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Does Fiscal Decentralization Drive CO_2 Emissions? A Quantile Regression Analysis

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Abstract: Achieving sustainable models is a crucial challenge today, where government actions play a fundamental role. Therefore, this study aims to analyze the impact of fiscal decentralization on CO_2 emissions in 40 economies between 2000 and 2020. To this end, an unbalanced panel was constructed, and the Method of Moments Quantile Regression (MMQR) was employed. As a robustness check, Driscoll and Kraay's standard errors approach was used. The MMQR results indicate that fiscal decentralization has a positive and significant effect across all quantiles of CO_2 emissions. Additionally, it was found that revenue-side decentralization has a greater impact on the lower quantiles of CO_2 emissions, while expenditure-side decentralization has a stronger effect on the upper quantiles. The findings also reveal that renewable energy mitigates CO_2 emissions, whereas economic growth, resource rents, and information and communication technologies increase them, although the latter with lower statistical significance. These findings are expected to serve as a basis for public policy formulation aimed at improving environmental quality.

Keywords: fiscal decentralization; CO_2 emissions; economic growth; MMQR

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1. Introduction

Human and economic activities have generated significant environmental problems, which have intensified over the past decades. These activities have contributed to increased climate variability and environmental pressures, endangering ecosystems, communities, and economic systems (Ali et al., 2025a). In this context, greenhouse gas (GHG) emissions are one of the main byproducts of these activities, exacerbating environmental damage. Carbon dioxide (CO_2) emissions, which account for approximately 76% of GHGs, pose the greatest risk to modern societies (Adebayo et al., 2022). According to the International Energy Agency (IEA, 2024), global CO_2 emissions increased by 1.1% in 2023, reaching a record high of 37.4 billion metric tons (Gt).

The intensity of CO_2 emissions varies across countries, as does their sensitivity to addressing environmental degradation, making government action crucial (L. Chen et al., 2024). In this regard, reducing CO_2 emissions requires more effective government regulation, particularly focused on revenue and expenditure activities (Fan et al., 2020). Fiscal decentralization has gained attention not only as a measure to mitigate CO_2 emissions but

also to promote sustainable development models. According to Hu et al. (2023), fiscal decentralization is a process through which central governments transfer responsibilities to local governments and grant them decision-making authority to achieve greater efficiency in resource management. Decentralized governments can thus better understand and effectively address the needs of local communities, leading to favorable economic, social, and environmental outcomes for citizens (Sima et al., 2023).

However, given the inherent complexity of fiscal decentralization processes, their environmental effects remain a subject of debate. On one hand, the traditional foundation of fiscal federalism, proposed by Tiebout (1956), suggests that higher levels of fiscal decentralization promote more efficient environmental regulation and, consequently, help reduce pollution. In this regard, greater autonomy for local governments in revenue collection and fiscal expenditure facilitates the implementation of strategies tailored to the specific characteristics of each community to mitigate CO_2 emissions (S. Zhang et al., 2024). This can translate into fiscal incentives and subsidies to attract sustainable investments or the allocation of resources toward technological innovation and efficient energy projects (Chang & Chang, 2024). On the other hand, fiscal decentralization can also have counterproductive effects. This includes phenomena such as the "race to the bottom", where local governments prioritize attracting investments by loosening environmental standards (Khan et al., 2021). Furthermore, the effects of decentralization are conditioned by governance quality and institutional factors such as corruption, budget constraints, distrust in public administration, and levels of democracy (Pinilla-Rodríguez & Hernández-Medina, 2024).

Since 2012, the responsibility for CO_2 emissions accumulation among both developing and developed countries has increased, reflecting the challenges the world faces in achieving the Sustainable Development Goals (Meng et al., 2023). In developing economies, the situation is particularly concerning, as they accounted for more than 60% of global CO_2 emissions by 2019. Countries such as India, Mozambique, Zimbabwe, Bolivia, Pakistan, and Thailand are among the most vulnerable economies to economic losses due to the high climate risks they face (Kabir et al., 2022). Nevertheless, while developed countries have made progress in mitigating climate change, evidence suggests that the average CO_2 emissions associated with external climate events are higher in these countries compared to lower-income nations. This has led to an alarming trend in mortality levels linked to meteorological phenomena (Amirkhani et al., 2022). At the same time, economies have experienced an increasing degree of fiscal decentralization aimed at ensuring a more efficient provision of public goods and services (Digdowiseiso, 2022). Garman et al. (2001) noted that, by the early 21st century, approximately 80% of a sample of 75 countries had implemented some form of fiscal decentralization.

Given the ongoing debate and lack of consensus in the literature, this study analyzes the impact of fiscal decentralization on CO_2 emissions in 40 economies between 2000 and 2020. Addressing certain identified gaps, this research contributes to literature in several fundamental ways. First, although prior studies have examined the relationship between fiscal decentralization and environmental indicators, most have focused on specific regions such as China, India, or Pakistan (e.g., S. Zhang et al., 2024; Ding et al., 2024) without considering a broader set of economies. This study expands the analysis by incorporating data from 40 countries with varying levels of development. Second, it considers key factors that influence CO_2 emissions trends, such as renewable energy consumption, economic growth, resource rents, and information and communication technologies. Third, since the levels and intensity of CO_2 emissions vary across countries, heterogeneity is a crucial aspect that must be accounted for. To capture this heterogeneity, this study employs the Method of Moments Quantile Regression (MMQR), allowing for an assessment of the differentiated impacts of fiscal decentralization across the lower, middle, and upper quantiles of CO_2

emissions. Finally, to ensure the reliability of the results, the study applies the pooled OLS method with Driscoll and Kraay (1998) standard errors, which is robust to both cross-sectional and temporal dependence. By incorporating these elements, this research aims to provide updated evidence to help policymakers design appropriate strategies for the transition toward environmental sustainability.

Following the introduction, the structure of this study is as follows. Section 2 presents the literature review. Section 3 describes the data and research methodology. Section 4 discusses the results, and Section 5 provides conclusions and recommendations.

2. Literature Review

2.1. Theorical Review

With growing environmental concerns, government action at all levels is crucial for mitigating greenhouse gas emissions (L. Wang et al., 2024). In this context, fiscal decentralization becomes particularly relevant as it empowers subnational governments to design policies that promote economic development and social well-being (Perugini, 2024). The relationship between fiscal decentralization and the environment has been analyzed within the framework of fiscal federalism, whose early formulations include Tiebout's (1956) "voting with one's feet" mechanism, Stigler's (1957) theory of optimal decentralization, and Oates's (1972) decentralization theory. These approaches were later revisited in the second-generation theories proposed by Seabright (1996), Qian and Weingast (1997), and Wildasin (1997). These theories help explain how the expansion of governmental responsibilities at different levels can influence environmental outcomes, either positively or negatively.

First-generation theory postulates that fiscal decentralization can improve environmental quality, as local governments, competing in a phenomenon known as "race to the top", seek to optimize efficiency and effectiveness in the provision of public goods and services, including those related to environmental quality (Yang et al., 2025). By having more detailed information about the environmental setting and ecological preferences of the community, local governments can make more informed decisions to raise environmental standards (Yu et al., 2023). In this way, they implement faster environmental actions tailored to the characteristics of their regions, such as policies for marine conservation or reforestation programs (Choudhury & Sahu, 2025). Likewise, the enforcement of environmental regulations by local governments favors effective environmental governance to control pollution by adopting mechanisms for monitoring, evaluation and sanctioning polluting companies (G. Zhang et al., 2020). In addition, local governments have the ability to drive sustainable energy development through various mechanisms such as subsidies and capital investments, encouraging the adoption of green technologies, the use of renewable energy, and greater energy efficiency in the industrial structure (Lin & Wang, 2024; Q.-S. Wang & Su, 2022). Behera et al. (2024) found that fiscal decentralization encourages renewable energy use in European Union nations because, by assuming greater responsibilities, local governments increase budget allocations toward renewable energy investment projects, making them more accessible and affordable. Finally, fiscal decentralization can promote the sustainable management of natural resources, reducing the environmental impact from the exploitation of these resources (Feng & Li, 2024).

A second perspective argues that fiscal decentralization may harm the environment, generating a phenomenon known as "race to the bottom", where local government action will exacerbate environmental damage. Second-generation theory states that, in essence, local governments act as "rational" agents, implying that, when faced with conflicts of interest with the community, local government officials tend to maximize their benefits to the detriment of public welfare (Yang et al., 2025; Yu et al., 2023). Local government prioritizes economic outcomes, and with that, they set low environmental standards and

engage in polluting businesses in search of rents and higher tax revenue (Sun et al., 2023). Moreover, in a competition to accelerate economic growth in the short term, they reduce environmental protection policies to attract private capital, favoring the development of highly polluting economic activities (X. Chen & Liang, 2021) and invest financial funds in projects that generate environmental pressures such as infrastructure construction, reducing their environmental governance budget (Cai et al., 2022). On the other hand, in weak governmental structures, fiscal decentralization may inhibit the development of renewable energy, since the energy industry, being able to generate substantial economic gains, may generate incentives for corruption, hindering the transition to a sustainable energy model (S. Wang & Ma, 2024). In this sense, the effects of fiscal decentralization on the environment are deeply conditioned by the quality of local governance.

2.2. Empirical Review

2.2.1. Fiscal Decentralization and the Environment

Fiscal decentralization has traditionally been a public finance strategy to boost economic efficiency (Martinez-Vazquez & McNab, 2003). In this context, some early empirical studies, such as that of Dietmar (1995), found that, by improving the efficiency of firms within certain levels of political regulation, fiscal decentralization can contribute to the reduction of environmental pollution. However, other studies point out that fiscal decentralization does not necessarily guarantee better environmental quality, as this outcome depends on certain preconditions, such as an effective democratic transition (Assetto et al., 2003). Therefore, the debate on the effects of fiscal decentralization on the environment persists in the empirical literature.

Thus, a body of research finds that fiscal decentralization benefits environmental conditions. Hu et al. (2023) revealed that this fiscal mechanism promotes environmental sustainability in OECD nations by reducing CO_2 emissions and the ecological footprint. For 187 cities in China between 2011 and 2020, S. Zhang et al. (2024) found that decentralization boosts energy savings and reduces urban carbon emission intensity. The study emphasizes the need for further digital transformation of government to improve efficiency in reducing pollutant emissions. Liu et al. (2022) examined the dynamic effect of fiscal decentralization for a set of European Union countries between 2000 and 2020. Applying a cross-sectional augmented distributed lags model (CS-ARDL), the results indicate that, in the short and long run, greater fiscal autonomy significantly improves ecological sustainability, with institutional governance and investment in renewable energy as key moderating factors. Similarly, Khan et al. (2021) found that, in OECD countries, decentralization reduces CO_2 emissions by improving institutional quality and fostering human capital development. Furthermore, using the Method of Moments Quantile Regression (MMQR), Sun et al. (2022) found that the interaction between fiscal decentralization and green investment significantly decreases the ecological footprint in OECD countries. In turn, F. Huang (2023) analyzed the impact of fiscal decentralization on green economic growth in China between 2000 and 2017. Making panel regressions, the results show that decentralization promotes renewable energy, which enables sustainable and environmentally friendly economic growth. Other research, such as that by Su et al. (2021) and Abbas et al. (2024) for the OECD, as well as F. Wang et al. (2024) for China, show that greater fiscal autonomy in local governments drives the energy transition. Among the mechanisms that support this transition are increased consumption of renewable energy, reduced use of non-renewable energy, improvements in industrial structure and greater green technological innovation. In short, fiscal decentralization improves environmental quality both directly and indirectly.

On the other hand, some studies warn that fiscal decentralization negatively affects environmental quality. Guo et al. (2020), Cai et al. (2022) and Zhao et al. (2022) show

that decentralization has exacerbated pollution in China. This effect is because greater fiscal autonomy promotes greater demand for foreign investment, limits technological progress, and relaxes environmental regulations. These factors reinforce the "race to the bottom" dynamic, where local governments, in a competition to accelerate economic growth, relax environmental protection. In turn, Xie et al. (2024), by applying quantile regression for the main emerging economies in the period 2004 to 2022, find that an increase in fiscal decentralization increases CO_2 emissions, the effect of which is greater in the higher quantiles. Similarly, J. Wang (2024), using data from Chinese companies listed from 2010 and 2020, find that decentralization reduces corporate commitment to the environment. This result is explained by the financial constraints faced by firms and increased deregulation of the green environment. In this context, Aziz and Bakoben (2024) find a negative and significant relationship between decentralization and green growth in China. This result is explained by a poor allocation of resources among different regions, reducing efficiency in administrative decentralization and generating incoherent policies in local contexts. In contrast, other studies find a non-linear relationship between fiscal decentralization and the environment. Cheng et al. (2020), using interprovincial data for China between 1997 and 2015, and Shan et al. (2021), for OECD countries between 1990 and 2018, find an inverted U-shaped relationship between fiscal decentralization and CO_2 emissions. In other words, above a certain threshold, greater autonomy of per capita fiscal spending reduces CO_2 emissions. These findings suggest the complex interplay between the role of subnational governments within environmental dynamics.

To date, different studies have examined the relationship between fiscal decentralization and the environment, with contradictory results. From these findings, it is possible to identify some gaps that need to be addressed. First, China has received the most attention regarding the implications of fiscal decentralization on different aspects of environmental sustainability. In this regard, the present study seeks to broaden this analysis by focusing on a more diverse set of developing economies. Second, studies that have incorporated various countries in their analyses have focused primarily on assessing linear effects. However, because economic, social, institutional, and political structures vary across countries, CO_2 emissions intensities also differ. To address this limitation, this study employs the Method of Moments Quantile Regression (MMQR), which allows heterogeneity to be captured. In this way, it seeks to strengthen the existing literature and generate relevant information for the formulation of more effective public policies in the ecological field. Therefore, the following research hypothesis is proposed.

Hypothesis 1. *Fiscal decentralization significantly affects environmental quality.*

2.2.2. Other Environmental Determinants

Since the seminal study by Grossman and Krueger (1995), which gave rise to the Environmental Kuznets Curve (EKC) theory, the literature on the determinants of environmental quality has diversified significantly. In this context, various studies have found contradictory results due to the use of different methodologies, analysis periods, and regional contexts. Table 1 presents a summary of previous studies that have examined different factors influencing CO_2 emissions intensities.

Table 1. Empirical studies on determinants of environmental quality.

Author	Country	Period	Methodology	Findings
Shabani (2024)	67 countries	1999–2019	Dynamic threshold panel data model	RE, HC and P $\xrightarrow{-}$ CO_2; GPD $\xrightarrow{+}$ CO_2
Ganda and Panicker (2025)	45 countries in sub-Saharan Africa	2000–2019	Panel threshold model	PE, FDI, GPD and ICT's $\xrightarrow{+}$ CO_2
You et al. (2024)	64 economies	2000–2021	Dumitrescu–Hurlin's group estimator of increased mean, group estimator of mean and panel causality	ICT's, HC and RE $\xrightarrow{-}$ CO_2
Islam et al. (2023)	GCC countries	1995–2019	Generalized least squares and pooled group means	ICT's and FD $\xrightarrow{-}$ CO_2
Nguea (2023)	32 African countries	1996–2018	Driscoll–Kraay standard and error generalized method of moments for instrumental variables	U, G and RE $\xrightarrow{-}$ EF; GDP and ICT's $\xrightarrow{+}$ EF
Ehigiamusoe et al. (2023)	Malaysia	1970–2019	Granger causality, vector error correction, variance decompositions	I, G and ICT's $\xrightarrow{\rightarrow}$ CO_2
Ngangnchi et al. (2024)	45 African countries	2005–2022	Generalized least squares, Driscoll–Kraay effects, Dynamic Driscoll–Kraay effects and quantile-on-quantile panel regression	NR and I $\xrightarrow{+}$ CO_2
Z. Huang and Ren (2024)	160 developing countries	2001–2022	Distributed lag model increased transversally	NR and EE $\xrightarrow{+}$ CO_2
Vallejo Mata et al. (2024)	30 high-income countries	2000–2020	Cross-sectional autoregressive distributed lag autoregressive model and the augmented mean group model	RE $\xrightarrow{-}$ CO_2; GDP and TO $\xrightarrow{+}$ CO_2
Patel and Mehta (2023)	India	1971–2019	Nonlinear autoregressive autoregressive distributional lag model	NR and EE $\xrightarrow{+}$ CO_2; G $\xrightarrow{-}$ CO_2
Bayramli and Karimli (2024)	7 South American countries	2000–2022	Apparently unrelated regression model	GPD, I and T $\xrightarrow{+}$ CO_2; RE $\xrightarrow{-}$ CO_2
Zhu et al. (2024)	20 OECD countries	2010–2020	Common correlated effects mean group y autoregressive distributed lag model	GF $\xrightarrow{-}$ CO_2; NR and E $\xrightarrow{+}$ CO_2

Note. Variables: renewable energy (RE), Gross Domestic Product (GPD), human capital (HC), population (P), primary energy (PE), foreign direct investment (FDI), information technology (ICT's), financial development (FD), urbanization (U), globalization (G), industrialization (I), natural resource rents (NR), economic expansion (EE), trade openness (TO), tourism (T), green finance (GF), electricity consumption (E), ecological footprint (EF), carbon dioxide emissions (CO_2). Results. Negative effect $\xrightarrow{-}$, positive effect $\xrightarrow{+}$, one-way causality $\xrightarrow{\rightarrow}$.

From the literature summarized in Table 1, four key factors related to environmental quality can be identified. First, renewable energy is positioned as an efficient mechanism for mitigating CO_2 emissions resulting from human activities. Renewable energy sources such as hydropower, solar, wind, and geothermal, by replacing fossil fuel sources, significantly reducing greenhouse gas emissions, promote energy efficiency in the production chain, and encourage technological development for advancing the energy structure (Shabani, 2024). Thus, an inverse relationship between renewable energy consumption and CO_2

emissions is evident. Second, the effects of economic growth on the environment remain a topic of debate, as three effects have been identified from this process: the scale effect, the composition effect, and the substitution effect. The scale effect suggests that greater economic growth increases the use of natural resources, which negatively impacts environmental quality. The composition effect states that, as economies develop, activities shift toward less polluting industries. Meanwhile, the substitution effect argues that technological advancements driven by societal development replace traditional production models, promoting environmental sustainability (Vallejo Mata et al., 2024). Third, the extraction of natural resources as a source of industrial expansion has been one of the key contributors to environmental degradation (Ngangnchi et al., 2024). Fourth, information and communication technologies (ICTs), while fundamental for promoting information, have varying effects on the environment, being both detrimental and beneficial (Nguea, 2023; Jahanger et al., 2023).

Therefore, the following additional hypotheses are proposed:

Hypothesis 2. *The consumption of renewable energy significantly affects CO_2 emissions.*

Hypothesis 3. *Economic growth significantly affects CO_2 emissions.*

Hypothesis 4. *The extraction of natural resources significantly affects CO_2 emissions.*

Hypothesis 5. *ICTs significantly affect CO_2 emissions.*

3. Data and Methodology

3.1. Description and Source of Data

This study aims to identify the effect of fiscal decentralization on the environment in 40 economies during the period from 2000 to 2020 (the details of the countries are provided in Appendix A). The sample, both temporal and cross-sectional, was established based on data availability and an effort to include countries from different regions of the world with varying levels of development. The dependent variable used to quantify environmental degradation was carbon dioxide (CO_2) emissions, measured in metric tons per capita. This indicator was chosen because CO_2 is the primary greenhouse gas resulting from the burning of fossil fuels in human and economic activities (Fatima et al., 2024). The independent variable of interest is fiscal decentralization. To accurately capture the dimensions of fiscal decentralization (FD), two representative variables, which have achieved some consensus in the literature, are used: First, expenditure decentralization (DS), measured as the proportion of total subnational government (regional or local) expenditure relative to national public expenditure. This indicator reflects the degree of autonomy decentralized governments have in allocating public resources; Second, revenue decentralization (DI), defined as the proportion of revenues generated by subnational governments relative to total general government revenues. This indicator captures the capacity of subnational governments to raise and generate their own resources, thus reflecting their level of financial autonomy (Q.-S. Wang & Su, 2022; He, 2015).

According to several studies on the determinants of environmental quality (e.g., Shabani, 2024; You et al., 2024; Ngangnchi et al., 2024; Bayramli & Karimli, 2024), four control variables have been selected. Renewable energy consumption (RE) is used to capture the transition to clean energy, GDP per capita (EG) represents economic growth, natural resource rent (NR) measures the extraction of raw materials, and individuals using the internet is the proxy for information and communication technology (ICT). The data for the variables CO_2, RE, EG, NR, and ICT come from the World Bank Development

Indicators, while the DS and DI variables are sourced from the International Monetary Fund. Table 2 provides a detailed description of the variables.

Table 2. Data description.

Variable	Symbol	Unit of Measurement	Source
CO_2 emissions	CO_2	Metric tons per capita	World Bank
Expenditure-side fiscal decentralization	DS	Ratio of local government spending to national spending	International Monetary Fund
Revenue-side fiscal decentralization	DI	Ratio of local government revenue to national revenue	International Monetary Fund
Renewable energy	ER	% of final energy consumption	World Bank
GDP	EG	USD at constant 2015 prices	World Bank
Natural resources	NR	Natural resource rent as % of GDP	World Bank
Information technology	ICT	Individuals using the internet as a % of population	World Bank

Figure 1 illustrates the CO_2 emission intensities for the year 2020 of the 40 selected countries. It is observed that Australia and Canada were the countries with the highest levels of CO_2 emissions. Meanwhile, Colombia, Peru, and Sweden were the countries with the lowest CO_2 emissions.

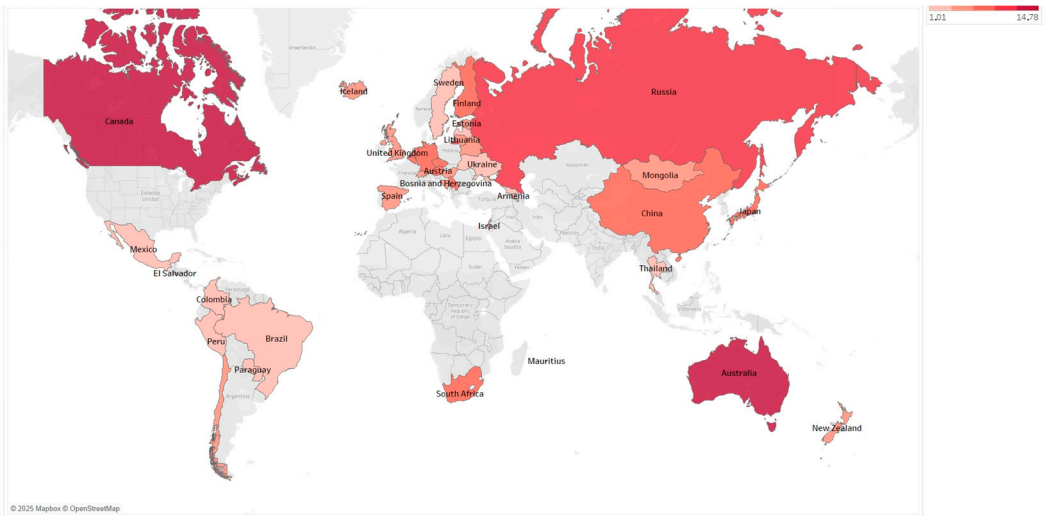


Figure 1. CO_2 emissions in 2020 for the countries. Note. Compiled based on information from the World Bank.

3.2. Empirical Model

Based on recent studies that have explored some determinants of environmental sustainability in different regions (Shabani, 2024; Ehigiamusoe et al., 2023), this research incorporates fiscal decentralization. The base empirical model is represented in Equation (1).

$$CO2_{it} = f(DF_{it}, RE_{it}, GDP_{it}, NR_{it}, ICT_{it}) \quad (1)$$

Since the study uses two variables to capture the effects of fiscal decentralization (FD), Equation (1) is broken down into two empirical models. Additionally, following the work of Hwang and Venter (2025) and Song et al. (2025), a logarithmic transformation is applied to the series to stabilize the variances, avoid heteroscedasticity, and facilitate the interpretation of the coefficients to be estimated. Therefore, the econometric models to be estimated are detailed in Equations (2) and (3).

Model 1:

$$LnCO2_{it} = \beta_0 + \beta_1 LnDS_{it} - \beta_2 LnRE_{it} + \beta_3 LnGDP_{it} + \beta_4 LnNR_{it} - \beta_5 LnICT_{it} + \delta_{it} \quad (2)$$

Model 2:

$$LnCO2_{it} = \beta_0 + \beta_1 LnDI_{it} - \beta_2 LnRE_{it} + \beta_3 LnGDP_{it} + \beta_4 LnNR_{it} - \beta_5 LnICT_{it} + \delta_{it} \quad (3)$$

where, Ln represents the natural logarithm, β_0 is the constant of the model, $\beta_1, \ldots, \beta_5$ are the coefficients to be estimated for the independent variables, and δ is the stochastic error term. Additionally, i represents the cross-sectional dimension (40 countries) and t the time dimension (2000 to 2020).

3.3. Methodological Strategy

3.3.1. Preliminary Estimates

Although panel data have the advantage of incorporating multiple observations that allow for comprehensive analysis, they also present some challenges, such as cross-sectional dependence and heterogeneity, which must be addressed to ensure robust estimates (Hossain et al., 2024). Thus, the study begins by analyzing cross-sectional dependence (CSD), which refers to the interdependence among economies due to externalities or common shocks (Soberon et al., 2025). To do this, the CD test proposed by M. Pesaran (2004) is used, which is efficient in the presence of serial correlation and heteroscedasticity (Ali et al., 2025b), and when the cross-sectional dimension exceeds the time dimension ($N > T$). The Pesaran CD test is summarized in Equation (4).

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{p}_{ij} \right) \quad (4)$$

where, T and N represent the period and the number of cross-sectional units, respectively, and p is the direct correlation coefficient between units i and j. The null hypothesis of this test states that there is no cross-sectional dependence. Subsequently, since heterogeneity among cross-sectional units has been observed within high-dimensional panels (Kutta & Dette, 2024), the study proceeds by applying the M. H. Pesaran and Yamagata (2008) slope homogeneity test, which is useful when the cross-sectional dimension (N) exceeds the time dimension (T) and is robust to cross-sectional dependence. The null hypothesis states that there is slope homogeneity across cross-sectional units.

After applying cross-sectional dependence and slope homogeneity tests, unit root tests are conducted to determine the stationarity of the variables. Following the work of Hossain et al. (2024), second-generation unit root tests are used, which are robust to cross-sectional dependence, specifically the Cross-Sectionally Augmented Dickey–Fuller (CADF) test by Im et al. (2003), which is based on averaging the individual panel unit root test statistics. The CADF test is expressed in Equation (5).

$$\Delta y_{it} = \alpha_{it} + \alpha_i y_{i,t-1} + \alpha_i \overline{y}_{t-1} + \Delta \overline{y}_t + \mu_{it} \quad (5)$$

where, $\overline{y}_t$ represents the cross-sectional averages. The null hypothesis of the test refers to the presence of at least one unit root, i.e., non-stationarity. Subsequently, long-term equilibrium relationships are examined. To address this analysis, three panel cointegration tests are employed: the Kao test (Kao & Chiang, 2001), the Pedroni test (Pedroni, 2001), and the Westerlund test (Westerlund, 2007). According to Rahman et al. (2023), the Westerlund cointegration test is the most efficient for addressing CSD. The null hypothesis assumed by these tests is that no cointegration exists between the variables under study.

3.3.2. Estimation Strategy

This study employs the Method of Moments Quantile Regression (MMQR) developed by Machado and Silva (2019), whose main advantage lies in its ability to capture structural heterogeneity in the conditional distribution of the variables under a location–scale framework. By estimating the differentiated effects of predictors across various quantiles, this method allows for an assessment of how the impact of fiscal decentralization varies among countries with different levels of CO_2 emissions. Furthermore, the model incorporates individual fixed effects throughout the distribution, enabling the capture of unobservable characteristics that may influence the results. Additional advantages supporting its use in this study include: (i) robustness to outliers and non-normal distributions; (ii) the ability to model non-linear relationships; and (iii) effective handling of issues such as endogeneity, cross-sectional dependence, and quantile crossing, ensuring consistent and reliable estimates (Sampene et al., 2024; Rehman et al., 2024). The conditional quantile model is calculated under the specification of Equation (6).

$$Y_{it} = \alpha_i + \ddot{X}_{it}\beta + (\sigma_i + W'_{it}\varphi)V_{it} \quad (6)$$

where $(\alpha, \beta', \sigma, \varphi)$ are the parameters to be evaluated, and the individual effects for each cross-sectional unit (i) are captured in (α_i, σ_i). W is a p-dimensional vector of differential conversions that depends on X; that is, $W_{it} = W(X)$. Additionally, the error terms independent of $\ddot{X}_{it}$ are represented in V_{it}, and are normalized to satisfy the moment conditions (Machado & Silva, 2019, p. 148). Thus, MMQR is represented in Equation (7).

$$Q_y(\tau|X_{it}) = (\alpha_i + \sigma_i q(\tau)) + \ddot{X}_{it}\beta + W'_{it}\varphi q(\tau) \quad (7)$$

where the quantile distribution of the dependent variable Y (in this case, CO_2) conditioned on the location of $\ddot{X}_{it}$ is represented as $Q_y(\tau|X_{it})$. Furthermore, $\alpha_i(\tau) = \alpha_i + \sigma_i q(\tau)$ is the scalar coefficient that represents the fixed effect of quantile τ for each individual i, capturing variations in influences across the conditional distribution of the dependent variable (Adebayo et al., 2022).

On the other hand, to verify the robustness of the MMQR estimates, the clustered OLS method with Driscoll and Kraay (1998) standard errors is employed. This technique is selected due to its several advantages, including: (1) it addresses temporal and cross-sectional dependence, heteroscedasticity, and autocorrelation; (2) it is applicable to panel data, even when they have an unbalanced structure or missing values; and (3) it is suitable when the cross-sectional dimension is greater than the temporal dimension (Sultana & Rahman, 2024; Ridwan et al., 2024; Appiah et al., 2022).

4. Results

4.1. Descriptive Statistics and Multicollinearity

Table 3 presents the descriptive statistics of the data, initially showing that the dataset is an unbalanced panel. The mean of $LnCO_2$ is 1.61, with a standard deviation of 0.75, followed by LnDS and LnDI, with means of −1.87 and −2.43, respectively, and standard deviations of 0.85 and 0.97. Although these standard deviations are below 1, LnDS exhibits higher volatility due to a wider range between its minimum and maximum values. On the other hand, LnRe, LnGDP, LnNR, and LnICT have means of 2.67, 9.48, −0.31, and 3.76, respectively. Among these, LnNR, LnICT, and LnGDP show a wider range in their minimum and maximum values, indicating greater volatility. In contrast, LnRE shows lower volatility, with a standard deviation of 0.85.

Table 3. Descriptive statistics.

Variables	Obs	Mean	Standard Dev	Min	Max
$LnCO_2$	756	1.61	0.75	−0.41	2.92
LnDS	696	−1.87	0.85	−6.99	−0.67
LnDI	750	−2.43	0.97	−7.36	−0.47
LnRE	756	2.67	0.97	−0.22	4.42
LnGDP	756	9.48	1.08	7.34	11.38
LnNR	745	−0.31	2.21	−9.13	3.76
LnICT	748	3.76	0.90	−0.72	4.60

Furthermore, in econometric models, one of the main concerns is the potential presence of multicollinearity, which occurs when there are high correlations between variables. To evaluate multicollinearity, the variance inflation factor (VIF) is used, and the results are presented in Table 4. The average VIF value for the two estimations is below 5, indicating that there are no issues with multicollinearity.

Table 4. Multicollinearity test VIF.

Variable	Model 1		Model 2	
	VIF	1/VIF	VIF	1/VIF
LnDS	1.07	0.93	-	-
LnDI	-	-	1.09	0.91
LnRE	1.04	0.96	1.03	0.97
LNGDP	2.49	0.40	2.54	0.39
LnNR	1.40	0.72	1.40	0.72
LnICT	1.88	0.53	1.90	0.53
Mean VIF	1.58		1.59	

4.2. Cross-Sectional Dependence and Slope Homogeneity

In a globalized world, economies have expanded their networks of connections across various dimensions (political, economic, and environmental, among others), making them susceptible to common shocks. Therefore, the CSD test is applied, and its results are summarized in Table 5. The Pesaran CD test for both models shows statistically significant results at the 1% level, indicating sufficient evidence of the presence of CSD.

Table 5. Cross-sectional dependence test.

Variable	Model 1	Model 2
LnC02	11.66 ***	13.57 ***
LnDS	4.58 ***	-
LnDI	-	8.64 ***
LnRE	3.51 ***	2.29 ***
LNGDP	17.15 ***	17.95 ***
LnNR	34.36 ***	36.89 ***
LnICT	56.97 ***	62.67 ***

Note: *** $p < 0.01$.

Additionally, as the study includes countries with varying levels of development, evaluating slope heterogeneity becomes crucial. The results of the M. H. Pesaran and Yamagata (2008) homogeneity of slope test are displayed in Table 6. The test statistics are significant at the 1% level, indicating slope heterogeneity in both models.

Table 6. Homogeneity of slope test.

Stats	Model 1	Model 2
Delta	8.01 ***	8.82 ***
Delta adjust	10.91 ***	12.03 ***

Note: *** $p < 0.01$.

4.3. Unit Root and Cointegration Test

Given the evidence of cross-sectional dependence and slope heterogeneity in the models, second-generation unit root tests are employed to determine the order of integration of the variables. Table 7 presents the results of the CADF test selected for this study. The findings show that the variables have a mixed order of integration; that is, at the 1% significance level, the variables LnDI, LnGDP, and LnICT are stationary at levels (I(0)), while the variables $LnCO_2$, LnDS, LnRE, and LnNR are stationary at first differences (I(1)).

Table 7. Unit root test.

Variable	Levels	First Differences	Observation
LnC02	5.42	−6.397 ***	I(I)
LnDS	−0.445	−3.789 ***	I(I)
LnDI	−3.48 ***	-	I(0)
LnRE	−2.04 **	−6.499 ***	I(I)
LnGDP	−7.30 ***	-	I(0)
LnNR	0.18	−6.499 ***	I(I)
LnICT	−7.485 ***	-	I(0)

Note: *** $p < 0.01$; ** $p < 0.05$.

Once the order of integration of the variables is determined, the next step is to assess cointegration, i.e., the existence of long-run equilibrium relationships among the variables. To ensure the robustness of the results, three cointegration tests are applied. Table 8 summarizes the results obtained. First, the Kao test shows significant statistics at the 1% level in both models, indicating that the variables are cointegrated. Second, the Pedroni test, considered more reliable for heterogeneous panels (Rahman et al., 2023), also shows significant statistics at the 1% level, validating the existence of cointegration. Finally, the Westerlund test confirms these findings, as the statistics are significant at the 5% level, thereby reinforcing the evidence of long-run equilibrium relationships in both models.

Table 8. Cointegration test.

Test	Model 1	Model 2
Kao Test		
Modified Dickey–Fuller t	3.51 ***	3.69 ***
Dickey–Fuller t	4.87 ***	5.1 ***
Augmented Dickey–Fuller t	4.24 ***	4.38 ***
Unadjusted modified Dickey–Fuller t	2.91 ***	2.85 **
Unadjusted Dickey–Fuller t	4.05 ***	3.96 ***
Pedroni Test		
Modified Phillips–Perron t	3.96 ***	3.95 ***
Phillips–Perron t	−6.04 ***	−7.33 ***
Augmented Dickey–Fuller t	−5.27 ***	−6.57 ***
Westerlund test		
Variance ratio	−2.50 **	−2.44 **

Note: *** $p < 0.01$; ** $p < 0.05$.

4.4. MMQR Estimation Results

The main objective of this study is to analyze the effect of fiscal decentralization on the lower (0.1 to 0.3), middle (0.4 to 0.6), and upper (0.7 to 0.9) quantiles of CO_2 emissions across 40 economies with different levels of development. To achieve this, the MMQR technique was employed, and the results are summarized in Table 9. The findings indicate that fiscal decentralization, both on the expenditure side (LnDS, model 1) and the revenue side (LnDI, model 2), has a positive and significant effect on all quantiles of CO_2 emissions. However, a heterogeneous dynamic is observed. On the one hand, the estimated coefficients of LnDS progressively increase, from 0.10 at the 0.10 quantile to 0.25 at the 0.9 quantile, suggesting a larger impact on the higher quantiles of CO_2 emissions, which is consistent with the results of Xie et al. (2024). On the other hand, the estimated coefficients of LnDI decrease gradually along the distribution, indicating a greater effect on the lower quantiles of emissions. For instance, for each 1% increase in LnDI, CO_2 emissions grow by 0.18% at the 0.3 quantile. These results suggest that fiscal decentralization, in its main dimensions, contributes to increasing CO_2 emissions, demonstrating harmful effects on the environment. Additionally, decentralization on the expenditure side has a larger effect in countries with higher emission levels, while decentralization on the revenue side has a greater effect in countries with lower CO_2 levels. These findings align with those of Guo et al. (2020), Cai et al. (2022), and Zhao et al. (2022), while contradicting Hu et al. (2023), Liu et al. (2022), and Khan et al. (2021). Therefore, there is sufficient evidence to not reject Hypothesis 1 proposed in this research.

Table 9. MMQR estimation results.

Variables	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
Model 1: Fiscal Decentralization on the Expenditure Side									
LnDS	0.10 ***	0.12 ***	0.14 ***	0.16 ***	0.17 ***	0.18 ***	0.19 ***	0.20 ***	0.23 ***
	(0.021)	(0.019)	(0.017)	(0.016)	(0.015)	(0.016)	(0.165)	(0.018)	(0.021)
LnRE	−0.44 ***	−0.41 ***	−0.394 ***	−0.37 ***	−0.36 ***	−0.35 ***	−0.33 ***	−0.314 ***	−0.28 ***
	(0.023)	(0.021)	(0.019)	(0.017)	(0.017)	(0.017)	(0.018)	(0.02)	(0.024)
LnGDP	0.39 ***	0.41 ***	0.43 ***	0.45 ***	0.46 ***	0.47 ***	0.483 ***	0.495 ***	0.522 ***
	(0.034)	(0.03)	(0.027)	(0.025)	(0.025)	(0.025)	(0.027)	(0.029)	(0.035)
LnNR	0.024 **	0.039 ***	0.052 ***	0.066 ***	0.074 ***	0.083 ***	0.093 ***	0.104 ***	0.124 ***
	(0.011)	(0.01)	(0.009)	(0.008)	(0.008)	(0.008)	(0.008)	(0.01)	(0.011)
LnICT	0.063 *	0.059 *	0.055 **	0.052 **	0.049 *	0.047 *	0.044	0.041	0.04
	(0.035)	(0.03)	(0.027)	(0.03)	(0.025)	(0.025)	(0.027)	(0.03)	(0.035)
Constant	−1.58 ***	−1.6 ***	−1.61 ***	−1.63 ***	−1.64 ***	−1.65 ***	−1.66 ***	−1.67 ***	−1.7 ***
	(0.286)	(0.247)	(0.222)	(0.21)	(0.205)	(0.208)	(0.22)	(0.238)	(0.290)
Model 2: Fiscal Decentralization on the Revenue Side									
LnDI	0.20 ***	0.195 ***	0.18 ***	0.18 ***	0.178 ***	0.17 ***	0.169 ***	0.16 ***	0.156 ***
	(0.024)	(0.02)	(0.017)	(0.016)	(0.016)	(0.016)	(0.016)	(0.017)	(0.020)
LnRE	−0.45 ***	−0.42 ***	−0.38 ***	−0.361 ***	−0.342 ***	−0.32 ***	−0.31 ***	−0.282 ***	−0.25 ***
	(0.023)	(0.02)	(0.02)	(0.016)	(0.015)	(0.015)	(0.016)	(0.017)	(0.02)
LnGDP	0.37 ***	0.38 ***	0.43 ***	0.439 ***	0.454 ***	0.47 ***	0.482 ***	0.501 ***	0.53 ***
	(0.034)	(0.029)	(0.025)	(0.023)	(0.023)	(0.023)	(0.023)	(0.025)	(0.029)
LnNR	0.039 ***	0.05 ***	0.07 ***	0.072 ***	0.079 ***	0.09 ***	0.09 ***	0.101 ***	0.114 ***
	(0.012)	(0.01)	(0.01)	(0.008)	(0.008)	(0.008)	(0.008)	(0.009)	(0.010)
LnICT	0.07 **	0.06 **	0.058 **	0.056 **	0.053 *	0.05 **	0.048 **	0.045 *	0.041
	(0.034)	(0.03)	(0.024)	(0.023)	(0.0022)	(0.022)	(0.023)	(0.025)	(0.029)
Constant	−1.01 ***	−1.17 ***	−1.35 ***	−1.42 ***	−1.512 ***	−1.61 ***	−1.68 ***	−1.79 ***	−1.95 ***
	(0.284)	(0.244)	(0.205)	(0.193)	(0.187)	(0.188)	(0.192)	(0.21)	(0.245)

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Standard error in parenthesis.

Table 9 also reveals some crucial results. First, renewable energy (LnRE) has a negative and significant effect on CO_2 emissions across all quantiles, from 0.10 to 0.90. Moreover, there is a gradual decrease in the magnitude of the estimated coefficients as quantiles increase. However, statistical significance remains at the 1% level, indicating that renewable energies play a fundamental role in mitigating CO_2 emissions. This result is consistent with that of Vallejo Mata et al. (2024), who found that the consumption of renewable energies reduces pollution in high-income countries, although its effect is smaller in countries with higher CO_2 emission levels. Therefore, there is evidence to not reject Hypothesis 2. Second, economic growth (LnGDP) has a positive and significant effect on CO_2 emissions across all quantiles. Furthermore, in both estimated models, it is observed that the coefficients increase in higher quantiles (0.40 and above). This result reflects the scale effect where, as economies grow, they intensify energy and raw material usage, leading to greater environmental degradation. This finding aligns with the work of Ganda and Panicker (2025) and Bayramli and Karimli (2024). Therefore, empirical evidence supports the non-rejection of Hypothesis 3.

Third, the effect of natural resource rent (LnNR) is positive and significant on CO_2 emissions. This effect is consistent across both models and all quantiles, gradually increasing from the lower to higher quantiles. This result aligns with the work of Ngangnchi et al. (2024) and Patel and Mehta (2023), supporting the non-rejection of Hypothesis 4. Therefore, economic dependence on the exploitation of natural resources leads to higher levels of polluting gases, which are detrimental to the environment. Finally, information and communication technologies (LnICT) show a positive effect on CO_2 emissions in both models and across all quantiles. However, their statistical significance is inconsistent, losing relevance in the higher quantiles, specifically at 0.70, 0.80, and 0.90. This result suggests that, despite greater access to information, pollution levels continue to rise. Since statistical significance diminishes across the CO_2 emission distribution, Hypothesis 5 is partially accepted.

The increasing magnitude of the estimated coefficients across higher quantiles suggests that the environmental impact of fiscal decentralization becomes more pronounced in countries with higher levels of CO_2 emissions. This heterogeneous pattern may be explained by the scale and intensity of economic activity in high-emission countries, where decentralized fiscal resources are more likely to be allocated toward infrastructure, energy, and industrial expansion—sectors typically associated with greater environmental pressure. In these contexts, subnational governments often face stronger incentives to attract investment and maintain economic competitiveness, which may lead to the relaxation of environmental controls or prioritization of short-term economic gains over sustainability goals.

Next, in Figures 2 and 3, the trends of the quantile effects of the two models obtained through the MMQR approach are illustrated.

4.5. Robustness Check

Table 10 displays the results from the robustness check using the OLS approach with Driscoll and Kraay standard errors. These findings align with those obtained using the MMQR approach. First, the results show that fiscal decentralization, both through the expenditure side (model 1) and the income side (model 2), has a positive and significant impact on CO_2 emissions. This supports the idea that greater autonomy for local governments is associated with higher levels of pollution. Second, renewable energy reduces CO_2 emissions, confirming its crucial role in promoting environmental sustainability. Third, economic growth, natural resource rents, and information and communication technologies increase CO_2 emissions, though the latter show a lower level of statistical significance.

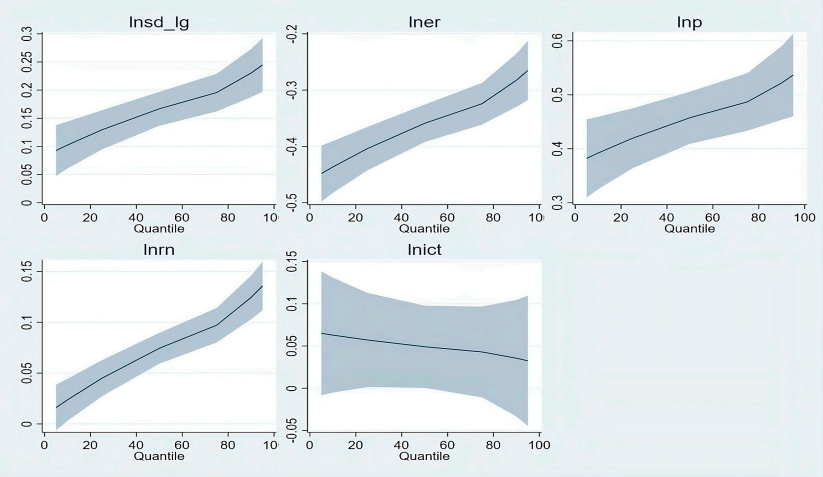


Figure 2. Trend of variables under the quantile approach for Model 1.

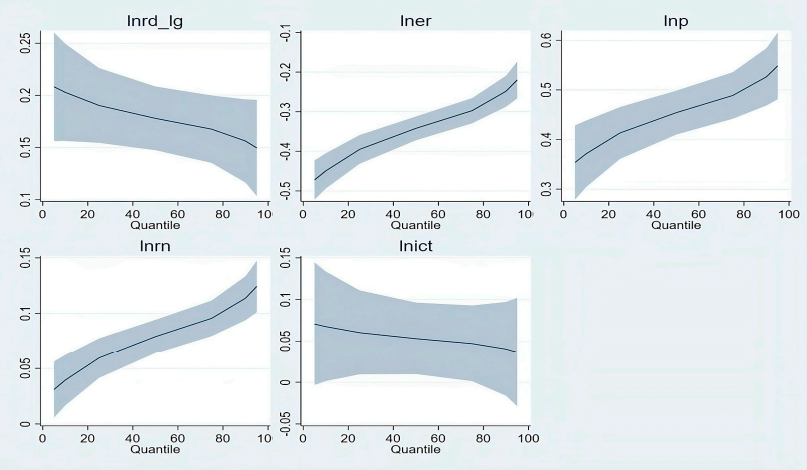


Figure 3. Trend of variables under the quantile approach for Model 2.

Table 10. Robustness check.

Variable	Model 1	Model 2
LnDS	0.17 *** (0.001)	-
LnDI	-	0.18 *** (0.006)
LnRE	−0.36 *** (0017)	−0.35 *** (0.016)
LNGDP	0.46 *** (0.016)	0.45 *** (0015)
LnNR	0.073 *** (0.01)	0.078 *** (0.01)
LnICT	0.05 * (0.024)	0.05 ** (0.022)
Constant	−1.64 *** (0.12)	−1.5 *** (0.11)
R-squared	0.7	0.7
Root MSE	0.43	0.41

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Standard error in parenthesis.

4.6. Brief Discussion of the Results

The findings of this empirical study suggest that fiscal decentralization, in terms of both expenditure and income, has a negative effect on the environment, as it contributes to an increase in CO_2 emissions. This result indicates that subnational and local governments tend to participate in a "race to the bottom" dynamic, prioritizing economic objectives over environmental sustainability, which reduces the efficiency of environmental regulations. When decentralized governments implement incentives with an opportunistic attitude, such as reducing tax rates or relaxing environmental regulations, they can attract investments that boost economic activities with a high environmental impact (Cai et al., 2022). This phenomenon is intensified in contexts of regulatory uncertainty on the part of state institutions (Umar et al., 2024). For example, in scenarios of uncertainty, companies tend to opt for fossil fuels due to their lower cost and greater availability, which allows them to increase their production and, with it, increase CO_2 emissions (Mushtaq et al., 2024). This result is consistent with the findings of S. Wang and Ma (2024), who suggest that fiscal decentralization, in a scenario of low institutional quality, inhibits the development of renewable energies. Furthermore, these factors have hampered technological progress, perpetuated the effects of climate change and made it difficult to meet the Sustainable Development Goals (Zhao et al., 2022).

As illustrated in Figure 2, the results also show that income-side fiscal decentralization has a greater impact on the lower quantiles of CO_2 emissions, while expenditure-side decentralization has a greater effect on the higher quantiles. This heterogeneity can be explained by the fact that, in their eagerness to generate higher tax revenues, local governments tend to establish less strict environmental regulations, which initially encourages a productive structure based on polluting industries (Ji et al., 2021). However, as industries grow and expand, local governments allocate more resources to infrastructure projects, which generates greater pressure on the highest quantiles of CO_2 emissions.

The results show that renewable energies represent an effective mechanism for mitigating CO_2 emissions. By increasing the consumption of renewable energies, such as wind, hydroelectric, solar and geothermal, industries are progressively replacing fossil fuels, which reduces polluting gas emissions throughout the production chain (Chien et al., 2023). Furthermore, renewable energies tend to increase energy efficiency and promote the development of green technologies, which significantly reduces CO_2 emissions. However, the magnitude of the impact tends to decrease in the highest quantiles of CO_2 emissions, which suggests that renewable energies require additional mechanisms, such as higher levels of human capital or financial development, to achieve greater sustainability.

The results indicate that economic growth has a positive effect on CO_2 emissions. This suggests that, as economic activities expand, the demand for raw materials and the use of primary energy increase, leading to higher CO_2 emissions (Bayramli & Karimli, 2024). On the other hand, there is evidence that a greater economic dependence on natural resources also has a positive impact on CO_2 emissions. This finding confirms that the extraction of natural resources is one of the activities that generates the greatest environmental degradation, due to the intensive use of energy from fossil fuels. Furthermore, the income derived from these resources is often used to finance investment projects that contribute to environmental damage, such as infrastructure projects for urban modernization (Krevel & Peters, 2024). Finally, information and communication technologies (ICTs) have a positive and low significance effect on CO_3 emissions. This result is in line with those of Ganda and Panicker (2025) and Weili et al. (2022). In this context, ICTs, as mechanisms that have interconnected markets globally, have promoted the demand for goods and services, increasing production and negatively impacting environmental quality.

5. Conclusions

In a world where concerns about global warming are on the rise, this research analyzed the impact of fiscal decentralization on CO_2 emissions in 40 economies between 2000 and 2020. In addition, the study also evaluated the impacts of renewable energy, economic growth, natural resource rents, and information and communication technologies (ICTs) on environmental quality. Bearing in mind that CO_2 emission intensities vary between economies, the study used the Moment Quantile Regression (MMQR) Model and the pooled OLS approach with Driscoll and Kraay standard errors as a robustness technique. The results of the preliminary tests showed the presence of cross-sectional dependence and slope heterogeneity. In view of these findings, the second-generation unit root test CADF was used, the results of which showed that the variables have a mixed order of integration (I(0) and I(I)). Subsequently, the cointegration tests of Pedroni, Kao and Westerlund were applied, which confirmed that there are long-term equilibrium relationships between the variables.

To evaluate the impact of fiscal decentralization, two models were estimated to differentiate the impacts on the expenditure and income sides. The results obtained using the MMQR approach revealed that fiscal decentralization has a positive and significant impact on CO_2 emissions at all quantiles. This suggests that the action of decentralized governments has followed a "race to the bottom" dynamic, prioritizing economic objectives over environmental considerations. In addition, a heterogeneous effect was identified: income-side decentralization had a greater impact on the lower quantiles, while expenditure-side decentralization had a greater impact on the upper quantiles. Consequently, the relaxation of environmental regulations and the allocation of resources to certain projects with a high environmental impact may explain this result.

On the other hand, it was found that the consumption of renewable energy reduces CO_2 emissions in all quantiles; however, its effect is reduced in the highest quantiles. It was also found that economic growth, natural resource income, and information and communication technologies have a positive influence on CO_2 emissions, although the latter to a lesser extent. These findings reveal that economic activities continue to generate high pressures on the environment, which hinders the comprehensive achievement of the Sustainable Development Goals. Finally, these results were corroborated with Driscoll and Kraay's standard error estimates.

The findings suggest that fiscal decentralization increases CO_2 emissions, although with a differentiated impact depending on its dimension. In terms of elasticity, a 1% increase in expenditure decentralization raises emissions to a greater extent in the upper quantiles, while income decentralization affects the lower quantiles more intensely. This result implies that mitigation strategies must be adapted to the fiscal and environmental characteristics of each country. For economies with high levels of emissions, it is recommended to establish strict regulatory limits on the use of decentralized spending, promoting budget allocations linked to investments in renewable energy and energy efficiency. In contrast, for economies with lower emissions, it is essential to improve local revenue collection through progressive environmental taxes and control mechanisms that avoid regressive tax competition between regions. In addition, the mitigating effect of renewable energy highlights the need for more effective tax incentives to accelerate the energy transition, especially in economies with a high dependence on fossil fuels. These measures, aligned with responsible fiscal decentralization, could reduce rigidity in the allocation of resources, optimizing environmental sustainability without compromising economic growth.

Although the findings of this research are relevant, it has certain limitations that can be addressed by future research. Firstly, only the direct effect of fiscal decentralization has been evaluated, while the indirect effects through other economic, political and social

channels have not been analyzed. Therefore, it is recommended that future studies opt for an analysis of indirect effects, which would allow for a more in-depth evaluation of the implications of fiscal decentralization on the environment. In addition, interaction analyses could also be carried out, revealing how the effect of decentralization could mitigate environmental damage. In this sense, variables that measure institutional quality could be added. Secondly, other econometric methodologies can be implemented to deepen the analysis of fiscal decentralization, such as vector autoregressive (VAR) models which, through the impulse-response function, reveal more information about the link between fiscal decentralization and the environment. Finally, it is recommended to use other control variables, such as urbanization, trade openness, technological innovation or specific environmental policies.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Countries considered in the empirical analysis.

Armenia	China	Israel	Peru
Australia	Colombia	Japan	Russia
Austria	El Salvador	Latvia	Serbia
Azerbaijan	Estonia	Lithuania	South Africa
Belarus	Finland	Mauritius	Spain
Belgium	Georgia	Mexico	Sweden
Bosnia and Herzegovina	Germany	Mongolia	Switzerland
Brazil	Honduras	Netherlands	Thailand
Canada	Hungary	New Zealand	Ukraine
Chile	Iceland	Paraguay	United Kingdom

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