intelligence, the successful implementation of expensive technology requires careful consideration of the homogeneity of circumstances, equality in digital access and political commitment at the local level.

5. METHODOLOGY

The research hypotheses are structured as follows:

H₁: Western Balkan countries that have more developed innovation ecosystem measured by the AI Preparedness Index (APII), achieve greater Green Growth measured by GGI.

H₂: Western Balkan countries that have more developed innovation ecosystem measured by the AI Preparedness Index (APII), achieve and lower Global Greenhouse Gas (GHG) total emissions and GHG per GDP emissions.

H₃: In the long run, all WB countries converge when measuring the value of GGI and GHG emissions.

This study is based on quantitative research methods to investigate the convergence trends in WB countries in relation to the level of development of the innovation ecosystem. The analysis

is based on a panel dataset covering Western Balkan countries, which maintain close relationships with the European Union. The target variables and data sources are given in Table 1.

Table 1. Target Variables

Variable	Measurement	Range Performance Level	Source
Green Growth Index (GGI)	2023 Index scores (0-100)	80–100 Very high performance 60–80 High performance 40–60 Moderate performance 20–40 Low performance <20 Critical underperformance	GGI Report 2023
AI Preparedness Index	2023 Index scores (0-1)	Higher scores represent more favorable AI preparedness	International Monetary Fund
Global Greenhouse Gas (GHG) per GDP emissions	t CO ₂ eq/1k\$	Lower scores represent more favorable environment	European Commission, EDGAR - Emissions Database for Global Atmospheric Research
Global Greenhouse Gas (GHG) total emissions	Mton CO ₂ eq	Lower scores represent more favorable environment	

Source: Authors presentation

The Green Growth Index (GGI) evaluates national performance across the following four dimensions of sustainable development: 1) Efficient and Sustainable Resource Use: Energy productivity, water efficiency, material footprint; 2) Natural Capital Protection: Biodiversity conservation, forest cover, soil health; 3) Green Economic Opportunities: Renewable energy adoption, circular economy investments, green job creation; Social Inclusion and Resilience: Income equality, access to education, healthcare quality. Higher values of the Index represent more favorable AI preparedness.

AI Preparedness Index (API) assesses the level of AI preparedness across 174 countries, based on a rich set of macro-structural indicators that cover the countries' digital infrastructure, human capital and labor market policies, innovation and economic integration, and regulation and ethics. The API is the sum of four key dimensions: 1) digital infrastructure, 2) human capital, 3) technological innovation, and 4) legal frameworks. These four dimensions are likely relevant for smooth AI adoption. The index should be seen as an indicative measure, which guiding policymakers in identifying areas for improvements.

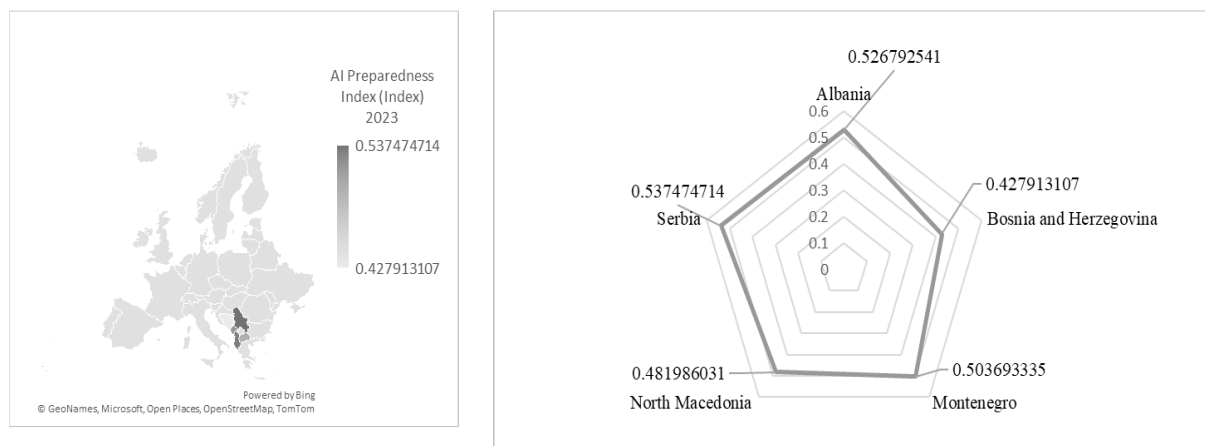
Global greenhouse gas (GHG) emissions have followed an increasing trend mainly due to the increase in emissions from emerging economies. As a result, the atmospheric concentrations of greenhouse gases substantially increased, enhancing the natural greenhouse effect. Greenhouse gas emissions include carbon dioxide, methane and nitrous oxide from all sources, including land-use change. They are measured in tons of carbon dioxide equivalent over a 100-year time scale. Carbon dioxide equivalents (CO₂eq) is a composite indicator that compares the impact of different greenhouse gases on global warming potential by converting the amounts of those gases into an equivalent amount of carbon dioxide with the same global warming potential (European Commission).

6. RESEARCH RESULTS AND DISCUSSION

As shown in Figure 2, Serbia is the leader in the region due to has the most developed innovation ecosystem among the countries of the Western Balkans, with an AI preparedness index value of 0.5374. On the other hand, the value of this index is the lowest in Bosnia and Herzegovina

(0.4279), which indicates the conclusion that the innovation ecosystem there is at the lowest level of development compared to the Western Balkans.

Figure 2. AI Preparedness Index in Western Balkans in 2023



Source: Authors according to IMF database

If we look at the GGI values in the countries of the Western Balkans in the period 2010-2023, based on Table 2, it can be concluded that Albania has the best results, followed by Serbia, Bosnia and Herzegovina, North Macedonia and Montenegro, respectively.

Table 2. Values of the Green Growth Index in Western Balkans in the period 2010-2023

Green Growth Index	Albania	Bosnia and Herzegovina	Montenegro	North Macedonia	Serbia
2010	61.19	55.59	45.37	56.44	58.42
2011	60.7	56.33	45.27	56.5	57.86
2012	60.32	57.07	45.01	56.37	57.12
2013	59.21	58.18	46.26	57.65	57.72
2014	59.83	58.02	45.92	57.99	58.08
2015	59.67	57.97	46.03	58.21	58.76
2016	61.45	56.39	45.73	58.46	58.99
2017	61.97	57.98	46.19	57.93	59.07
2018	62.58	59.31	46.97	58.72	59.36
2019	63.13	59.53	48.01	58.76	59.51
2020	64.25	60.3	47.73	59.08	59.94
2021	65.09	60.69	48.72	59.93	60.45
2022	65.19	61.15	48.91	60.16	60.46
2023	65.16	60.85	48.96	59.9	60.34

Source: Authors presentation based on GGI Report 2023

Descriptive statistics for the period 2010-2023 dataset were computed using SPSS 27 (Table 3), presents mean, standard deviation, minimum and maximum values, 25% and 75% quantile, median, rank, and variance providing insights into green growth index across the Western Balkan countries.

Table 3. Descriptive statistics for GGI

Country	Mean	Std	Min	25% quantile	Median (50%)	75% quantile	Max	Rank	Variance
Albania	62.12	2.14	59.21	60.42	61.71	63.97	65.19	5.98	4.58
Bosnia and Herzegovina	58.53	1.82	55.59	57.30	58.10	60.11	61.15	5.56	3.30
Montenegro	46.79	1.41	45.01	45.78	46.22	47.94	48.96	3.95	1.99
North Macedonia	58.29	1.26	56.37	57.72	58.34	59.00	60.16	3.79	1.60
Serbia	59.01	1.07	57.12	58.16	59.03	59.83	60.46	3.34	1.16

Source: Authors calculation

Table 3 shows that the country with the greatest progress in the Green Growth Index from 2010 to 2023 is Bosnia and Herzegovina, with an increase of 5.26 index points. Albania shows clear growth, with slight oscillations to stable growth after 2016. Montenegro has the lowest values, with slight growth over the years. Other countries have stable but slower growth. Albania has the highest median and the largest range. Montenegro has the smallest variation and the lowest indices. Serbia and North Macedonia are similar in stability and index level.

Figure 3. Green Growth Index trendline by WB countries

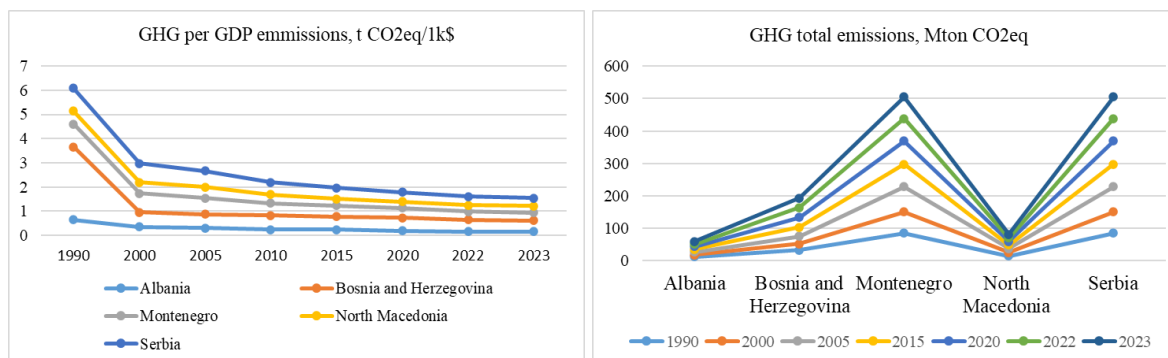


Source: Authors illustration based on GGI Report 2023

Figure 3 shows the distribution of values by country, and how the Green Growth Index has changed over the years for each country. Albania has the convergence trends with average scores in EU. In addition, range of the performance level indicate that all analyzed countries have moderate performance, except for Albania, which achieves high performance of the GGI

in the whole period 2016-2023.

Figure 4. GHG emissions in Western Balkans from 1990-2023



Source: Authors based on Eurostat database

Figure 4 highlights GHG emissions in Western Balkans in the period from 1990 to 2023, measured by two indicators: GHG per GDP emissions and GHG total emissions. All countries have similar converge trends in the whole period, so it indicates that so significance difference between selected countries. Serbia is leader with the highest level of GHG emissions while Albania has the lowest scores.

7. CONCLUSION

The results of this research confirm the relevance of innovation ecosystems in the context of green growth and decarbonization, although their influence is neither uniform nor exclusive. As some authors confirmed ([Đorić, 2021](#)), in the emerging countries, such as the countries of the Western Balkans, the challenges for the green transition are significantly greater due to the deficit of adequate resources, such as knowledge, technologies, financial resources and public support ([Moralisyska, 2023](#)). Digital technologies and innovation ecosystems can directly and indirectly influence the development of a low-carbon economy.

Hypothesis H1 is largely confirmed. Albania, for instance, which ranks high on the APII scale, also achieves the highest GGI score among Western Balkan (WB) countries, indicating a positive correlation between innovation capacity and green development.

However, Hypothesis H2 is only partially supported. While Albania demonstrates both high APII and low greenhouse gas (GHG) emissions, Serbia, the country with the most developed innovation ecosystem in the region, still records the highest total GHG emissions and GHG emissions in total and per GDP. This indicates that innovation alone is insufficient to drive decarbonization and must be supported by broader structural, regulatory, and infrastructural reforms.

Hypothesis H3, which proposes long-term convergence of WB countries in terms of GGI and GHG emissions, is also only partially confirmed. A convergence trend is observed in GHG emissions across the region, but not in GGI values, suggesting differing capacities and policy approaches in achieving sustainable development goals.

The key limitation of this study lies in its focus solely on technological innovations, while ignoring the growing role of financial innovations in enabling green investments and transitions. Furthermore, GHG emissions are influenced by a complex interplay of factors, including a country's level of development, infrastructure, human capital, regulatory quality, and energy efficiency. Although many authors agree that innovations significantly contribute to emission reductions, their impact should be evaluated within a broader socio-economic and policy context. Countries that strategically invest in developing their AI and innovation ecosystems create

stronger foundations for green growth and smoother implementation of the green transition. Literature review confirms that green innovation, political stability, and digital transformation are all significant enablers of sustainable development and emission reduction (Qamruzzaman & Karim, 2024; Udeagha & Ngepah, 2023; Chen et al., 2024b). Future research should explore the financial dimensions of the green transition, including the cost of aligning Western Balkan countries with EU green targets, and the scale of investment needed to develop innovation ecosystems capable of supporting long-term green growth. It is necessary to estimate how much it would cost to implement green policies in accordance with EU standards, especially in the context of limited resources in the region. Research may include an assessment of the required public and private investments for the development of infrastructure, technologies and human resources. Additionally, examining the interaction between financial and technological innovations may offer a more comprehensive view of the drivers of decarbonization in emerging economies.

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