FINANCIAL IMPLICATIONS OF TACKLING CLIMATE CHANGE FOR INNOVATION AND GOOD GOVERNANCE

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Abstract
In the fight against climate change, the focus is often put on energy sources and how they are used, although the fight to achieve climate neutrality must be fought on several fronts, given the complexity of the challenge. Thus, according to the literature, innovation, green technologies, sustainable financing and, by extension, the adoption by individuals of more sustainable lifestyles play an important role. Based on this premise, our study aims to highlight the influence of two important variables, namely innovation (using R&D expenditure as a proxy) and governance, on a sample of the 20 most innovative countries over the period 2010-2023, using the OLS model.
The empirical results underline the need for public authorities to step up their efforts by developing and implementing more ambitious public policies. These should include additional measures to stimulate technological innovation, financial support for green projects and raising public awareness. At the same time, international collaboration and research investments need to be expanded to accelerate the transition to climate neutrality.

Keywords
green innovations, good governance, environmental quality, carbon-reduction, and environmental policies.

JEL Classification
Î54, Q55, O30

Introduction

Currently, research activities in the field of environmental economics focus primarily on sustainable development strategies. This research direction reflects the links between the economy and the environment, highlighting the need to strike a balance between natural resources and the needs of a growing population. Against the backdrop of this transition, governments around the world and international organisations have paid increased attention to green growth, and in this context, innovation has emerged as a

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fundamental element in addressing environmental challenges and achieving the Sustainable Development Goals.

The accumulation of greenhouse gases (GHGs), melting ice caps, desertification, and the increasing frequency of extreme weather events have become defining issues of our time. According to Peters et al. (2011), there are two types of compounds that lead to changes in global average temperature. The first category is dominated by compounds that have a short lifespan and mainly affect the ozone layer (SO_2, NOx, BC, OC), while the second category refers to compounds with a longer lifespan (CO_2, CH_4, and N_2O). Given their lifespans, combined with the continued use of fossil fuels, the road to achieving climate goals is long and challenging.

In the scientific literature, particular attention is paid to carbon dioxide, which is one of the main elements responsible for the greenhouse effect. The Intergovernmental Panel on Climate Change (2021) states that carbon dioxide concentrations have reached their highest level in 2 million years. Science suggests that without a profound transformation in the way economies and industries operate, achieving the goals set out in the Paris Agreement could become nearly impossible. This statement is based on observations of global GHG emissions, which have continued to rise despite international commitments. A notable exception was 2020, when emissions fell temporarily because of restrictions imposed by the pandemic crisis.

Given the increasingly pronounced climate challenges, modern societies are called upon to redefine their development paradigms, integrating solutions that respond to both economic and environmental needs. In this context, innovation has come to the forefront of government programs, offering the nation a last hope in the fight against climate change, which seems to be moving faster than our ability to counteract it. Innovation refers to the development of new technologies, products, services, and production methods designed to reduce environmental pollution and promote sustainable development (Schumpeter, 1934; Xiang, Liu and Yang, 2022). Therefore, in an increasingly connected society that is aware of the seriousness of environmental issues, innovation appears to be the "lifeline". However, success in achieving these changes will only be possible with the help of high-quality governing institutions. In the context of environmental recovery, good governance makes a fundamental contribution to the creation of regulations that encourage environmentally friendly practices (Li and Tong, 2024). Good governance, characterised by transparency, accountability, and the active participation of all stakeholders, lays the foundation for a strong institutional infrastructure that supports technological initiatives for sustainable development.

The idea that innovation is an essential pillar of environmental improvement has been widely accepted. This has been supported by a considerable amount of theoretical and empirical research, giving rise to a vibrant academic community. However, the literature also includes studies (Du, Li and Yan, 2019; Su et al., 2021) that highlight the fact that innovation does not contribute significantly to reducing CO_2 emissions. Therefore, the results presented in the literature on the effects of innovation on CO_2 emission reduction remain uncertain, indicating the need for further investigation. In this context, the objective of this research is to investigate the impact of innovation and good governance on CO_2 emissions to understand their role in addressing climate change and, implicitly, in developing appropriate policies. Through the development and dissemination of green technologies in most economic sectors, innovation makes it possible, on the one hand, to reduce carbon intensity at the production level and, on the other hand, to increase energy efficiency. What is more, it stimulates the productivity and competitiveness of economic sectors. At the same time, good governance provides the necessary tools that economies need to achieve the objectives set out in the Paris Agreement, thus laying the foundations on which all climate actions must be built. Based on these premises, the research aims to highlight how innovation and good governance contribute to strengthening sustainable economic growth, with direct implications for fiscal policies and climate-responsible investments. This paper makes a significant contribution to the existing literature, presenting evidence from the economies ranked as the most innovative worldwide. All these economies stand out for their ability to introduce new ideas and implement modern technologies on the market, bringing real change in various fields and creating new and sustainable economic opportunities (WIPO, 2023). They are also characterised by a favourable environment for research and development, high-performance infrastructure, a well-trained workforce, and a culture of innovation and entrepreneurship.

This paper is structured as follows: the next section reviews the existing literature on the correlation between innovation, good governance, and CO_2 emissions; section 2 describes the methodology and data used; section 3 highlights the main results and related discussions; section 4 presents the conclusions of the study; and the last section presents the limitations of the paper and future research directions.

1. Review of the scientific literature

1.1. Innovation and CO_2 emissions

The literature emphasises that innovations will have a considerable impact on reducing CO_2 emissions. Therefore, this topic has attracted considerable interest among academics, scientists, and policymakers, thus providing valuable contributions to the literature in the field.

Researchers around the world who have analysed innovation have argued that it brings many benefits to the environment and society (*reducing energy consumption* (Hermundsdottir and Aspelund, 2021), *digitization capacity* (Lee and Roh, 2023), *low operating costs and reduced harmful emissions* (Mubarak et al., 2021), *improved corporate image* (Chang and Chen, 2013), and *reduced carbon footprint* (Kumar, 2020)). Using the ARDL method, Ahmad et al. (2023) found that technological innovation contributes to reducing emissions in China. Specifically, a one-unit increase in technological innovation increases sustainable development by 0.33% in the short term and 0.14% in the long term. Hashmi and Alam (2019) conduct a similar empirical analysis based on OECD countries between 1999 and 2014. The results of the study highlight the important role that technological innovations play in reducing CO_2 emissions. Gu (2022) also presents evidence indicating that technological innovation not only significantly reduces CO_2 emissions but also shapes the relationship between economic development and emissions. Using the ARDL approach, Xuan (2025) shows that green innovation, together with renewable energy consumption, contributes to improving environmental quality.

As this has been a hotly debated topic in recent years, there are also studies in the specialist literature that argue how the implementation of these new technologies does not reduce CO_2 emissions. In this context, Erdoğan et al. (2020) analyse the impact of technological innovations on CO_2 emissions at the sectoral level in the G20 countries. The authors' analysis is based on the period between 1991 and 2017, and after applying econometric models, it is found that technological innovations in construction lead to increased CO_2 emissions. Similarly, Nguyen and Le (2024) find that technological innovations have no impact on CO_2 emissions. At the same time, Khattak et al. (2020) have shown that innovation activities have failed to reduce CO_2 emissions in China, India, Russia, and South Africa.

While most empirical studies have focused on how innovation contributes to mitigating climate change, Su and Moaniba (2017) set out to analyse how innovations respond to climate change. The analysis is based on a sample of 70 countries covering the period 1976-2014. Using several econometric tools, the study shows that increased CO_2 emissions tend to stimulate the development of technologies to combat climate change. At the same time, the authors found that countries with higher CO_2 emissions tend to develop more environmentally friendly technologies. Given the complexity of the interactions between technology, politics, economics, and society, it is to be expected that there will be conflicting results in this area. In addition, the strategies implemented at the national level and the policies adopted depend on a multitude of factors, but the most notable is the level of development of countries, which is uneven (Grinin, Malkov and Korotayev, 2023).

H1: Innovation capacity has a positive impact on CO_2 emissions.

1.2. Good governance and CO_2 emissions

Specialised studies in the field have identified, from both a theoretical and empirical perspective, that better governance is a key factor in the transition to a green and productive economy. These findings are based on the idea that effective governance frameworks can facilitate the implementation of climate policies by ensuring that environmental considerations are included in decision-making processes (Rahman, 2025).

A recent study by Otim et al. (2025), based on a group of countries in the East African Community, demonstrates, using the STIRPAT model, that good governance and renewable energy consumption contribute to reducing CO_2 emissions. Rahman and Hossain (2025) focus on a sample of 18 developed and developing countries between 2013 and 2019 to explore the impact of good governance and other indicators on the sustainable management of natural resources. Using various econometric models, the results show that good governance plays an important role in shaping the conditions necessary for the sustainable use of natural resources. Pursuing the same objective, namely to investigate the relationship between good governance and CO_2 emissions, Rahman (2025) uses panel data for the period 1997-2020, and the FMOLS regression results demonstrate that good governance contributes to a cleaner environment. Ronaghi et al. (2020) focus on data from the Organization of Petroleum Exporting Countries for the period 2006-2015 to examine the correlation between governance and economic performance, as well as its impact on carbon emissions. Spatial econometric methods

applied to panel data were used in this research, and the findings highlighted that the governance index contributes to lower carbon dioxide emissions.
However, we also find studies that argue that governance indicators contribute to increased emissions. In this context, Sarwar and Alsaggaf (2021) investigate the impact of governance indicators on CO_2 emissions in Saudi Arabia. Using quantile regression techniques, the results obtained highlighted that only governance effectiveness and regulatory quality contribute to reducing emissions. Saba et al. (2025) also showed that governance indicators worsen environmental quality.
H2: Good governance has a positive impact on CO_2 emissions.

2. Research methodology

2.1. Data and variable definitions

According to our objective, we use a panel dataset covering the period 2020-2023. The top twenty "green" countries, according to Yahoo Finance's ranking, are: Denmark, the United Kingdom, Finland, Malta, Sweden, Luxembourg, Slovenia, Austria, Switzerland, Iceland, the Netherlands, France, Germany, Estonia, Latvia, Croatia, Australia, Slovakia, the Czech Republic, and Norway. We included these countries in our analysis because they are considered leaders in climate policy.
In our study, the dependent variable is represented by CO_2 emissions, measured in metric tons per capita. This indicator is relevant to our research because it is still considered a representative indicator of a country's pollution. Based on studies in the literature, we have observed that innovation is measured by a variety of indicators, including research and development expenditure, the global innovation index, and renewable energy consumption. Therefore, our study used research and development expenditure as a proxy for innovation, as it has a significant advantage over other indicators (it encompasses a broader spectrum of innovative activities). Given the significant role that good governance plays in a country's development process, the governance index was also included in the analysis. Secondary data at the national level were extracted from the World Bank's World Development Indicators (WDI) database. The specifications of all variables used in the econometric models, as well as the data source, are highlighted in Table no. 1.

Table no. 1. Description of variables

Nature	Variable	Description	Source
Dependent	**CO_2**	CO_2 emissions (metric tons per capita)	WDI
Independent	**R&D**	Research and development expenditure (% of GDP)	WDI
Independent	**GOV**	Index	WDI
Control	**FDI**	Foreign direct investment, net inflows (% of GDP)	WDI
Control	**FD**	Domestic credit to private sector (% of GDP)	WDI
Control	**TRD**	Trade (% of GDP)	WDI
Control	**GDP**	GDP growth (annual %)	WDI

Source: Author's conception.

2.2. Methodology

Given that this study uses panel data and that most macroeconomic data are non-stationary, certain steps are necessary to validate the use of the ordinary least squares (OLS) method. Therefore, the most important issue to address when using panel data is the presence of non-stationarity. To prevent inconclusive results, we establish the stationarity of the implicit series using the best-known unit root test, namely the Augmented Dickey-Fuller (ADF) test. At the same time, we must consider the issue of multicollinearity in a dataset that has m independent variables [e.g., $x_1, x_2, \ldots, x_j, \ldots, x_m$]. In this context, according to Vu et al. (2015), one of the following methods can be applied: (1) Pearson's correlation matrix, (2) the eigenvalues of the matrix [$X'*X$], or (3) the variance inflation factor (VIF). The VIF_j of a predictor x_j is calculated based on the linear relationship between the predictor x_j and the other independent variables:

$$VIF_j = 1/(1 - R_j^2) \quad (1)$$

Where, R_j^2 = the coefficient of determination of the regression of on all other independent variables in the dataset [$x_1, x_2, \ldots, x_{j-1}, x_{j+1}, \ldots, x_m$] (see Vu et al. (2015)).

To determine the appropriate estimation approach between random effects (RE) and fixed effects (FE) models, we run a specification test known as the Hausman test. The null hypothesis is that the individual effects are not correlated with X'_{it}s. The basic idea behind this test is that the FE estimator β_{FE} is consistent regardless of whether the effects are correlated with X'_{it}s (see Baltagi (2014)). The Hausman test suggests that the fixed effects (FE) model is stronger. In this context, our main empirical model is based on the following equation:

$$y_{i,t} = \alpha_i + X_{i,t} \times \beta + \varepsilon_{i,t} \quad (2)$$

Where, i = entity (province); t = time (2010-2023); $y_{i,t}$ = the dependent variable; α_i (i = 1…n) is the unknown intercept for each entity; $X_{i,t}$ = represents the independent and control variables; β = the coefficient for respective independent and control variables; $\varepsilon_{i,t}$ = the error term.

3. Results and discussion

Table no. 2 provides an overview of the descriptive statistics of the variables used in our study.

Table no. 2. Data summary

Variable	Obs	Mean	Std. Dev.	Min	Max
CO_2	280	0.243695	0.180102	0.042741	1.104594
R&D	243	2.016526	0.872885	0.43514	3.70532
GOV	280	2.40E-09	2.202548	-5.28459	2.969869
FDI	280	9.437404	56.43544	-444.707	452.221
FD	271	96.77384	37.09702	28.70284	192.8299
TRD	280	124.4399	68.47011	40.30248	394.2207
GDP	280	2.135193	2.971774	-10.2969	13.29979
Year				2010	2023
Country				1	20

Source: Author's own creation.

The results obtained show notable fluctuations for most variables. The TRD variable stands out with the highest average value, 124.4399, while the lowest average value is recorded by the CO_2 variable. Regarding the dependent variable (CO_2 emissions), we observe that it ranges between a minimum of 0.0427 (Switzerland, 2023) and a maximum of 1.1045 (Estonia, 2010), with a standard deviation of 0.1801. At the same time, the R&D variable has a standard deviation of 0.8728, ranging from a minimum of 0.4351% of GDP (Latvia, 2016) to a maximum of 3.7053% of GDP (Finland, 2010). The evolution of research and development expenditure can be analysed in the image below.

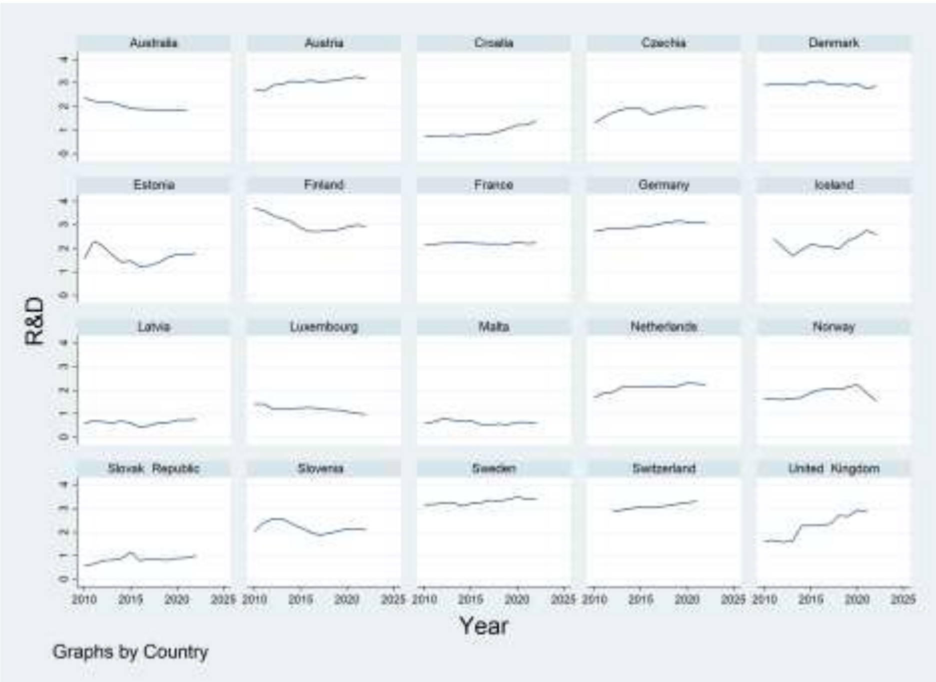

Figure no. 1. Trends in research and development expenditure, 2010-2023
Source: Author's own creation.

Table no. 3 presents the results of the correlation matrix. Since econometric studies suggest that variables become strongly correlated after the threshold of 0.8, our correlation matrix does not suggest the existence of potential problems.

Table no. 3. Correlation metrics

	CO_2	R&D	GOV	FDI	FD	TRD	GDP
CO_2	1						
R&D	-0.3292	1					
GOV	-0.4664	0.6377	1				
FDI	-0.0649	-0.2135	-0.113	1			
FD	-0.5298	0.4772	0.7014	-0.0802	1		
TRD	0.1299	-0.5029	-0.1085	0.159	-0.3094	1	

GDP	0.061	-0.2073	-0.1033	0.2878	-0.1421	0.175	1

Source: Author's own creation.

Table no. 4 reports the results of the variance inflation factor (VIF), which is a tool for detecting multicollinearity in econometric models. The average VIF is within the normal range (i.e., below 5), and each variable has normal values, indicating that multicollinearity is unlikely to be a problem.

Table no. 4. VIF test

Variable	VIF	1/VIF
GOV	3.28	0.305137
R&D	2.61	0.382601
FD	2.29	0.436845
TRD	1.72	0.580073
GDP	1.13	0.885023
FDI	1.13	0.888706
Mean VIF	***2.03***	

Source: Author's own creation.

Before estimating the models, we apply the ADF unit root test to examine the stationarity of the data. Table no. 5 presents the main results obtained after running the test. While the variables *CO_2*, *GOV*, *FDI*, *FD*, *URB*, and *TRD* are stationary at the level (i.e., their order is zero, I(0)), the variable *R&D* becomes stationary after applying the first difference (i.e., their order is one, I(1)).

Table no. 5 . ADF unit root test

	At level	Prob	At 1st Difference	Prob	Stationarity
CO_2	-3.977946	0.0018	-17.21652	0.0000	I(0)
R&D	-1.409874	0.5779	-16.77091	0.0000	I(1)
GOV	-3.496336	0.0088	-16.33931	0.0000	I(0)
FDI	-4.927171	0.0000	-16.88568	0.0000	I(0)
URB	-2.889162	0.0479	-16.50478	0.0000	I(0)
FD	-3.713495	0.0044	-16.74222	0.0000	I(0)
TRD	-2.889694	0.0478	-16.64295	0.0000	I(0)

Source: Author's own creation.

As mentioned in the methodology section, the Hausman test was applied to determine the appropriate approach between the two models. According to the results, the alternative hypothesis of random effects is rejected, as the result obtained is equal to 0.0020. Following this confirmation, the fixed effect is applied to determine the impact of innovation and good governance on CO_2 emissions.

The empirical results obtained regarding the analysis of the impact of innovations and governance indicators on CO_2 emissions are highlighted in Table no. 6.

Table no. 6. Regression results

Independent variables	Dependent variable - CO_2 emissions		
	Pooled OLS	**Fixed Effect**	**Random Effect**
R&D	-0.0191	-0.0219	-0.0403**
	(0.0189)	(0.0196)	(0.0185)
GOV	-0.0119	-0.0172	-0.0282***
	(0.00837)	(0.0135)	(0.0106)
FDI	-0.000402**	-0.0000670	-0.0000968
	(0.000178)	(0.0000868)	(0.0000893)
FD	-0.00210***	0.00188***	0.00136***
	(0.000423)	(0.000395)	(0.000380)
TRD	-0.000103	-0.00147***	-0.00102***
	(0.000191)	(0.000377)	(0.000311)
GDP	0.000859	0.00281*	0.00209
	(0.00350)	(0.00152)	(0.00157)
Cons	0.509***	0.302***	0.322***
	(0.0790)	(0.0782)	(0.0783)
Hausman		Accept	

Source: Author's own creation. *Notes:* Stars indicate the significance level * p<.05; ** p<.01; *** p<.001. Standard errors are reported in parentheses.

First, the empirical results indicate that research and development (*R&D*) expenditure contributes to reducing CO_2 emissions, confirming our research hypothesis. In other words, a 1% increase in research and development spending in the countries analysed will lead to a reduction in CO_2 emissions of 0.0219 units. These results are also consistent with the findings of other studies in the existing literature, which highlight the importance of R&D expenditure in the transition to a more sustainable economy (Fernández, López and Blanco, 2018; Petrović and Lobanov, 2020).

In order to achieve climate neutrality, national climate action has focused on policies to stimulate the use of clean energy. In this context, policymakers have focused on research and development as one of the feasible solutions to stimulate the use of clean energy and, at the same time, reduce CO_2 emissions (Churchill, Inekwe and Ivanovski, 2021). The results of the *GOV* variable also reflect a negative relationship with carbon dioxide emissions. This implies that when the governance index increases by 1%, CO_2 emissions will decrease by 0.0172 units. According to Kaufmann et al. (2010, p. 4), good governance includes the process by which governments are selected, their ability to formulate and adopt effective policies, and respect for citizens' rights. Thus, the positive correlation between the two variables highlights the importance of good governance in promoting sustainable development. Our results are consistent with the literature that argues that good governance contributes to improving the environment and, implicitly, to achieving the Sustainable Development Goals by making effective and appropriate decisions, including the implementation of robust regulatory frameworks (Ronaghi, Reed and Saghaian, 2020; Otim et al., 2025; Rahman, 2025).

Regarding control variables, empirical results show a negative relationship between foreign direct investment (*FDI*) and CO_2 emissions. Thus, a 1% increase in FDI will lead to a reduction in carbon dioxide emissions of -0.0000670 units. Similar results were obtained by Pazienza (2019) and Xie et al. (2020). At the same time, we find a statistically significant negative relationship between trade (*TRD*) and CO_2 emissions. Studies in the literature on the correlation between trade and the environment often fall into two categories. One category argues that trade affects the environment as a result of the intensive use of non-renewable energy sources(Wang, Zhang and Li, 2024; Hanvoravongchai and Paweenawat, 2025) and another category that argues that it contributes to reducing emissions through the production of green technologies (Haug and Ucal, 2019; Essandoh, Islam and Kakinaka, 2020). Thus, trade creates conditions for more sustainable production and consumption.

Finally, empirical results indicated that financial development (*FD*) has a positive and statistically significant impact on CO_2 emissions. A 1% increase in financial development leads to a 0.00188 unit increase in carbon emissions. One possible explanation for the relationship between the two variables is that when financial institutions expand access to capital, companies can invest these resources in industries with high CO_2 emissions (e.g., the cement industry, the metallurgical industry). Ultimately, this will lead to an increase in emissions. Saygın et al. (2025) and Tao et al. (2023) obtained similar results.

Conclusions

In the modern era, climate change is one of the most pressing challenges facing humanity. In this context, we investigate the impact of innovation and good governance on CO_2 emissions in a sample of 20 EU and non-EU countries between 2010 and 2023. The ordinary least squares (OLS) method was used to explore the correlation between our variables of interest.

Climate change is measured using carbon dioxide emissions, while innovation is measured using research and development expenditure. In this context, the following findings are established. As expected, research and development (*R&D*) expenditure is an important catalyst in our quest to achieve climate neutrality. These results are very important for policymakers, as they highlight the areas on which we should place greater emphasis in order to create a green economy. Environmental protection policies are a fundamental tool in the search for solutions to mitigate the negative impact of climate change. All these aspects highlight the importance of governance measures, as all environmental protection policies could be successfully implemented under high-quality governance (Simionescu, Strielkowski and Gavurova, 2022). In this context, the results showed that the governance index reduces CO_2 emissions, thus confirming the above-mentioned aspects. In a world marked by environmental degradation and governance disparities, environmental issues require urgent political action, in which the commitment and behaviour of governments are a key factor.

Although it is often cited as a determining factor in the increase in CO_2 emissions, according to the results obtained, trade (*TRD*) contributes to their reduction. This seemingly paradoxical result can be explained by a set of technological and economic mechanisms that favour the decoupling of economic growth from increased pollution. For example, trade promotes the international spread of innovative green technologies, becoming in this context a channel for the transmission of green innovation and, why

not, a factor that helps accelerate the transition to a prosperous environment. However, in the absence of high-quality regulations on CO_2 emissions and constant monitoring, trade can have adverse effects, encouraging the relocation of polluting activities to countries with much more permissive regulations.
Empirical findings highlight a positive and statistically significant relationship between financial development (*FD*) and CO_2 emissions, indicating that improvements in the financial system are associated with an increase in emissions. In this context, the results confirm the hypothesis that financial development can also have adverse effects on the environment. Financial development can lead to increased CO_2 emissions as it facilitates companies' access to credit, allowing them to invest in expanding production capacity and purchasing equipment that produces significant amounts of air pollutants. At the same time, there is an increase in energy consumption, which automatically leads to an increase in CO_2 emissions. In light of these results, by promoting the green bond market, sustainable funds, and credit mechanisms geared toward projects that benefit the environment, the financial sector can become a catalyst for the transition to a zero-emission economy. Moreover, there is also a positive and statistically significant relationship between *GDP*, a variable that reflects economic growth, and CO_2 emissions. The positive relationship between the two variables can be explained by the fact that most of the world's economies still rely heavily on non-renewable energy sources, thus generating considerable emissions.

4. Limitations and future research

Although the study makes important contributions to the literature on environmental protection, it has some limitations that can be used for future research. First, due to data availability, our analysis covers the period 2010-2023. Second, due to its particularities, research and development (R&D) expenditure is used as an indirect indicator of innovation. Based on this premise, future research could expand empirical studies by including alternative indicators, such as patent applications. Third, the research sample used in the econometric analyses comprises 20 countries considered to be the "green". Expanding the geographical scope to include emerging economies, for example, would allow for a comparison of the mechanisms through which innovation and good governance influence emissions in different economic contexts. Furthermore, given the complexity of the relationship between innovation, good governance, and emissions, future research could integrate a range of financial variables (e.g., green bonds) into the analysis of this topic to provide a more nuanced perspective on how capital market mechanisms support the transition to a low-emission economy.

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