NEW ECONOMETRIC MODEL OF SUSTAINABLE ECONOMIC DEVELOPMENT QUANTIFYING THE IMPACT OF THE IMPLEMENTATION OF SDG 9 IN THE EUROPEAN CONTEXT

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Abstract

In the context of European integration, sustainable economic development in the European Union is a strategic priority. In recent years, the European Union has made progress towards sustainable development objectives, reflecting a commitment to economic growth that respects the principles of environmental protection, social equity and economic efficiency. The European Union plays an important role in shaping sustainable development policies and initiatives through legislation, directives and financial funds aimed at both protecting the environment and stimulating innovation and competitiveness. We aim to analyse the level of innovative sustainability of the European economy in relation to the European dimension of innovative sustainability using an econometric model. The methods used consist of a literature survey, database consolidation and econometric modelling. The econometric model shows that environmental taxes and raw material consumption have a negative impact on GDP per capita in the short run, while technological innovation, measured by the number of patents and R&D personnel, contributes significantly to economic growth and sustainable development, underlining the need for long-term investment in human capital and green technologies to support the competitiveness and sustainability of European economies. The results of the study will lead to the formulation of European public policies on sustainable economic development regarding the implementation of Sustainable Development Goal 9.

Keywords

sustainable development, econometric model, public policies, sustainable development goals

JEL Classification

O1, O3, O4

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Introduction

Sustainable development in Europe is a central pillar of the European Union's agenda, aiming to promote economic growth that is environmentally friendly and ensures social equity for all citizens. This commitment is reflected in the many policies, directives and strategies adopted by the EU to guide Member States towards more sustainable practices. From the European Green Pact to the 2030 Agenda for Sustainable Development Goals (European Commission, 2021), the European Union aims to turn environmental and social challenges into opportunities by promoting innovation and the transition to a circular economy. Sustainable Development Goal 9 (Industry, Innovation and Infrastructure) emphasizes the importance of resilient infrastructure, sustainable industrialization and innovation as key pillars for achieving a sustainable economy (Monaco, 2024; R. Sharma & Gupta, 2024). This objective aims to strike a balance between economic development and environmental protection by fostering innovation and industrial modernization, which are considered fundamental for economic competitiveness and for reducing economic disparities between EU Member States (Brodny & Tutak, 2023; United Nations, 2024). As part of Europe's green and digital switchover strategy (European Commission, 2024e), SDG9 is becoming a central goal of change, helping to integrate cutting-edge technologies, reduce the ecological footprint and increase energy efficiency (Gao, 2024). European Union, through the European Green Deal (European Commission, 2023a) and various funding programs such as Horizon Europe (European Commission, 2024c), has placed innovation and green infrastructure at the heart of its economic policies. Innovations in technology, resource efficiency and digital transformation are seen as solutions to accelerate sustainable industrialization. At the same time, the promotion of the circular economy and smart resource use contribute to achieving carbon reduction targets and protecting ecosystems. Investments in research and development, technological infrastructure and digitization are considered important to sustain a competitive and resilient economy. By supporting technological development and the deployment of smart infrastructures, SDG9 has the potential to help reduce economic disparities and create new employment opportunities. As such, SDG9 is an important component of the European vision for the future, combining economic performance with environmental responsibility (D'Adamo et al., 2022). Sustainable development of the European economy relies on the ability to harness technological innovation and modernize industries while ensuring long-term sustainability (Virjan et al., 2023). In this context, successful implementation of SDG9 will depend on effective coordination between national and European policies, the involvement of the private sector and the ability to adapt existing infrastructure to new technological and environmental requirements. The role of the European Union in promoting sustainable development is particularly significant in the context of this study, as the EU represents a unique example of economic and political integration, capable of developing coherent and harmonized policies that address both the economic and the environmental and social dimensions of sustainable development. In the context of the review of the implementation of SDG9, the EU plays an important role in promoting investment in resilient infrastructure, innovation and sustainable industrialization, providing both a legislative framework and substantial financial resources to stimulate the transition towards a green and competitive economy. This

capacity to formulate policies with trans-national impact is particularly relevant for the present study, as it allows quantifying and assessing the impact of European policies on economic and sustainability indicators at regional level. In the context of the economic diversity within the EU, where Member States have different levels of development and innovation capacity, the coordinating and facilitating role of the EU becomes essential in reducing economic disparities and ensuring uniform progress towards the sustainable development goals.

The aim of this study is to analyse the impact of Sustainable Development Goal 9 indicators on economic and sustainable development in the European context, using an econometric model. The study aims to investigate the relationships between factors such as R&D expenditure, technological innovation, consumption of raw materials, environmental taxes and other relevant indicators, and to quantify how they influence GDP per capita, thus reflecting the level of economic development. By applying this model, the paper aims to provide a deeper understanding of the mechanisms through which economic and innovation policies contribute to sustainable industrialization and increased competitiveness of European economies, while identifying challenges and opportunities in achieving long-term sustainability goals.

The main objectives of the study are:

O1: literature review on sustainable development from an SDG9 perspective

O2: design and validation of the econometric model for quantification of SDG9 implementation results

O3: dissemination of results

In the European context, Romania faces the challenge of aligning these global objectives with national specificities, a task that requires complex and innovative measures.

1. Review of the scientific literature

Sustainable development is a complex concept encompassing three key dimensions: economic growth, environmental protection and social inclusion. At its core is the principle of meeting the needs of the present without compromising the ability of future generations to meet their own needs. This approach was formalized in 1987 in the Brundtland Report (United Nations, 1987), which marked a turning point in redefining the relationship between economic development and sustainability. Officially entitled "Our Common Future" and produced by the World Commission on Environment and Development, the report emphasized the importance of maintaining a balance between economic, social and environmental interests, drawing attention to the environmental limits of uncontrolled growth and the need for more responsible development.

Sustainable development is one of the main global priorities and in the context of the European Union it is integrated into economic and political strategies through the Sustainable Development Goals. Specifically, SDG9 stresses the importance of resilient infrastructure, sustainable industrialization and innovation as essential pillars for achieving a sustainable economy. Figure no 1 is produced using data extracted from the Web of Science platform and represents a bibliometric analysis of the main concepts and themes discussed in the literature on sustainable development, with a particular focus on the implementation of SDG9 (Industry, Innovation and Infrastructure). The

terms illustrated reflect the frequency and relevance of the topics analyzed in scientific studies, and the thematic connections are highlighted by variations in color, providing insight into the interdependence between innovation, sustainability and economic development.

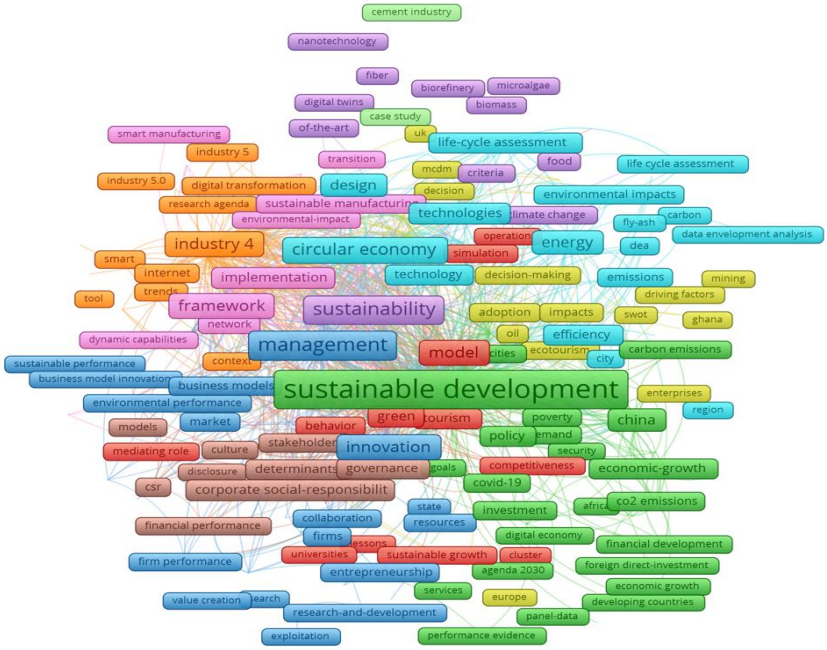

Figure no. 1: Bibliometric analysis on sustainable economic development in the context of Sustainable Development Goal 9

Source: Elaborated by the authors using the VOSviewer program

At the center of the bibliometric analysis is the concept of 'sustainable development', which forms the core around which the other sub-themes revolve. The importance of sustainable development in the contemporary literature is reflected in the scope of this term, emphasizing the need for an integrated approach combining economic growth with environmental protection and social inclusion (Goutte & Sanin, 2024; van Niekerk, 2024). It also demonstrates the complexity of the relationships between technological innovation, economic policies and sustainability, providing a global perspective on the transition towards a more environmentally responsible development model (Safi et al., 2023). Of paramount importance is the role played by innovation and the circular economy, both of which are central to the sustainable development debate (Jesus & Jugend, 2023; Le et al., 2024). The terms 'innovation' and 'circular economy' are widely discussed, suggesting that significant research interest is focused on identifying new economic models capable of optimizing resource use and minimizing waste. In this context, technological innovations, as well as smart technologies under Industry 4.0, play an important role in accelerating the transition towards a green and digital

economy (Costa et al., 2023). There is also a significant concern for the efficient management of economic and industrial processes, directly associated with corporate governance and the implementation of sustainability policies.

The European Union has been a global leader in integrating sustainable development into its economic and environmental policies, starting with the European Sustainable Development Strategy in 2001 (European Union, 2001). This has been reinforced by the Europe 2020 Strategy (European Commission, 2010), which promoted a smart, sustainable and inclusive economy.

These objectives have been supported through investments in energy efficiency, emission reduction and innovation in key sectors such as renewable energy and sustainable transport, and through programs, which support research and innovation for sustainable development. European Green Deal (European Commission, 2023b), launched in 2019, is an ambitious European Union initiative to make the European economy climate neutral by 2050. It proposes measures to transition to a circular economy, increase energy efficiency and protect biodiversity. The EU has set a target to reduce emissions by at least 55% by 2030 compared to 1990 levels, using mechanisms such as the EU taxonomy to guide investment in green projects. Complementing the Just Transition Facility (European Commission, 2024d) supports a just transition, ensuring that no region or community is left behind, reflecting the EU's commitment to sustainable and equitable economic development.

The European Union has introduced regulations and directives to guide Member States and the private sector towards a greener and fairer future. Non-financial reporting directive (European Union, 2014) obliges large companies to disclose their environmental and social impacts, emphasizing the importance of sustainable corporate governance. EU taxonomy (European Commission, 2024a) provides a clear framework for defining environmentally sustainable economic activities, facilitating green investments. These measures reflect the EU's commitment to sustainable development, seen as an opportunity for innovation, job creation and the transition to a digital and green economy, in line with the UN Sustainable Development Goals (Hummel & Jobst, 2024; Krasodomska et al., 2023; Perevoznic & Dragomir, 2024).

Sustainable Development Goal 9 (SDG9), which focuses on industry, innovation and infrastructure, plays a key role in promoting economic sustainability by linking these areas to sustainable economic growth. The literature emphasizes that innovation is a key driver of sustainable development, facilitating the creation of technologies and processes that optimize the use of resources and reduce negative environmental impacts (Al-Emran & Griffy-Brown, 2023; Shahzad et al., 2021; Triguero et al., 2022). According to recent studies, industries that adopt green innovations contribute directly to the transition to a circular economy by reducing waste and maximizing resource efficiency (Bag et al., 2022; Bassi & Guidolin, 2021; Chiappetta Jabbour et al., 2020). Resilient infrastructure is another pillar of SDG9, seen as vital for sustaining long-term economic growth, particularly in the face of the challenges of climate change. Research shows that investing in sustainable infrastructure, such as green transport and renewable energy, not only supports industrial development, but also contributes to reducing carbon emissions and meeting the EU's environmental goals (Androniceanu & Sabie, 2022; Filipović et al., 2022; Kharlamova et al., 2022). SDG9 is also closely linked to

technological innovations that stimulate both the development of sustainable industry and the transition to a green economy. Within this transition, Industry 4.0 and digital technologies play a central role, supporting more efficient production processes, reduced energy consumption and the development of business models based on sustainability (Broccardo et al., 2023; Javaid et al., 2022; I. S. Khan et al., 2021).

Innovation and the circular economy play a central role in transforming the EU economy towards a sustainable model and are essential pillars of Sustainable Development Goal 9 (SDG9), which promotes sustainable industrialization and innovation. Studies show that technological innovations, supported by circular economies and green and regenerative economic models, are fundamental to reducing environmental impacts and improving economic efficiency in key sectors of the European economy (D'Amato & Korhonen, 2021; S. A. Khan et al., 2022; Rodríguez-Espíndola et al., 2022).

Smart technologies and the advances associated with Industry 4.0 are seen as key to accelerating the transition to sustainability. These technologies, including the Industrial Internet of Things (IoT), artificial intelligence and process automation, facilitate the optimization of production chains, improve resource management and reduce waste, all of which are central to the development of circular economies and increased industrial efficiency. Research shows that Industry 4.0 technologies enable companies to adopt cleaner industrial processes, reducing emissions and energy consumption, which contributes to sustainability and economic competitiveness goals (Dantas et al., 2021; Jan et al., 2024; Javaid et al., 2022).

The European Union supports these initiatives through dedicated policies and programs such as Horizon Europe (European Commission, 2024c) and European Innovation Council (EIC) (European Commission, 2024b). These programs reflect the European Union's commitment to support innovation and encourage the adoption of sustainable solutions to global environmental and economic development challenges.

Corporate governance plays a key role in the implementation of sustainability policies, facilitating the alignment of companies' interests with sustainable development objectives such as those set out in Sustainable Development Goal 9 (SDG9). Studies show that firms that integrate SDG9-related policies improve their resource efficiency, adopt cleaner industrial practices and invest in sustainable infrastructure, generating economic and environmental benefits (Berrone et al., 2023; Santiago et al., 2024).

EU regulations, such as the EU Taxonomy and non-financial reporting directives, have forced companies to adopt more transparent strategies and comply with sustainability standards. The EU Taxonomy provides a clear framework for classifying sustainable activities, stimulating more responsible governance.

The literature also emphasizes the importance of corporate social responsibility (CSR), which improves stakeholder relations and enhances the reputation of organizations. CSR contributes directly to sustainability goals, including SDG9, by promoting ethical and environmentally sound practices (Fallah Shayan et al., 2022; Galeazzo et al., 2024; E. Sharma & McLean, 2024).

Thus, effective corporate governance and well-implemented sustainability policies accelerate the transition to a green economy and support competitiveness in the context of global regulation. The literature review on sustainable development and Sustainable

Development Goal 9 (SDG9) highlights the mainstreaming of sustainability into EU economic and industrial policies, emphasizing the EU's role in promoting a green and inclusive economy. SDG9 is essential for innovation, sustainable industrialization and resilient infrastructure, supporting sustainable economic growth. Advanced technologies such as Industry 4.0 play a significant role in accelerating this transition. Effective corporate governance and sustainability policies are vital for SDG9 implementation, and European regulations incentivize companies to adopt green practices. Econometric models provide an empirical basis for assessing the impact of SDG9 on European economies, helping to develop effective policy strategies.
Further research on sustainability policies and the use of econometric models is needed to support the EU's transition towards a green and innovative economy, while highlighting gaps in the literature that open new directions for research, in particular on the long-term impacts of the implementation of SDG9.

2. Research methodology

We aim to develop an economic sustainability model by quantifying the impact of the dynamics of the main SDG9 indicators on the real GDP per capita deflator. For the implementation of the economic sustainability model, we have developed a database of indicators based on Eurostat and OECD reports for the period 2010-2021 of the following indicators: ODD9TAXM - Environmental taxes (% GDP) (OECD, 2024); ODD9VTAXT- Revenue from charges related to road transport (% of total revenue from environmental charges) (OECD, 2024); ODD9CMPR- Consumption of raw materials (Thousand tonnes) (Eurostat, 2024d); ODD9CBV- Patent applications filed at the European Patent Office by country of residence of applicants/inventors (Number) (Eurostat, 2024b); ODD9PCDI- Research and development personnel (%) (Eurostat, 2024c); ODD9CHCDI - Gross domestic expenditure on research and development (%) (Eurostat, 2024a); ODD9PIBloc- GDP per capita (Euro per capita) (Eurostat, 2024e); ODD9DTHM- Development of environmental technologies (% inventions per capita) (OECD, 2024); ODD9AOF- Official Development Assistance (% GNI) (OECD, 2024). The variables chosen in the econometric model, such as R&D expenditures, environmental taxes, patent applications and raw material consumption, were selected because they reflect the critical interdependencies between innovation, sustainability and economic growth, which are fundamental elements in assessing the implementation of SDG9. R&D spending is essential to stimulate technological progress and innovation, which directly contributes to sustainable economic growth and long-term competitiveness, while environmental taxes serve as policy instruments to regulate negative environmental impacts and encourage a shift towards greener practices. Patent applications, as a measure of innovative activity, indicate the degree of technological advancement, while consumption of raw materials is closely linked to economic efficiency and resource sustainability and is a key determinant for the adoption of the circular economy. Thus, these variables are directly related to the research objectives, providing a complex perspective on how innovation policies and environmental regulation influence sustainable economic development within the European Union.
The following research hypotheses were established to achieve the study objectives:

H1: The specialisation of R&D staff in the use of new technologies has a direct and significant effect on economic and sustainable development;
H2: Patenting inventions contributes directly and proportionately to sustainable development;
H3: In the short term R&D spending reduces sustainable development due to slow returns on investment.
Data were log-normalized. The linear regression equation of the model was designed:

$$ln(Y) = \beta_0 + \beta_1 ln(X_1) + \beta_2 ln(X_2) + \beta_3 ln(X_3) + \cdots + \beta_n ln(X_n) + \epsilon \quad (1)$$

Where,
ln(Y), is the natural logarithm of the dependent variable.
$\beta 0$, is the intercept, or constant, that shows the value of ln(Y) when all explanatory variables are zero.
$\beta 1, \beta 2, \ldots, \beta n$ are regression coefficients showing how much ln(Y) varies when each explanatory variable ln($X1$), ln($X2$)…, ln(Xn) increase by one unit, keeping the rest constant.
ln($X1$), ln($X2$)…, ln(Xn) are the natural logarithms of the explanatory variables (factors influencing the dependent variable)

ϵ, is the error term, which reflects all other unobserved or unobserved influences not included in the model.

3. Results and discussion

The European Union is undergoing a green and digital transition, and investment in R&D, technological innovation, energy efficiency and environmental policies are becoming increasingly important to sustain a competitive and resilient economy. The presented econometric model reflects how these factors contribute to GDP per capita growth, providing an overview of the complex interactions between innovation, sustainability and economic development. In the European context, where the balance between economic development and environmental protection is important, this type of analysis becomes essential for the formulation of effective policies to support long-term growth. The results of the model provide insights into the factors that spur or hinder sustainable economic development in different EU Member States. These results are presented in Table 1 below.

Table no. 1. Regression results of OLS model

Source	SS	df	MS	Number of obs =321		
Model	112.769	8	14.096	F(8, 312) = 311.99		
Residual	14.096	312	0.045	Prob > F = 0.0000		
Total	126.866	320	0.396	R-squared = 0.8889		
				Adj R-squared = 0.8860		
				Root MSE = 0.21256		
ln_ODD9PIB~c	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
ln_ODD9CHCDI	-0.224	0.054	-4.10	0.000	-0.332	-0.116
ln_ODD9TAXM	-0.256	0.049	-5.21	0.000	-0.353	-0.159

ln_ODD9VTAXT	0.063	0.019	3.31	0.001	0.025	0.101
ln_ODD9CMPR	-0.225	0.016	-13.67	0.000	-0.257	-0.192
ln_ODD9CBV	0.203	0.016	12.36	0.000	0.171	0.235
ln_ODD9PCDI	0.368	0.064	5.71	0.000	0.241	0.495
ln_ODD9DTHM	0.036	0.017	2.05	0.041	0.001	0.072
ln_ODD9AOF	0.170	0.032	5.21	0.000	0.106	0.234
_cons	11.713	0.163	71.80	0.000	11.392	12.03

Source: Elaborated by the authors using STATA 18

Table 1 reflects the impact of different economic and environmental indicators on GDP per capita using statistical regression. Analysis of the regression table provides insight into how the different variables influence GDP per capita (ODD9GDP), using the estimated coefficients for each independent variable. The model is statistically significant, with an adjusted R-squared of 0.886, indicating that the variables included explain approximately 88.6% of the variation in GDP per capita. These results underline the importance of environmental policies, innovation and research for economic growth. A 1% increase in R&D expenditure is associated with a 0.224% decrease in GDP per capita indicating that R&D investment has not yet had a direct positive impact on economic growth. The high positive ODD9PCDI coefficient indicates that investment in human capital in R&D is highly beneficial to the economy. Table 2 presents the Variance Inflation Factor (VIF) results that focus on identifying potential multicollinearity issues among the independent variables in the regression model.

Table no. 2. Variance Inflation Factor (VIF)

Variable	VIF	1/VIF
ln_ODD9CBV	8.70	0.114934
ln_ODD9PCDI	7.20	0.138973
ln_ODD9CHCDI	7.12	0.140482
ln_ODD9DTHM	4.58	0.218127
ln_ODD9AOF	4.54	0.220141
ln_ODD9CMPR	3.74	0.267417
ln_ODD9VTAXT	1.28	0.781024
ln_ODD9TAXM	1.20	0.836775

Source: Elaborated by the authors using STATA

According to Table 2, the VIF values allow us to examine the extent to which each variable is correlated with the other variables in the model, thus providing clues to the degree of stability of the regression coefficient estimates. All variables are below the threshold of 10 suggesting that there is no multicollinearity.

Hypothesis H1, according to which the specialization of R&D personnel in the use of new technologies has a direct and significant effect on economic and sustainable development, the positive coefficient of 0.368 associated with the variable ODD9PCDI (R&D personnel) demonstrates a clear link between the presence of specialized personnel and the growth of GDP per capita. This relationship emphasizes the importance of investment in skilled human capital in R&D, thus confirming the

hypothesis that this type of personnel plays a key role in supporting economic and sustainable development, contributing to innovation and economic efficiency. Regarding hypothesis H2, which states that patenting of inventions contributes directly and proportionally to sustainable development, the coefficient of 0.203 on the variable ODD9CBV (patent applications at the European Patent Office) confirms this relationship. A higher number of patent applications is associated with significant economic growth, indicating that innovations protected by patents have a direct impact on improving economic competitiveness and sustainability. This positive effect emphasizes that technological innovation not only stimulates economic growth but also contributes to long-term sustainability, confirming the hypothesis that patenting is a key factor for sustainable development. As for hypothesis H3, which states that in the short-run R&D expenditure reduces sustainable development due to slow returns on investment, the negative coefficient of -0.224 on the variable ODD9CHCDI (gross domestic expenditure on R&D) supports this argument. This negative relationship suggests that R&D investment may have an initial negative impact on GDP per capita, probably because the concrete results of R&D investment materialize in the long run. Thus, the hypothesis that R&D expenditures may have a reducing effect on sustainable development in the short run is validated by these results.

The results showing a positive impact of R&D personnel on GDP per capita suggest the need for targeted investment in training and attracting skilled human capital, essential for innovation and increasing long-term economic competitiveness. In this respect, public policies should prioritize education and training programmes in cutting-edge areas such as green technologies and digitization to support the transition to a sustainable economy.

Also, the results on environmental taxes that have a negative impact on GDP in the short run but can stimulate innovation in the long run, highlight the need to reform these taxes to provide incentives for companies to invest in green technologies and resource efficiency. At the same time, the positive correlation between patent applications and economic growth underlines the importance of promoting innovation by simplifying access to the patent system and creating financial support programs for small and medium-sized enterprises. By linking these results to public policy recommendations, not only can a better understanding of the impact of economic and environmental indicators be provided, but also a solid foundation for the development of effective strategies to support sustainable development in the EU.

Figure no 2 shows the analysis of each indicator in the context of the economic and sustainable development of European economies, taking into account their relationship with Sustainable Development Goal 9 (Industry, Innovation and Infrastructure).

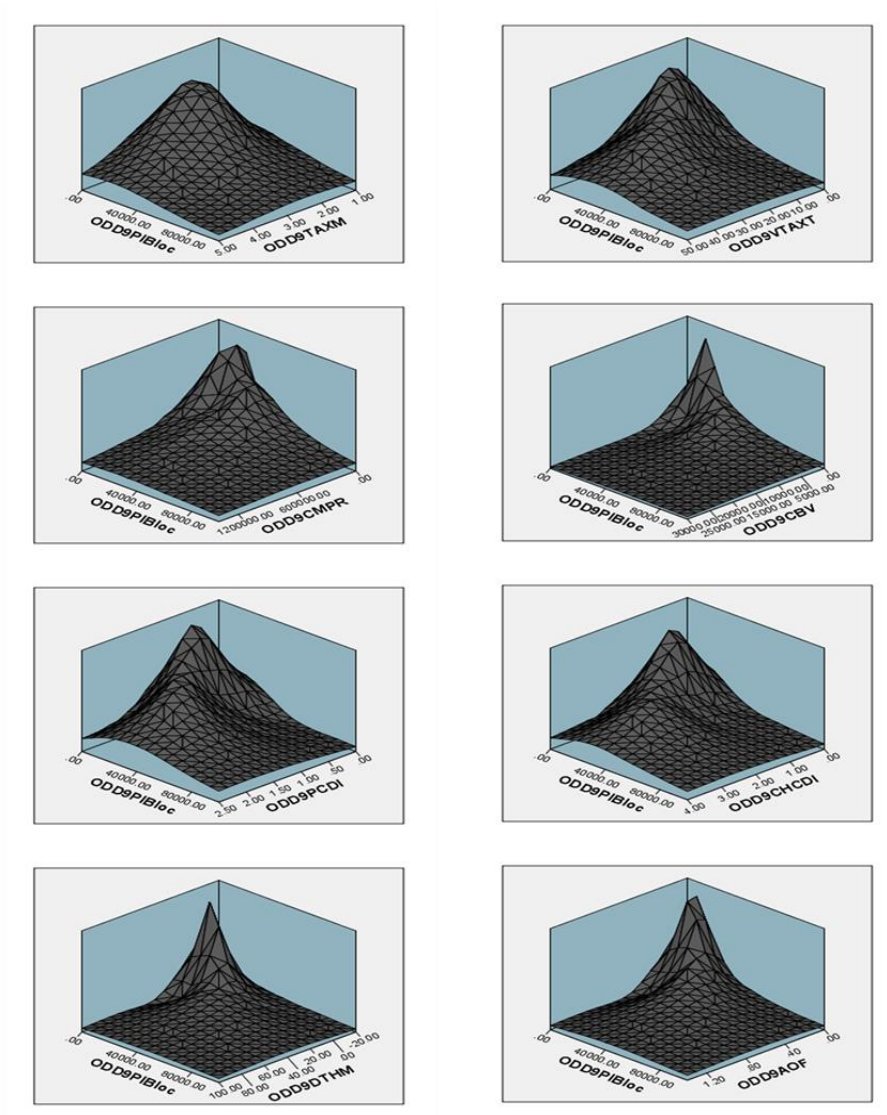

Figure no. 2: Relationship between economic development and sustainable development indicators for the SDGs9

Source: Elaborated by the authors using SPSS Program

Environmental taxes as % of GDP highlight a link between environmental taxation and economic sustainability, and Figure 2 suggests an inverse relationship between environmental taxes and GDP per capita. This can be explained by the fact that imposing higher environmental taxes creates additional costs for companies, leading to reduced competitiveness in the short run, especially in traditional industrial sectors.

However, in the longer term, such a policy can stimulate the transition towards a greener and more sustainable economy by fostering innovation and resource efficiency. The implementation of efficient taxes needs to be calibrated in such a way that it does not inhibit economic growth but stimulates the transition towards more sustainable economic models. Raw material consumption has a negative influence on GDP per capita, indicating that an increase in material resource use is correlated with a decrease in economic efficiency. In advanced European economies, a high dependence on raw materials affects long-term competitiveness and sustainability, as they tend to generate high external costs such as environmental degradation and resource depletion. This relationship underlines the need for the adoption of circular economy practices and a transition towards less resource-intensive economic models to support sustainable economic growth. In Europe, where natural resources are relatively scarce, reducing dependence on raw materials is becoming a strategic priority to achieve sustainable development goals. The number of patent applications is a crucial indicator of an economy's innovative and technological activity, and the graphs show a strong positive correlation between patenting and GDP per capita. Patenting is a marker of an economy's capacity to create new technologies and innovative solutions that contribute significantly to productivity growth and sustainable development. In Europe, where innovation plays a central role in the global competitiveness strategy, patents not only reflect technological progress but also protect intellectual capital, facilitating technology transfer and stimulating investment in high value-added sectors. Thus, a patent-intensive economy enjoys a significant competitive advantage capable of supporting sustainable development. The specialization of R&D personnel has a very strong positive impact on GDP per capita, suggesting that skilled human resources are essential for innovation and economic competitiveness. Figure 2 reveals a direct correlation between the presence of a skilled workforce and economic growth, thus confirming the central role of R&D in achieving economic sustainability. In Europe, policies supporting the training and attraction of talent in innovative fields contribute directly to economic performance and the transition to a knowledge-based economy. R&D personnel are also a determining factor in the development of sustainable technologies, which play a vital role in reducing the environmental footprint and increasing economic efficiency. Figure 2 also reveals a negative short-run relationship between R&D expenditure and GDP per capita, suggesting that the returns on these investments are slow and take time to generate noticeable economic impact. This supports the hypothesis that R&D investment does not produce immediate economic effects but can have a significant impact in the long run. In the European context, economies that invest in R&D tend to gain competitive advantages in the long run, but this process involves an adjustment period during which the results are not immediately visible. Despite this initial negative effect, investment in research is important for innovation and for underpinning a sustainable and resilient economy in the long term. The positive, but moderate, impact of the development of environmental technologies on GDP per capita reflects the fact that these technologies contribute to economic growth in a sustainable manner, but the pace of this impact depends on the level of widespread adoption and deployment. In Europe, the development of green technologies is a central pillar of the green transition agenda, but the technological and economic challenges associated with their deployment may limit

the pace of economic growth in the short term. In the long term, however, they can generate significant cost savings and contribute to reducing the carbon footprint, thereby strengthening the basis for a sustainable European economy. The positive relationship between official development assistance and GDP per capita underlines that financial support for sustainable development has beneficial effects on European economies, helping to reduce economic disparities and promote more sustainable economic models. This indicator suggests that countries providing official development assistance not only support overall economic growth, but also strengthen their own economies by stimulating trade, investment and international partnerships. Analysis in relation to GDP per capita reveals a complex landscape of economic and sustainability interactions in Europe. Innovation, patenting and the specialization of research personnel have a positive impact on economic and sustainable development, while high resource consumption and inappropriately imposed environmental taxes can create negative pressures in the short term. The European Union must continue to invest in innovation and green technologies, while maintaining a balance between environmental regulation and economic development, to ensure a sustainable and competitive transition in the global economy. Based on the results obtained from the econometric model and the impact of the various variables on GDP per capita, we formulate public policies at the European level to support the implementation of the SDG9 (Industry, Innovation and Infrastructure) and to stimulate sustainable development. Figure no. 3 shows the public policies formulated at European level on sustainable development in the context of the implementation of Sustainable Development Goal 9.

1. Increased investment in research and development with a focus on resource efficiency

- The results suggest that R&D spending has a short-term negative impact on GDP per capita, probably due to the long payback period. Thus, a public policy in this respect should aim at streamlining and prioritizing investments in strategic sectors such as green technologies and industrial innovation. At the same time, tax incentives and European funds dedicated to the development of applied research projects and partnerships between universities and companies can be created to ensure a faster return on investment in innovation.

2. Reform environmental taxes to boost green transition

- The negative impact of environmental taxes on GDP per capita suggests the need for a balance between environmental protection and economic competitiveness. A necessary European policy is to reform the system of environmental taxes, making the transition from punitive taxes to a system of "rewards and penalties" that provide incentives for companies that reduce emissions and make their resource consumption more efficient. In addition, part of the revenues generated from environmental taxes should be reinvested in research and development projects in the field of clean and sustainable technologies.

3. Promoting patenting and innovation through financial and legislative support

- The results show a strong positive effect of patenting on economic growth. In this respect, public policy should facilitate access to the European patent system for small and medium-sized enterprises by simplifying procedures and reducing costs. Subsidies and funding schemes can also be offered to companies that develop innovations with a positive impact on the environment and sustainability. The protection of intellectual property rights and support for technology transfer between research institutions and industry should be priorities in innovation policies.

4. Developing and implementing green and sustainable technologies

- Public policy at European level should stimulate research and development in green technologies, such as renewable energy sources, energy efficiency, and recycling of raw materials. The creation of funds dedicated to the green transition and digitalization could accelerate the uptake of these technologies, contributing both to sustainable development and to the EU's climate goals.

5. Supporting R&D education and training

- Given the strong positive impact of skilled R&D personnel on GDP per capita, the European Union should adopt policies to support training and education in high-tech, research and innovation.

6. Reducing consumption of raw materials and promoting the circular economy

- High consumption of raw materials has a negative impact on economic development, according to the model. Therefore, a European policy should encourage the adoption of the circular economy by creating regulations that stimulate the reuse and recycling of resources. Measures can also be implemented to reduce dependence on natural resources by encouraging sustainable and innovative substitutes, as well as funding research into alternative and biodegradable materials.

7. Official Development Assistance and International Cooperation

- The positive impact of official development assistance suggests that public policies at European level should continue to support global sustainable development initiatives. The EU should play a leading role in providing technological and financial assistance to developing economies, facilitating the transfer of knowledge and green technologies. Through such policies, Europe can help create global sustainable partnerships to support the implementation of SDG9 beyond its borders.

Figure no. 3: Public policies formulated on sustainable economic development in terms of Sustainable Development Goal indicators 9

Source: Elaborated by the authors

These public policies support the implementation of SDG9 and contribute to the sustainable development of the European economy by providing long-term solutions to increase economic competitiveness and reduce environmental impacts.

Conclusions

Industrial strategy, innovation strategy and digital strategy are highly topical elements of EU sustainable development policy. Research has shown that at European level the intensity of reforms in the SDG9 area has increased over the last decade with significant progress being made in the transition to the digital economy and the green economy. For Romania, the transition process is only at the beginning, ranking last in the DESI (Digital Economy and Society Index). The innovative sustainability model has highlighted the significant differences between the national economy and the European economy, with sustainable development being achieved based on a costly technological and innovation effort, but with real benefits for long-term economic development. Romania, unlike the EU, has a low innovative sustainable development, which is highlighted by the low values of the regression coefficients and the projection of GDP development because of innovation. Europe's economic and social development will be influenced by digitisation and technologies. The industrial revolution will lead to the integration of different technologies with an impact on the workforce. Rapid economic concentration and new technical solutions around the world are generating 'innovative' economies. Public authorities and policy makers need to invest in long-term planning and engage in dialogue with stakeholders to prepare for transitions and to shape policies effectively. Addressing data protection, data privacy, digital governance and digital transformation issues is important.

The practical implications of the results suggest the need for strategic investment in R&D, especially in green technologies, through tax incentives to accelerate the uptake of innovations and bridge the gap between upfront costs and long-term economic benefits. At the same time, a reform of the environmental tax system, with a focus on balancing penalties with rewards for companies that adopt sustainable practices, could stimulate industrial innovation while ensuring environmental protection and economic competitiveness. Simplifying access to patent systems and supporting technology transfer between academia and industry are also key to strengthening European competitiveness and developing sustainable solutions. Embracing the circular economy and reducing the consumption of raw materials requires policies that encourage recycling, reuse of resources and the adoption of technologies that minimize environmental impact, thus facilitating a sustainable and competitive transition.

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References

[1] Al-Emran, M., & Griffy-Brown, C. (2023). The role of technology adoption in sustainable development: Overview, opportunities, challenges, and future research

agendas. Technology in Society, 73, 102240. https://doi.org/https://doi.org/10.1016/j.techsoc.2023.102240
[2] Androniceanu, A., & Sabie, O. M. (2022). Overview of Green Energy as a Real Strategic Option for Sustainable Development. In Energies (Vol. 15, Issue 22). https://doi.org/10.3390/en15228573
[3] Bag, S., Dhamija, P., Bryde, D. J., & Singh, R. K. (2022). Effect of eco-innovation on green supply chain management, circular economy capability, and performance of small and medium enterprises. Journal of Business Research, 141, 60–72. https://doi.org/https://doi.org/10.1016/j.jbusres.2021.12.011
[4] Bassi, F., & Guidolin, M. (2021). Resource Efficiency and Circular Economy in European SMEs: Investigating the Role of Green Jobs and Skills. In Sustainability (Vol. 13, Issue 21). https://doi.org/10.3390/su132112136
[5] Berrone, P., Rousseau, H. E., Ricart, J. E., Brito, E., & Giuliodori, A. (2023). How can research contribute to the implementation of sustainable development goals? An interpretive review of SDG literature in management. International Journal of Management Reviews, 25(2), 318–339. https://doi.org/https://doi.org/10.1111/ijmr.12331
[6] Broccardo, L., Zicari, A., Jabeen, F., & Bhatti, Z. A. (2023). How digitalization supports a sustainable business model: A literature review. Technological Forecasting and Social Change, 187, 122146. https://doi.org/https://doi.org/10.1016/j.techfore.2022.122146
[7] Brodny, J., & Tutak, M. (2023). The level of implementing sustainable development goal "Industry, innovation and infrastructure" of Agenda 2030 in the European Union countries: Application of MCDM methods. 14, 47–102. https://doi.org/10.24136/oc.2023.002
[8] Chiappetta Jabbour, C. J., De Camargo Fiorini, P., Wong, C. W. Y., Jugend, D., Lopes De Sousa Jabbour, A. B., Roman Pais Seles, B. M., Paula Pinheiro, M. A., & Ribeiro da Silva, H. M. (2020). First-mover firms in the transition towards the sharing economy in metallic natural resource-intensive industries: Implications for the circular economy and emerging industry 4.0 technologies. Resources Policy, 66, 101596. https://doi.org/https://doi.org/10.1016/j.resourpol.2020.101596
[9] Costa, F., Frecassetti, S., Rossini, M., & Portioli-Staudacher, A. (2023). Industry 4.0 digital technologies enhancing sustainability: Applications and barriers from the agricultural industry in an emerging economy. Journal of Cleaner Production, 408, 137208. https://doi.org/https://doi.org/10.1016/j.jclepro.2023.137208
[10] D'Adamo, I., Gastaldi, M., & Morone, P. (2022). Economic sustainable development goals: Assessments and perspectives in Europe. Journal of Cleaner Production, 354, 131730. https://doi.org/https://doi.org/10.1016/j.jclepro.2022.131730
[11] D'Amato, D., & Korhonen, J. (2021). Integrating the green economy, circular economy and bioeconomy in a strategic sustainability framework. Ecological Economics, 188, 107143. https://doi.org/https://doi.org/10.1016/j.ecolecon.2021.107143
[12] Dantas, T. E. T., de-Souza, E. D., Destro, I. R., Hammes, G., Rodriguez, C. M. T., & Soares, S. R. (2021). How the combination of Circular Economy and Industry 4.0 can contribute towards achieving the Sustainable Development Goals. Sustainable Production and Consumption, 26, 213–227.

https://doi.org/https://doi.org/10.1016/j.spc.2020.10.005
[13] European Commission. (2010). Europe 2020 Strategy. https://ec.europa.eu/eu2020/pdf/COMPLET EN BARROSO 007 - Europe 2020 - EN version.pdf
[14] European Commission. (2021). Sustainable Development Goals. https://international-partnerships.ec.europa.eu/policies/sustainable-development-goals_en
[15] European Commission. (2023a). A European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
[16] European Commission. (2023b). Delivering the European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_ro
[17] European Commission. (2024a). EU taxonomy for sustainable activities. https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en
[18] European Commission. (2024b). European Innovation Council. https://eic.ec.europa.eu/index_en
[19] European Commission. (2024c). Horizon Europe. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en
[20] European Commission. (2024d). Just Transition funding sources. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism/just-transition-funding-sources_en
[21] European Commission. (2024e). Shaping Europe's digital future. https://digital-strategy.ec.europa.eu/en
[22] European Union. (2001). Strategy for sustainable development. https://eur-lex.europa.eu/EN/legal-content/summary/strategy-for-sustainable-development.html
[23] European Union. (2014). Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups Text with EEA relevance. https://eur-lex.europa.eu/eli/dir/2014/95/oj
[24] Eurostat. (2024a). Gross domestic expenditure on R&D by sector. https://ec.europa.eu/eurostat/databrowser/view/sdg_09_10/default/table?lang=en
[25] Eurostat. (2024b). Patent applications to the European Patent Office by applicants' / inventors' country of residence. https://ec.europa.eu/eurostat/databrowser/view/sdg_09_40/default/table?lang=en
[26] Eurostat. (2024c). R&D personnel by sector. Europa.Eu.
[27] Eurostat. (2024d). Raw material consumption (RMC). https://ec.europa.eu/eurostat/databrowser/product/view/sdg_12_21?lang=en
[28] Eurostat. (2024e). Real GDP per capita. https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10/default/table?lang=en&category=sdg.sdg_08
[29] Fallah Shayan, N., Mohabbati-Kalejahi, N., Alavi, S., & Zahed, M. A. (2022).

Sustainable Development Goals (SDGs) as a Framework for Corporate Social Responsibility (CSR). In Sustainability (Vol. 14, Issue 3). https://doi.org/10.3390/su14031222
[30] Filipović, S., Lior, N., & Radovanović, M. (2022). The green deal – just transition and sustainable development goals Nexus. Renewable and Sustainable Energy Reviews, 168, 112759. https://doi.org/https://doi.org/10.1016/j.rser.2022.112759
[31] Galeazzo, A., Miandar, T., & Carraro, M. (2024). SDGs in corporate responsibility reporting: a longitudinal investigation of institutional determinants and financial performance. Journal of Management and Governance, 28(1), 113–136. https://doi.org/10.1007/s10997-023-09671-y
[32] Gao, X. (2024). The EU's twin transitions towards sustainability and digital leadership: a coherent or fragmented policy field? Regional Studies, 1–11. https://doi.org/10.1080/00343404.2024.2360053
[33] Goutte, S., & Sanin, M.-E. (2024). Main challenges regarding development and sustainability in economics and finance. Development and Sustainability in Economics and Finance, 1, 100002. https://doi.org/https://doi.org/10.1016/j.dsef.2024.100002
[34] Hummel, K., & Jobst, D. (2024). An Overview of Corporate Sustainability Reporting Legislation in the European Union. Accounting in Europe, 1–36. https://doi.org/10.1080/17449480.2024.2312145
[35] Jan, A., Salameh, A. A., Rahman, H. U., & Alasiri, M. M. (2024). Can blockchain technologies enhance environmental sustainable development goals performance in manufacturing firms? Potential mediation of green supply chain management practices. Business Strategy and the Environment, 33(3), 2004–2019. https://doi.org/https://doi.org/10.1002/bse.3579
[36] Javaid, M., Haleem, A., Singh, R. P., Suman, R., & Gonzalez, E. S. (2022). Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability. Sustainable Operations and Computers, 3, 203–217. https://doi.org/https://doi.org/10.1016/j.susoc.2022.01.008
[37] Jesus, G. M. K., & Jugend, D. (2023). How can open innovation contribute to circular economy adoption? Insights from a literature review. European Journal of Innovation Management, 26(1), 65–98. https://doi.org/10.1108/EJIM-01-2021-0022
[38] Khan, I. S., Ahmad, M. O., & Majava, J. (2021). Industry 4.0 and sustainable development: A systematic mapping of triple bottom line, Circular Economy and Sustainable Business Models perspectives. Journal of Cleaner Production, 297, 126655. https://doi.org/https://doi.org/10.1016/j.jclepro.2021.126655
[39] Khan, S. A., Umar, M., Asadov, A., Tanveer, M., & Yu, Z. (2022). Technological Revolution and Circular Economy Practices: A Mechanism of Green Economy. In Sustainability (Vol. 14, Issue 8). https://doi.org/10.3390/su14084524
[40] Kharlamova, T., Desfonteines, L., Barykin, S., & Gavrilova, R. (2022). Prospects for the development of transport infrastructure to ensure sustainable development. Transportation Research Procedia, 63, 789–797. https://doi.org/https://doi.org/10.1016/j.trpro.2022.06.075
[41] Krasodomska, J., Zieniuk, P., & Kostrzewska, J. (2023). Reporting on Sustainable Development Goals in the European Union: what drives companies' decisions? Competitiveness Review: An International Business Journal, 33(1), 120–146.

https://doi.org/10.1108/CR-12-2021-0179
[42] Le, T. T., Behl, A., & Pereira, V. (2024). Establishing linkages between circular economy practices and sustainable performance: the moderating role of circular economy entrepreneurship. Management Decision, 62(8), 2340–2363. https://doi.org/10.1108/MD-02-2022-0150
[43] Monaco, S. (2024). SDG 9. Build Resilient Infrastructure, Promote Inclusive and Sustainable Industrialization, and Foster Innovation. In Identity, Territories, and Sustainability: Challenges and Opportunities for Achieving the UN Sustainable Development Goals (pp. 87–93). Emerald Publishing Limited. https://doi.org/10.1108/978-1-83797-549-520241010
[44] OECD. (2024). Green Growth Indicators. OECD.Stat.
[45] Perevoznic, F. M., & Dragomir, V. D. (2024). Achieving the 2030 Agenda: Mapping the Landscape of Corporate Sustainability Goals and Policies in the European Union. In Sustainability (Vol. 16, Issue 7). https://doi.org/10.3390/su16072971
[46] Rodríguez-Espíndola, O., Cuevas-Romo, A., Chowdhury, S., Díaz-Acevedo, N., Albores, P., Despoudi, S., Malesios, C., & Dey, P. (2022). The role of circular economy principles and sustainable-oriented innovation to enhance social, economic and environmental performance: Evidence from Mexican SMEs. International Journal of Production Economics, 248, 108495. https://doi.org/https://doi.org/10.1016/j.ijpe.2022.108495
[47] Safi, A., Wei, X., Sansaloni, E. M., & Umar, M. (2023). Breaking down the complexity of sustainable development: A focus on resources, economic complexity, and innovation. Resources Policy, 83, 103746. https://doi.org/https://doi.org/10.1016/j.resourpol.2023.103746
[48] Santiago, F., Haraguchi, N., & Lavopa, A. (2024). Global Trends and World Order: Implications for New Industrial Policies in Developing Countries. Journal of Industry, Competition and Trade, 24(1), 5. https://doi.org/10.1007/s10842-024-00419-4
[49] Shahzad, M., Qu, Y., Zafar, A. U., & Appolloni, A. (2021). Does the interaction between the knowledge management process and sustainable development practices boost corporate green innovation? Business Strategy and the Environment, 30(8), 4206–4222. https://doi.org/https://doi.org/10.1002/bse.2865
[50] Sharma, E., & McLean, G. N. (2024). Corporate social responsibility, the United Nations' Sustainable Development Goals and financial performance, with implications for human resource development. European Journal of Training and Development, ahead-of-print(ahead-of-print). https://doi.org/10.1108/EJTD-10-2023-0151
[51] Sharma, R., & Gupta, H. (2024). Leveraging cognitive digital twins in industry 5.0 for achieving sustainable development goal 9: An exploration of inclusive and sustainable industrialization strategies. Journal of Cleaner Production, 448, 141364. https://doi.org/https://doi.org/10.1016/j.jclepro.2024.141364
[52] Triguero, Á. the loop through eco-innovation by E. firms: C. economy for sustainable development, Cuerva, M. C., & Sáez-Martínez, F. J. (2022). Closing the loop through eco-innovation by European firms: Circular economy for sustainable development. Business Strategy and the Environment, 31(5), 2337–2350. https://doi.org/https://doi.org/10.1002/bse.3024
[53] United Nations. (1987). Report of the World Commission on Environment and

Development - Our Common Future. https://gat04-live-1517c8a4486c41609369c68f30c8-aa81074.divio-media.org/filer_public/6f/85/6f854236-56ab-4b42-810f-606d215c0499/cd_9127_extract_from_our_common_future_brundtland_report_1987_foreword_chpt_2.pdf

[54] United Nations. (2024). Goals 9 - Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. https://sdgs.un.org/goals/goal9#overview

[55] van Niekerk, A. J. (2024). Economic Inclusion: Green Finance and the SDGs. In Sustainability (Vol. 16, Issue 3). https://doi.org/10.3390/su16031128

[56] Virjan, D., Manole, A. M., Stanef-Puica, M. R., Chenic, A. S., Papuc, C. M., Huru, D., & Banacu, C. S. (2023). Competitiveness-the engine that boosts economic growth and revives the economy. FRONTIERS IN ENVIRONMENTAL SCIENCE, 11. https://doi.org/10.3389/fenvs.2023.1130173