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Environmental Regulation and Renewable Energies: Evidence from Generalized Panel Unconditional Quantile Regression

Abstract
This study aims to measure the impact of environmental regulation on the production of renewable energies in OECD countries from 1990 to 2021. Environmental policies stringency, environmental taxes, and CO2 emissions are variables indicating environmental regulation, which affect renewable energies production. The study relied on unconditional quantitative regression methods. The study found that strict environmental policies do not necessarily enhance renewable energy production in countries with high or low production. Moreover, environmental tax revenues have varying impacts on renewable energy production based on renewable energy production in each country. For countries with below-average levels of renewable energy (Q25), environmental taxes positively affect renewable energy production; however, in countries with high production levels (Q90), environmental taxes show a negative effect. Furthermore, CO2 emissions negatively affect the total production of renewable energy in all quantiles except Q50, whereas R&D spending positively affects renewable energies in all quantiles except Q75. The estimates also showed a significant negative effect of patents on the renewable energy production in quantile Q10. The results underscore the importance of flexibility and adaptability in environmental policies and taxes. Finally, the study indicates that policies must be dynamic and respond to the specificity of each stage of renewable energy development in the studied countries.

Keywords
stringency of environmental policies | environmental taxes | CO2 emissions | production of renewable energies | quantile regression

JEL Codes
C01, K32, Q42

1. Introduction

The global energy crisis includes increasing growth in the global demand for energy, with limited reserves available from traditional sources, and the rise of prices since 2014. Another issue is the international interest in confronting the phenomenon of climate change. In this context, both local and international interest in discussing energy issues is compulsory in order to achieve sustainable development goals by shifting from an economy based on traditional energy to an economy based on a sustainable one.

Energy transition refers to the global energy sector's shift from fossil-based systems of energy production and consumption—including oil, natural gas, and coal—to renewable energy sources such as wind, solar, and lithium-ion batteries (S&P Global, 2020).

The energy transition is a continuous process requiring long-term energy strategies and planning with a country-tailored focus on applying appropriate energy technologies to reach net-zero emissions (United Nations Development Programme, 2023).

In 2015, the United Nations Climate Change Conference (UNFCCC) in Paris adopted a transformative universal climate change agreement. This landmark agreement articulates the social and economic opportunities offered by low emissions and a climate-resilient future. It also articulates the intrinsic relationship between climate change action, sustainable development, and poverty eradication. The 2015 Paris Agreement represents a historic turning point as a global response to the need for urgent action at scale to mitigate climate change. At the same time, the UN 2030 Agenda and the Sustainable Development Goals (SDGs) call for action by all countries to improve people's lives everywhere (United Nations, 2018, p. 3).

Seventeen SDGs were announced, with goal number seven defining targets to "ensure access to affordable, reliable, sustainable and modern energy for all" (United Nations Economic Commission for Europe, n.d.).

Both the Paris Agreement and the 2030 Agenda (with SDGs, particularly SDG 7) set clear directions and paths for humanity towards a development powered by clean energy. These agreements are based on the efficient use of resources and are defined by resilience to climate impacts (United Nations, 2018, p. 3).

Energy transition is driven by a combination of factors, including environmental regulations. Environmental regulation refers to the imposition of limitations or responsibilities on individuals, corporations, and other entities to prevent environmental damage or improve degraded environments (McManus, 2009).

Environmental regulations can have a significant influence on energy transition performance in several ways (Zou and Wang, 2023):

- Stringent environmental regulations, such as emissions standards and renewable energy targets, can incentivize industries and individuals to transition towards cleaner energy sources.
- Environmental regulations can drive technological advancements and innovation in the energy sector.
- Clear and consistent environmental regulations provide stability and certainty for businesses and investors in the energy sector.
- Environmental regulations can influence consumer behavior and energy consumption patterns.

The present study sheds light on the relationship between environmental regulation and renewable energy production in OECD countries during 1990–2021. The study relied on unconditional quantitative regression methods. To determine the effects of the independent variables on the distribution of the dependent variable, we used quantile regression, which allows for several effects of the independent variables on the dependent variable.

We divide the article into multiple sections. First, the introduction addresses environmental regulation and renewable energies. In the second section, we review the literature. In the third section, we examine the existing body of literature. In the fourth section, we examine the results of the study. Lastly, we provide some concluding remarks.

2. Literature Review

Many authors have tackled the relationship between environmental regulations and energy transition. According to the available literature, we can divide them into studies that found a negative relationship between the two variables and studies that found a positive relationship, i.e., environmental regulations can lead to an increase in renewable energy production or consumption. In addition, some studies have used renewable energy consumption; in contrast, others have used renewable energy production, represented by the number of patents in renewable energy or the renewable energy capacity.

Concerning the first group of studies, Bashir et al. (2022) suggested that environmental regulations impede renewable energy consumption in OECD economies. In addition, Li et al. (2022) claimed that in BRICST (Brazil, Russia, India, China, South Africa, Turkey) economies, the environmental stringency index contributed positively to renewable energy consumption with low consumption of renewable energy and vice versa. Likewise, Huang and Zou (2020) found that energy-specific environmental regulation has a significant positive impact on energy transition in China; however, this impact is weakened by high-energy intensity.

Moreover, in several studies, environmental taxes have been found to harm the production of renewable energy (Bilan et al., 2022; Altay Topcu, 2023; Dogan et al., 2023). In addition, the research of Farhan Bashir et al. (2020) conducted on biofuel production and consumption indicated a significant impact of environmental taxation on the volumes of biofuel production and consumption. Similarly, the empirical results of the work of Regueiro-Ferreira and Cadaval Sampedro (2022) suggested that increasing environmental taxes hinders the deployment of renewable energy in EU countries.

However, many studies found a positive relationship between renewable energy production or consumption and environmental regulations. For instance, Wissema and Dellink (2007) discovered that a carbon energy tax of 10–15 euros per tonne of CO_2 could achieve a 25.8% reduction target in Ireland; simultaneously, it stimulates renewable energy use and reduces peat and coal use. In addition, Nesta et al. (2014) found that renewable energy policies are more effective in fostering green innovation in countries with liberalized energy markets. We also find that environmental policies are crucial only generating high-quality green patents, whereas competition enhances the generation of low-quality green patents. Moreover, Hille et al. (2020) concluded that more comprehensive portfolios of renewable energy support policies increase patenting in solar and wind-power-related technologies.In addition, Godawska and Wyrobek (2021) claimed that stringent environmental policies, eventually improve renewable energy production and the replacement of energy from fossil sources. Barnea et al. (2022) revealed that market-based instruments (MBIs) affect renewable energy production. Regulatory and market instruments, along with electoral democracy and government effectiveness, expand wind and solar electricity production. Furthermore, Zhang et al. (2022) found that economical environmental regulations have the greatest positive impact on sustainable growth for renewable energy enterprises. In contrast, resource endowment has a negative moderating effect on environmental regulations and growth. Similarly, Yang and Zhong (2022) concluded that green supervision and public regulations significantly enhance renewable energy investments in China, while green accounting regulations show no significant impact.

Zhang and Chen (2022) also found a mutual promoting effect between renewable energy technological innovation and environmental regulation intensity. Additionally, the findings of Dzwigol et al. (2023) confirmed that environmental regulation has a mediating positive effect on interconnections among knowledge spillover, innovations, and renewable energy.

Moreover, Zhao et al. (2022) showed that environmental regulation significantly contributes to renewable energy development. Liu et al. (2023b) exhibited that green energy investment, financial development, and environmental policy stringency eventually stimulate sustainable energy transition. Manifestly, the interaction between financial development and ecological regulations offers a comparatively stronger influence than their individual effects, implying that effective environmental regulations direct the movement of financial resources toward the renewable energy transition. Lastly, Ulfatun Najicha et al. (2023) concluded that transition management has an essential role in the shift towards renewable energy production. It involves proactive management and acceleration of transitions in the energy sector, focusing on securing energy justice. The just transition management framework combines transition management with the concept of “just transitions” in order to mitigate negative impacts on workers and communities in traditional energy production regions. This framework can help identify political barriers to transitions and achieve distributional, recognition, and procedural justice in the energy sector.

Some works focused on the link between environmental regulations and renewable energy efficiency. For example, Zhang and Du (2022) claimed that environmental regulation directly improves the green energy efficiency of polluting industries and clean industries, and it has a positive intermediary role between technology and green energy efficiency in China. Similarly, Liu et al. (2023a) had multiple findings. First, there are four green energy efficiency enhancement paths: the government pressure type, the market mobilization type, the government-led public association type, and the multiple subject type. Second, the command-and-control type of environmental regulation enhances green energy efficiency in most provinces of China. Third, the multiple subject type of enhancement paths can achieve higher green energy efficiency.

Finally, Zou and Wang (2023) examined the relationship between environmental regulation and energy transition performance in China. The study employed statistical analysis techniques to analyze the correlation between environmental regulation stringency and various energy transition metrics, including renewable energy capacity, carbon intensity, and energy efficiency. The findings provided valuable insights into the role of environmental regulation in shaping China's energy transition landscape. .

To conclude, other recent studies are close to ours. We mention Hasan et al. (2023), who found that fossil fuel consumption leads to environmental deterioration, while renewable energy consumption, financial development, and trade openness enhance environmental quality. Additionally, the results support the validity of the EKC (Environmental Kuznets Curve) hypothesis for all BRICS countries (Brazil, Russia, India, China, and South Africa). In addition, Yang et al. (2023) employed the novel quantile-based econometrics approach of "Method of the Moments Quantile Regression" (MMQR), which provides the direction and magnitude of the asymmetric association of natural resources NTR, green finance GFN, green energy GEC, and economic growth GDP with the ecological footprint. This test's results revealed that the NTR and GDP have a significantly positive influence, whereas GEN and GEC have significantly negative associations with an ecological footprint across all quantiles. This implied that green finance and green energy work as the solution, while natural resources and economic growth are key drivers of environmental degradation. Lastly, Igeland et al. (2024) indicated that economic policy uncertainty (EPU) positively impacts the returns of renewable stocks, attributing that to an increased engagement towards a renewable transition.

3. Study Variables and Model

This study aims to estimate the impact of environmental regulation on the production of renewable energies to judge whether environmental regulation has contributed to maximizing the roles of innovation. Thus, it contributes to the creation of new investments in clean industries and environmentally friendly sectors, and it expands production in these sectors. This is done by considering the impact of environmental policy strength (EPS), environmental related tax revenue (ERTR), research and development expenditure (RDE), patents (patent applications, residents) (PAR), CO_2 emissions (CO_2EME), environmentally adjusted multifactor productivity growth (EAMPG), households and NPISHs (Non-profit institutions serving households) final consumption expenditure (FCE), and gross fixed capital formation (GFCF) on total renewable energy (TRE). Accordingly, the model is written as follows:

$$TRE=f(EPS,ERTR,CO2EME,EAMPG,PAR,RDE,FCE,GFCF)$$

The OECD database was relied on for study data related to the production of renewable energies, the stringency of environmental policies, environmental taxes, CO_2EME , and EAMPG. We also relied on the World Bank database for the variables of family expenditure, fixed capital accumulation, research and development (R&D) expenditures, and patents.

4. Method and Tools

Estimation has two strategies. The first strategy is static panel data analysis; in this strategy, we used the Fisher test to compare pooled and fixed effects, and in the next step, we used the Hausman test to distinguish fixed and random effects models. To assess the model's statistical robustness, we used the Pesaran test to confirm that the residuals are not correlated at the cross-sectional level. Next, we tested heteroscedasticity using the modified Wald test. Additionally, to test autocorrelation, we applied the Wooldridge test. Conversely, if one of these three difficulties exists, the model must be estimated using feasible generalized least squares.

The findings of the Fisher test reveal that the fixed effects (FE) model is more valid and effective than the pooled model. The Hausman test showed that the FE model is more effective than the random effects (RE) model; thus, we use it for the rest of the robustness tests. In the Pesaran CD test, residuals correlate at the cross-sectional level. Heteroskedasticity is seen in the modified Wald test. Furthermore, the Wooldridge test showed an autocorrelation of residuals. We must estimate FE using the feasible generalized least squares (FGLS) method.

The second method uses unconditional quantile regression. One of the main benefits of the ordinary least squares approach is its consistent estimation of the independent variables' impact on the dependent variable. The law of iterative expectations converges the conditional mean E(Y/X) to the unconditional mean E(Y). Therefore, conventional least squares calculate the independent variables' influence on the dependent variable's mean value without considering how they affect one of its levels.

Quantile regression is among the most important econometric methods that seek the effects of independent variables on the distribution of the dependent variable (Martínez-Zarzoso et al., 2019). In addition, the production of renewable energies and their levels differ between the countries under study. Therefore, research on the factors affecting the production of renewable energies requires that it be built based on quantile regression estimates to avoid problems of heterogeneity in the distribution of data. This type of regression is more robust than OLS (ordinary least squares) due to the problems of heterogeneity, outliers, and structural change. This allows us to draw conclusions about the influence of independent variables on the distribution of the dependent variable.

Koenker and Bassett (1978) first introduced quantile regression, where the parameters of the model β ˆ_τ represent the marginal effect of the variable X on the quantile τ of the distribution Y conditional on the average values of all other variables. This type is called conditional quantile regression, which takes into account the distribution of independent variables. Therefore, conditional quantile regression provides us with the marginal effect of the variable X on the quantile τ of the distribution Y, taking into account all changes occurring in these independent variables.

According to Firpo et al. (2009), conditional quantile regression does not answer the question that aims to search for the marginal effect of the variable X on the quantile τ of the distribution Y, with other factors remaining constant. In this context, Firpo et al. (2009) developed a method to search for the marginal effect of the variable X on the quantile τ of the distribution Y with other factors remaining constant, called unconditional quantile regression. In this method, we obtain the parameters of β ˆ_τ that correspond to the effect on the quantity τ of Y regardless of the changes occurring in the rest of the independent variables. The parameters are estimated based on the recentered influence function (RIF). This type of regression provides us with two types of parameters. The first parameter represents the marginal effect of the variable X on the quantile τ of the distribution Y. The second parameter represents the effects of overall changes in the distribution of independent variables (policy effect) on the quantile τ of the distribution Y based on a non-parametric approach.

5. Results and Discussion

Table 1 provides detailed data on the main statistical descriptive measures, including the mean, standard deviation, and minimum and maximum values of dependent and independent variables across sample countries. Growth rate exhibited the highest volatility values per the standard deviation metrics, whereas the ERTR demonstrated the lowest values. Furthermore, based on the results of the Jarque–Bera test, it was determined that six of the variables exhibited a non-normal distribution at a significance level of 5%, whereas two variables had a normal distribution. The findings from Table 2 show that there is no high correlation among the variables, indicating the absence of multicollinearity in the estimated model.

The results of the static model estimation confirm the significant positive effect of stringent environmental policies, environmental tax revenues, CO_2 emissions, patents, and investment in total renewable energies. In contrast, the outcomes of the static model estimation show the significant negative effect of both the growth rate and spending on R&D on total renewable energy.

Estimates of unconditional quantile conventional standard errors show a significant positive effect of the stringency of environmental policies in the quantiles Q25, Q50, and Q75 related to the distribution of total renewable energies. This means that the stringency of environmental policies does not lead to an increase in the levels of renewable energies in countries characterized by high and weak levels of renewable energies. The results maintain their statistical significance with the estimates: bootstrapped standard errors. In contrast, these results keep their statistical significance with the Q75 quantile with both the cluster–robust standard errors and the cluster–bootstrapped standard errors.

Additionally, the estimates reveal a significant positive effect of environmental tax revenues on total

Table 1. Statistics Descriptive of Variables Study

Variable	Mean	Std. dev.	Min	Max	Jarque–Bera test	*p*-value
Total renewable energy	9.716629	1.999758	2.890372	15.08672	84.71	0.0000
Environmental policy stringency	2.03709	1.174578	0	5.055555	318.99	0.0000
Environmentally related tax revenue	6.581747	0.8795824	2.88759	8.155826	1224.68	0.0000
CO_2 emissions	11.58532	1.558937	7.152589	15.56919	3.04	0.2184
Patent applications	7.402104	2.23668	0.8526029	12.86712	28.80	0.0000
Research and development expenditure	1.676507	0.9343578	0.25067	5.00197	16.47	0.0003
Growth rate	2.218023	4.115878	-14.62906	24.37045	801.61	0.0000
Gross fixed capital formation	25.00864	1.651858	20.30501	29.2283	3.56	0.1686
Observations: N =1056, n =33, T =32						

Source: STATA 16.0

Table 2. Correlation Matrix

	Total renewable energy	Environmental Policy Stringency	Environmentally Related Tax Revenue	CO_2 emissions	Patent applications	R&D expenditure	Growth rate	Gross fixed capital formation
Total renewable energy	1.0000							
Environmental policy stringency	0.2096	1.0000						
Environmentally related tax revenue	−0.0489	0.3926	1.0000					
CO2 emissions	0.4253	0.0516	−0.1258	1.0000				
Patent applications	0.5782	0.2537	0.0420	0.5957	1.0000			
R&D expenditure	0.3516	0.4917	0.3552	0.1887	0.5100	1.0000		
Growth rate	−0.0482	−0.1153	0.0676	−0.0168	−0.0567	−0.0056	1.0000	
Gross fixed capital formation	0.6874	0.4009	0.0238	0.6294	0.8670	0.4277	−0.0520	1.0000

Source: STATA 16.0

renewable energies in Quantile Q25. It also shows the significant negative effect of environmental tax revenues on the total renewable energies in Quantile Q90. These results maintain their statistical significance with the estimates: bootstrapped standard errors in addition to the statistical significance of the negative impact of Q50 in these estimates. These results also maintain their statistical significance with the quantile Q25 with the cluster–robust standard errors. This indicates that environmental tax revenues contribute to increasing total renewable energies in countries with lower-than-average levels of renewable energies. However, they adversely affect total renewable energies in countries with medium and high levels.

Table 3. Total Renewable Energy Static Models

	Pooled	Fixed	Random	GLS
Environmental policy stringency	–.273***	.152***	.145***	.056***
Environmentally related tax revenue	–.161***	–.029	–.038	.08***
CO_2 emissions	–.045	–1.297***	–.805***	.203***
Patent applications	–.208***	.026	.016	.196***
Research and development expenditure	.428***	.433***	.443***	–.028***
Growth rate	–.014	–.034***	–.031***	–.004***
Gross fixed capital formation	1.077***	.44***	.475***	.286***
_cons	–14.236***	12.773***	6.329***	–1.848***
Observations	1056	1056	1056	1056
**** p<.01, ** p<.05, * p<.1*				

Source: Prepared by the authors based on STATA 16.0

Table 4. Total Renewable Energy Non-Robust

	Q10	Q25	Q50	Q75	Q90
Environmental policy stringency	–.177	.177*	.201***	.563***	–.016
Environmentally related tax revenue	.184	.241***	–.086	–.013	–.159**
CO_2 emissions	–2.585***	–.698**	–.01	–1***	–2.162***
Patent applications	–.779***	–.188	.115	.043	–.056
Research and development expenditure	.862***	1.074***	.196*	–.148	.391***
Growth rate	–.017	–.035***	–.045***	–.011	–.013
Gross fixed capital formation	2.201***	.658***	.182	–.65***	–.128
_cons	–14.352*	–2.208	4.678	37.747***	40.951***
Observations	1056	1056	1056	1056	1056
**** p<.01, ** p<.05, * p<.1*					

Source: Prepared by the authors based on STATA 16.0

Furthermore, the estimates indicate a significant negative impact of CO_2EMEs on the total production of renewable energy in all quantiles except Q50. These results maintain their statistical significance with the estimates: bootstrapped standard errors, which indicates that CO_2EMEs weaken the levels of renewable energy production. In all countries other than those with intermediate levels, these results maintain their statistical significance with the Q10 quantile with the estimates: cluster–robust standard errors. In contrast, these results keep their statistical significance with Q90 with the cluster–robust standard errors and cluster–bootstrapped standard errors in most quantiles.

Additionally, the estimates display a significant positive effect of spending on R&D on total renewable energies in all quantiles except Q75. These results maintain their statistical significance with the estimates: bootstrapped standard errors. This indicates that spending on R&D increases the levels of renewable energies in all countries except the ones with above-average levels. These results also maintain their statistical significance with Q90 with cluster–robust standard errors. In contrast, these results keep their statistical significance with Q25 with the estimates: cluster–robust standard errors and cluster–bootstrapped standard errors.

Table 5. Total Renewable Energy Cluster-Robust

	Q10	Q25	Q50	Q75	Q90
Environmental policy stringency	–.177	.177	.201	.563**	–.016
Environmentally related tax Revenue	.184	.241*	–.086	–.013	–.159
CO_2 emissions	–2.585*	–.698	–.01	–1	–2.162*
Patent applications	–.779	–.188	.115	.043	–.056
Research and development expenditure	.862	1.074**	.196	–.148	.391*
Growth rate	–.017	–.035	–.045*	–.011	–.013
Gross fixed capital formation	2.201**	.658	.182	–.65**	–.128
_cons	–14.352	–2.208	4.678	37.747***	40.951***
Observations	1056	1056	1056	1056	1056
**** p<.01, ** p<.05, * p<.1*					

Source: Prepared by the authors based on STATA 16.0

Table 6. Total Renewable Energy Bootstrap

	Q10	Q25	Q50	Q75	Q90
Environmental policy stringency	–.177	.177**	.201***	.563***	–.016
Environmentally related tax rRevenue	.184	.241**	–.086*	–.013	–.159**
CO_2 emissions	–2.585***	–.698**	–.01	–1***	–2.162***
Patent applications	–.779***	–.188	.115	.043	–.056
Research and development expenditure	.862***	1.074***	.196*	–.148	.391***
Growth rate	–.017	–.035***	–.045***	–.011	–.013
Gross fixed capital formation	2.201***	.658***	.182**	–.65***	–.128
_cons	–14.352	–2.208	4.678	37.747***	40.951***
Observations	1056	1056	1056	1056	1056
**** p<.01, ** p<.05, * p<.1*					

Source: Prepared by the authors based on STATA 16.0

The findings also reveal a significant negative impact of the number of patents on total renewable energies in the Q10 quantile, meaning that patents reduce the levels of renewable energies in countries with weak levels. These results maintain their statistical significance with the estimates: bootstrapped standard errors.

In addition, the results show a significant negative effect of economic growth on total renewable energies in Quantile Q25 and Quantile Q50. These results maintain their statistical significance with estimates of bootstrapped standard errors. They also keep their statistical significance with the quantile Q50 with the cluster–robust standard errors, which indicates that economic growth weakens renewable energies in countries with average and below-average levels.

Additionally, the findings reveal a significant positive effect of investment on the total renewable energies in Quantiles Q10 and Q2, as well as a significant negative effect of investment on total renewable energies in Quantile Q75. These results maintain their statistical significance with the estimates: bootstrapped standard errors, alongside the significance of the statistical positive effect of quantile Q50 in these estimates. In addition, these results maintained their statistical significance with Quantile Q10 and Quantile Q75 with each of the following: cluster–robust standard errors and cluster–bootstrapped standard errors. This

Table 7. Total Renewable Energy Cluster-Bootstrap

	Q10	Q25	Q50	Q75	Q90
Environmental policy stringency	–.177	.177	.201	.563***	–.016
Environmentally related tax revenue	.184	.241	–.086	–.013	–.159
CO_2 emissions	–2.585	–.698	–.01	–1	–2.162***
Patent applications	–.779	–.188	.115	.043	–.056
Research and development expenditure	.862	1.074*	.196	–.148	.391
Growth rate	–.017	–.035	–.045	–.011	–.013
Gross fixed capital formation	2.201**	.658	.182	–.65**	–.128
_cons	–14.352	–2.208	4.678	37.747***	40.951***
Observations	1056	1056	1056	1056	1056
**** p<.01, ** p<.05, * p<.1*					

Source: Prepared by the authors based on STATA 16.0

indicates that investment contributes to increasing the levels of renewable energy in countries with average, below-average, and weak levels while reducing the levels of renewable energies in countries with above-average levels.

Regarding the effects of stringent environmental policies, the estimation results show that in countries with a weak production of renewable energy, stringent environmental policies do not maximize the production of this type of energy. We can say that a group of factors determines the relationship between strict environmental policies and renewable energy production in countries with weak production and weak infrastructure for the production of renewable energies. These factors include high initial investment costs and excessive economic dependence on fossil fuels. This constitutes a major challenge to the energy transition because switching to renewable energy sources requires significant financial resources as well as comprehensive economic restructuring of many economic and production sectors. In addition, the lack of technical knowledge and technology, the weak implementation and enforcement of environmental policies, and inadequate incentives hinder the development of renewable energy and obstruct energy transition pathways.

Concerning countries with high levels of renewable energy production, more stringency in environmental policies is neither effective nor necessary in promoting renewable energy production; rather, additional stringent environmental policies may lead to diminishing returns. This is because the easiest and most impactful initial changes have already been implemented, and the policy spheres of influence have been exhausted. Therefore, the effectiveness and necessity of stricter environmental policies become more precise. Notably, the necessity in this case may require shifting the focus from increasing production to improving, integrating, and efficiently using renewable energy in addition to achieving a balance among economic, social, and global considerations.

Regarding countries with medium and high renewable energy production, strict environmental policies can be viewed as responses to the limited nature and environmental externalities of traditional energy sources. In this context, some environmental policies and regulations require a specific percentage of energy to come from renewable sources or set targets for renewable energy production. These plans guarantee a market for renewable energies and encourage investment and development in this sector. By contrast, the previous results indicate that stringent environmental policies would contribute to creating regulations and restrictions on non-renewable energy sources and strict restrictions on emissions, making traditional sources of energy less attractive from an economic standpoint. This creates a market incentive for energy producers to shift towards renewable energy sources, increase investment in associated technologies, and adopt cleaner technologies to comply with environmental standards. This is consistent with the MBI.

Moreover, the results support the arguments assumed by the institutional theory. Among the arguments is that strict environmental policies should create a new institutional environment that encourages the adoption of clean and sustainable practices. Organizations should modify their strategies and operations to comply with environmental standards, leading to increased investment in and use of renewable energy sources. That also confirms the impact of the dynamics of transition management from traditional energy systems to sustainable energy systems.

Finally, the differential impact across quantiles indicates the need for a more nuanced and tailored approach to environmental policy. Policies should consider the current level of renewable energy production in a country. For countries with low renewable energy production, policies can focus on incentives and support mechanisms for the private sector to increase renewable energy production, concurrently achieving some production through government investments in this field. In contrast, countries with high levels of production require different strategies. One strategy is shifting the focus of policies from increasing production to complementary or more influential aspects, such as improving efficiency or exporting renewable energy. This is essential for the global environmental efforts by focusing on technology transfer, sharing practices, and supporting development and investment in renewable energy in less developed countries rather than intensifying private environmental policies. For the remaining groups of countries, it is necessary to design effective environmental policies and efforts to measure the impact and evaluation of these policies and to identify the goal gaps to be achieved and the levels of necessary interventions. In addition to strengthening international cooperation, technology transfer and supporting frameworks are necessary to promote greater growth of renewable energy production in these countries.

Concerning the environmental impacts of taxes, environmental tax revenues have a positive impact on total renewable energy for countries with renewable energy production capacities at a lower-than-average level. This indicates that in countries at the beginning of the energy transition, environmental taxes effectively encourage the development of renewable energy sources and support this transition. This result can be attributed to contributions linked to recycling tax revenues and investing them in renewable energy projects or providing support and incentives to institutions developing renewable energy production. For countries at that level, it is desirable to maintain or increase environmental taxes. Proceeds should be strategically reinvested in renewable energy projects, and policies could include tax incentives or subsidies for companies and consumers who adopt renewable energy sources.

On the other hand, for the total number of countries that make up 90 quantiles, the results indicate that environmental taxes hinder the growth of production for renewable energies. This is related to the effects of the tax burden and the resulting diminishing returns, as was indicated by the impact of stringent environmental policies. For these countries, it is important to reconsider and re-evaluate the structure of environmental taxes and their application areas to avoid burdening the renewable energy sector. Supportive interventions through targeted subsidy mechanisms are also necessary to sustain growth in this sector.

Finally, in countries with medium levels of renewable energy production (Q50), the large negative effect indicates thresholds for transition in the impact of environmental policy instruments. This shows that in countries with acceptable levels of renewable energy production, environmental taxes may reach a turning point, as its negative effects begin to outweigh the benefits. Therefore, a careful balance must be achieved in implementing environmental policies through harmonization between tax tools and other environmental regulation tools. It may be necessary to adjust the level of environmental taxes or redirect their revenues towards more efficient and targeted support for the renewable energy sector. Notably, it is important to design environmental tax policies to allow flexibility and adaptability to changing economic and environmental conditions and to the goals of transitioning towards renewable energies. The process of regular monitoring and evaluation of the results and effects of environmental tax policies is vital to evaluate their effectiveness. According to the levels reached by the country in the production of renewable energies, regular reviews and evaluations of policies should be conducted to assess the materiality and the thresholds of their impact, to identify potential improvements, and to ensure that they remain in line with the development production goals in this sector.

Additionally, the study results reveal a complex relationship between CO_2EMEs and renewable energy production. It highlights the challenges that countries, especially those in transition, face in balancing the immediate economic and environmental costs with the long-term benefits of a sustainable energy transition. While increased emissions generally lead to a decrease in the production of renewable energies, the effect is not uniform across all countries under study regarding their level of renewable energy production. However, this trend does not persist in the middle group (Quantile 50), suggesting that in countries with medium levels of renewable energy production, increased CO_2EMEs are driving the adoption and production of renewable energies, which supports the energy transition.

Accordingly, in their transitional phase, these countries increased their carbon footprint by building the necessary infrastructure for renewable energy. This stage is crucial because it represents the transition from traditional energy sources to sustainable sources. Despite increasing emissions, this transition is vital for long-term sustainability. In economic terms, it reflects a significant investment phase, where short-term costs (both economic and environmental) are incurred to achieve long-term gains. This phase can be financially challenging and may require support through economic policy incentives, international aid, or local and international technology and private–public sector partnerships.

The relationship between spending on R&D and the production of renewable energies can be explained by the technological progress generated by the efficiency of spending on R&D. The efficiency of R&D policies and plans as well as the increase in financial allocations for R&D lead to the development of new technologies and the efficiency of innovations in the renewable energy sector. Furthermore, R&D efforts help reduce the cost of renewable energy technologies by improving the manufacturing and production processes. Lower costs also make renewable energy more competitive with fossil fuels, encouraging increased investment and production, not to mention there are implications associated with efficiency improvements in renewable energy systems, enabling them to generate more energy with the same amount of resources.

On the other hand, the effects of patents on total renewable energies contradict the proposition of environmental innovation and technological change in Porter's hypothesis. This finding can be linked to the effects of technology lock-in. In some cases, countries that invest heavily in patented non-renewable technologies experience technology lock-in. Consequently, the development of production processes and investment recede and concentrate within the areas of existing technologies due to large investments, which hinders the transition towards renewable energies. Alternatively, patent holders may exercise their patent rights to create regulatory barriers to entry in the renewable energy sector, making it difficult for new technologies and players to enter the market.

There is an overlapping relationship between spending on R&D and patents. Therefore, in order to enhance the positive impact of spending on R&D on renewable energies and to reduce the negative impact of patents on the production of renewable energies, R&D expenditures need to be allocated to areas of research in renewable energy. Moreover, a fund must be established for renewable energy technology innovation. Next, it is necessary to formulate licensing measures related to core renewable energy technologies and to encourage patent holders to license their technologies at affordable prices to promote a more open and collaborative ecosystem within the renewable energy sector. Emphasizing the importance of public–private partnerships by creating and strengthening innovation networks, which bring together government agencies, research institutions, and energy industry stakeholders. This supports the development of common standards and open-source technologies to accelerate innovation and reduce the cost of renewable energy production.

To conclude, the present study focused on the complex and diverse effects of environmental regulation on various renewable energy production levels for each country under study. The findings intersect with previous study results and differ from another set, considering that the current study addresses the varying impacts based on different levels of advancement in renewable energy production.

Regarding the effects of environmental policy stringency, previous studies have often indicated a positive relationship between environmental policy stringency and the promotion of renewable energy production, such as in studies by Hille et al. (2020); Nesta et al. (2014); and Wissema and Dellink (2007). These findings are supported by Dzwigol et al. (2023); Godawska and Wyrobek (2021); He (2023); Jafri and Liu (2023), Lu et al. (2022); and Mihai et al. (2023).

However, the current study suggests that stringent environmental policies do not uniformly work to enhance renewable energy production across countries with different production levels. This variation may reflect methodological differences, such as the use of Generalized Panel Unconditional

Quantile Regression, which allows for a precise analysis of renewable energy production distribution on different levels.

Concerning the impact of environmental taxes, previous research has concluded a positive relationship between environmental taxes and renewable energies in production and consumption. For instance, Andersen and Ekins (2019) suggested that environmental taxes can incentivize renewable energy by making fossil fuels more costly. Shayanmehr et al. (2023) found that environmental taxes directly and significantly contribute to shifting the energy structure towards environmentally friendly sources as well. In addition, Dashoor and Abdullah (2023) state that green taxes increase investments in renewables, job opportunities, and the production of green electricity. These findings are supported by Ayodele et al. (2023); Bashir et al. (2021); Máté et al. (2023); and Peng et al. (2022).

However, in several studies, environmental taxes were found to harm the production of renewable energy, such as Altay Topcu (2023); Bilan et al. (2022); Dogan et al. (2023); Farhan Bashir et al. (2020); and Regueiro-Ferreira and Cadaval Sampedro (2022). The results of this study show that the impact of environmental taxes varies significantly across different levels of renewable energy production in countries. We conclude that there is a negative relationship between environmental taxes and renewable energies in a group of countries, whereas an inverse relationship is evident in another group of countries. This confirms the importance of designing tax policies tailored to the economic context, the levels of development of each country's renewable energy sector, and the production levels achieved.

Lastly, compared to previous experimental literature, the variation in results in some aspects can be linked to the econometrics approaches used in this study. The adopted methodology enables modelling the effects of economic relationships across different production levels, allowing for a more detailed understanding of how environmental regulation impacts renewable energy production at various points in the distribution chain. This relatively new approach provides insights that may be obscured in traditional regression techniques studies.

6. Conclusion

Finally, the study reveals that strict environmental policies do not necessarily enhance renewable energy production in countries with high or low production levels. In countries without minimal renewable energy infrastructure, factors such as high upfront costs and reliance on fossil fuels hinder progress; in contrast, incremental policies provide diminishing returns in high-production countries. However, for countries with moderate production, stringent policies can shift the focus from non-renewable to renewable sources by stimulating investment and compliance with environmental standards. Therefore, based on current renewable energy situations in a country, there is a need for tailored environmental policies ranging from supporting primary infrastructure in low-production countries to focusing on efficiency and global environmental contributions in high-production countries.

Moreover, the study findings confirm that environmental tax revenues have varying effects on renewable energy production based on the current level of renewable energy development in each country. For countries with below-average renewable energy levels (Q25), environmental taxes positively affect renewable energy production. However, in countries with higher renewable energy levels (Q90), environmental taxes have a negative effect, indicating that increased tax burdens influence decreasing revenues. Therefore, these countries need to re-evaluate their environmental tax structures to avoid hindering the growth of renewable energy. Next, for countries with moderate levels of renewable energy (Q50), there is a critical threshold where the negative effects of environmental taxes begin to outweigh their benefits. This necessitates a balanced approach to policy implementation and regular policy reviews to ensure effectiveness and alignment with renewable energy development and the achievement of associated goals.

In connection with the above, this study emphasizes the complex dynamics between environmental regulation tools, especially environmental policies and regulations, environmental taxes, and renewable energy development. This is related to the different stages of progress within the levels of renewable energy production. This calls for tailored strategies aligned to a country's specific stage of renewable energy production. For countries at the lower end of the production spectrum, the focus is shifting towards alleviating barriers such as high costs and dependence on fossil fuels. Conversely, countries with advanced renewable energy sectors are encouraged to enhance efficiency and global contributions. This understanding facilitates the development of comprehensive policies that target environmental objectives, including economic, social, and technological dimensions that promote more effective and sustainable ecosystems.

In addition, the study emphasizes the need for policy flexibility and adaptability and emphasizing the importance of dynamic environmental tax policies that respond to specific phases of renewable energy development. By identifying thresholds for environmental tax impacts, especially in medium-producing countries, it contributes vital insights into the optimal timing and the extent of policy interventions. Thus, it strengthens the scientific basis for environmental policy formulation and harmonization.

Finally, the results reveal the complexity of the relationship between carbon emissions and renewable energy production. It highlights the challenges countries encounter, especially those in the middle of the transition phase (quantile 50 countries), in balancing the immediate economic and environmental costs with the long-term benefits of a sustainable energy transition. The varying impacts across countries also highlight the critical role of national and international policies in managing this transition. Economic strategies must be designed to suit each country's unique context, balancing the urgent need to reduce emissions with the practical aspects of developing renewable energy infrastructure.

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Appendices

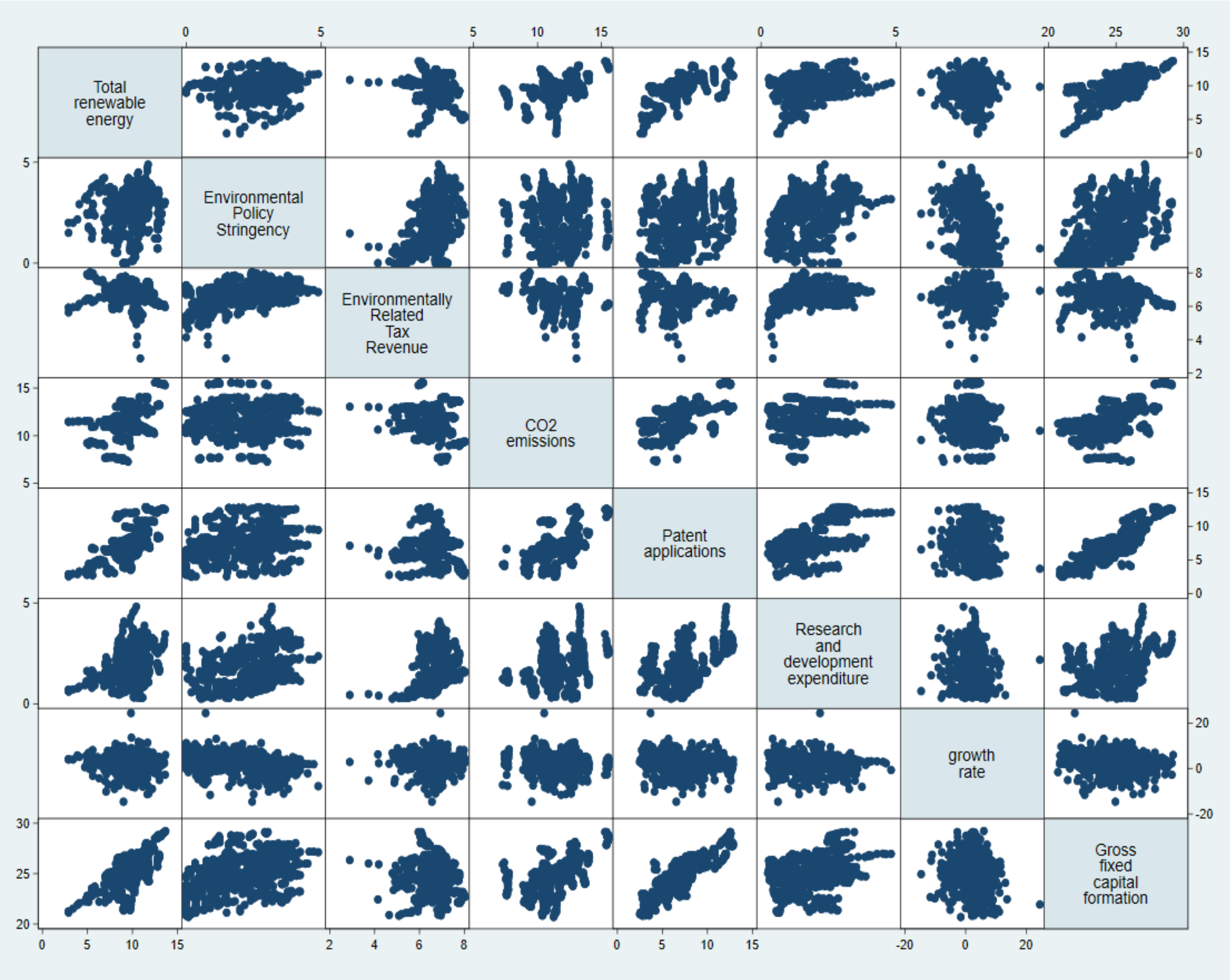

Figure 1. Scatter graph between variables
Source: STATA 16.0