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Environmental Policy Stringency and Sustainable Development of OECD Countries: Moderating Role of Institutional Quality

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ABSTRACT

With every passing day, policymakers are bringing strict environmental regulations with an aim to promote sustainable development in response to increasing worries about climate change, pollution, and resource scarcity. The overarching aim of this study is to examine the complex relation between stringent environmental policies and sustainable development, with the moderating role of institutions. The panel data from 1990 to 2022 of 33 OECD countries were employed using advanced econometric techniques, including panel quantile regression and GLS regression. The results indicate that the strict environmental regulations have a beneficial effect on sustainable development, particularly in the middle and upper quantiles, where institutional quality plays a critical role in reinforcing the positive relationship. In contrast, at lower levels of sustainable development, the benefits of stringent regulations are less pronounced, which suggests that weaker institutional frameworks may hinder their effectiveness. This study finds that other variables, such as technological advancements, economic growth, foreign direct investment, and population density, also play a pivotal role in attaining sustainable development objectives. The study is very important because it provides policymakers, researchers, regulators, and other stakeholders with invaluable information to formulate and implement sound environmental policies that can promote sustainable development without posing risks to economic growth. The analyses of the variables that impact sustainable development in OECD countries in their entirety provide grounds on which the development of evidence-based measures can be established. In addition, international organizations, governments and NGOs can use the findings of this research in determining their course and compare their level of success with OECD countries.

Introduction

With concerns about climate change, pollution, and scarcity of resources, the increasing interest in the environment has emerged as a priority issue for policymakers in many parts of the

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world. The business practices of most sectors in OECD countries have been adopting the environmental policy over the past two decades. International agreements like the Paris Climate Accord have also put pressure on OECD members to take the lead in emissions-reduction efforts (Falkner, 2016). Whether they succeed or fail in this will have serious implications to the world sustainability campaign, especially in the third world countries.

The theoretical foundation for stringent environmental regulations rests on Porter's hypothesis, which suggests that well-designed environmental standards trigger innovation that often fully offsets compliance costs (Porter & Linde, 1995). This scenario suggests that as regulations become stricter, the potential for innovative solutions can surpass rising compliance costs, leading to positive rather than negative economic outcomes. Empirical evidence from various sectors supports this proposition: stringent fuel efficiency standards have driven automotive manufacturers to invest heavily in innovative engines and EV technologies (Lee & Veloso, 2006), while the EU Emissions Trading System has motivated power companies to transition toward renewable energy sources (Bayer & Aklin, 2020).

Although we have ample research on environmental policy effectiveness, two critical gaps persist in the literature. Firstly, studies do examine linear relationships between environmental regulations and sustainability (Li et al., 2022; Wu et al., 2022), but existing research lacks distributional analysis across different sustainability performance levels. Secondly, the institutional quality is given importance (Fredriksson, Vollebergh, and Dijkgraaf, 2004; Mihai et al., 2023); the moderating role of institutional quality in environmental policy effectiveness remains systematically unexplored, particularly across varying sustainability contexts in OECD countries.

This study addresses these gaps by employing quantile regression analysis to examine environmental policy stringency effects across sustainability performance distributions, coupled with systematic institutional moderation analysis. Our findings reveal two key insights: (1) Environmental policy stringency demonstrates heterogeneous effects across quantiles, with stronger positive impacts in higher sustainability quantiles supporting the Porter Hypothesis primarily for developed countries; (2) Institutional quality exhibits a dual role—direct negative effects but significant positive moderation, indicating that strong institutions enhance policy effectiveness rather than directly improving sustainability.

This study addresses two fundamental research questions: (1) How does environmental policy stringency affect sustainable development outcomes across different quantiles of sustainability performance in OECD countries? (2) To what extent does institutional quality moderate the relationship between environmental policy stringency and sustainable development? These questions are examined through advanced econometric techniques applied to a comprehensive panel data from OECD countries. The results of this research provide new theoretical insights and practical guidance for environmental policy design. Our findings provide policymakers, evidence-based recommendations for designing more effective environmental regulations that account for both development and institutional quality.

Literature Review

Environmental Regulations and Sustainable Development

Environmental rules are pertinent to protect nature and stop harmful things people do (Percival, Schroeder, Miller, & Leap, 2021). These regulations encompass stringent measures aimed at mitigating pollution, conserving resources, and catalyzing the adoption of cleaner technologies. Wu et al. (2022) imply that environmental regulations can spur industrial innovations and contribute to sustainable development. Li et al. (2022) investigated how environmental regulations facilitate green development and concluded that they play a critical role in sustainability and green innovation by incentivizing technological advancements. In contrast, Li et al. (2024) highlight that overly stringent regulations in developing economies can sometimes stifle economic growth, creating a trade-off with sustainability goals, particularly when enforcement is inconsistent. Li et al. (2022)

studied the role of environmental policy stringency (regulations) in OECD economies from 2001 to 2018 using (CS-ARDL) model and confirmed that environmental stringency policies in OECD countries are considered as provide sources for the sustainable environment among selected countries Mihai et al. (2023) also support the notion of strictness of environmental policies can aid in sustainable development by striking a balance between environmental, economic, and social goals. There are many other studies that emphasize the role of Environmental regulations in achieving sustainability. For instance, Oteng-Abayie, Mensah, and Duodo (2022) found in Sub-Saharan African countries that environmental regulatory qualities play a crucial role in improving sustainability.

Despite the consensus on the positive role of environmental regulations, the literature reveals inconsistencies. For instance, while Wu et al. (2022) and Li et al. (2022) emphasize innovation as a direct outcome, studies like Li et al. (2024) suggest that regulatory stringency may disproportionately burden smaller economies or firms, potentially leading to uneven sustainability outcomes. Additionally, most of the available studies concentrate on the developed nations, and this leaves a knowledge gap on the application of such dynamics in less industrialized jurisdictions with weak regulatory frameworks. Therefore, this present study focuses on the interaction between environmental laws and sustainability within different economic settings and tests the research hypothesis that regulation effectiveness varies with the mechanism of enforcement and different economic environments.

Institutional Quality and Sustainable Development

Institutional quality is important in determining the sustainability outcomes of countries. Acemoglu et al. (2001) demonstrated that good governance positively influences environmental sustainability by encouraging responsible resource management and pollution control. Similarly, Besley & Persson (2011) found that institutional quality links positively with long-term economic development and environmental conservation efforts. However, they caution that weak institutions, characterized by corruption or lack of transparency, can lead to policy failures, a limitation often overlooked in optimistic assessments of governance. Sound institutions, characterized by transparency, accountability, and well-regulated systems, will guarantee a competent process of environmental-related policies and promote an atmosphere that would drive the generation and uptake of sustainable technologies. Conversely, weak institutions can lead to regulatory stagnation, corruption, and inadequate investment in clean technologies (IMF, 2025). Gao & Fan (2023) evaluated the impact of high quality institutions and technological innovation on environmental sustainability in BRI countries from 2002 to 2019 and found that countries having high institutional quality can acquire sustainable development along with the use of green technology and renewable energy . Ashraf, Luo and Anser (2022) further argue that effective institutions moderate the relationship between environmental policy and sustainability by ensuring consistent enforcement, though they note that political instability can undermine these efforts, a factor underexplored in the literature. The correlation between Environmental sustainability and institutional quality is strong as effective institutions are essential for fostering sustainable behaviors and addressing environmental challenges. Countries with robust institutional frameworks are more adept at enforcing environmental regulations, promote sustainable development initiatives and responsibility managing their resources effectively (Dam, Işık and Ongan, 2023).

Xaisongkham and Liu (2022) demonstrated through results that institutional quality factors like government effectiveness (GE) and the rule of law (RL) lead to decreased CO_2 emissions and enhanced environmental quality in developing countries. Obobisa, Chen and Mensah (2023) examined the African countries and concluded that efficient institutions and eco innovations can certainly serve as an efficient approach to addressing the climate crisis, thus leading to sustainability. Ibrahim & Law (2016) argue that institutional reforms undeniably lead to environmental enhancement. Dam et al. (2023) examined the Institutional quality of OECD countries from 1999-2018 and found that institutional quality plays an important role in promoting environmental sustainability. Similarly, Ali et al. (2019) state that institutional quality positively influences environmental policy.

Technological Innovation and Sustainable Development

Technological innovation is a stepping-stone towards sustainability objectives, offering promising solutions to mitigate environmental degradation and enhance resource efficiency. There are many studies which highlighted the potential of technological advancements in promoting sustainable practices across various sectors. Schiederig, Tietze and Herstatt (2012) emphasize the role of eco-innovations in reducing environmental impacts, citing examples such as renewable energy technologies and green building materials. Technological innovations offer a path towards sustainable production. Clean technologies, renewable energy sources, and low-energy production processes can act as a bridge, mitigating the environmental impact of economic activity. Yet, the development and widespread adoption of these technologies heavily rely on supportive policies and infrastructure (OECD, 2008).

Saqib, Ozturk and Usman (2023) studied the influence of technological innovation, financial inclusion, economic growth and renewable energy on the ecological footprint of emerging economies from 1990 to 2019 and they found that the technological innovation contribute to reducing the environment pollution and diminishing ecological footprints. The research by Raza , Habib and Hashmi (2023) analyzed the importance of technological innovation and renewable energy in fostering the sustainable environment in G20 countries and found that technological innovation play an important role in decreasing the ecological footprints. According to Wang et al. (2021), the technological innovation driven by environmental regulations can positively influence ecological footprints by promoting green innovation technology and corporate environmental responsibility, ultimately leading to reduce environmental impact and resource consumption.

Cheng et al. (2021) verified the role of technological innovation in mitigating the CO_2 emission in OECD countries and suggests that technological innovation directly decreases CO_2 emissions through investment in research and education. Furthermore, Böhringer, Dijkstra and Rosendahl (2014) suggest that for reducing greenhouse gas emissions, we need technological progress, particularly in clean energy technologies is important for achieving long-term sustainability goals by promoting renewable energy adoption. These studies collectively underscore the significant contributions of technological innovation in driving sustainability transitions and developing a more environmentally conscious society. However, Saqib et al. (2023) focus on emerging economies; they do not explore how weak institutions might hinder technology adoption- a critical oversight. This study aims to fill this gap by hypothesizing that technological innovation, supported by strong institutions and effective regulations, significantly enhances sustainability outcomes.

Theoretical Framework and Hypotheses Development

Several environmental restrictions are applied to attain sustainability and safeguard the environment. Porter & Van Der Linde (1995) proposed that more stringent regulations on the environment encourage investment in green innovation research, reduce waste, boost efficiency, and promote sustainable development. However, some studies, such as Martínez-Zarzoso, Bengochea-Morancho, and Morales-Lage (2019) and Albrizio, Kozluk, and Zipperer (2017), contend that stricter environmental laws would result in higher costs and fewer benefits, which would reduce investment in green research and development. There is also the pollution haven hypothesis (PHH), which postulates that firms with stricter environmental laws in one country may transfer to another with less stringent rules. PHH implies that foreign direct investment (FDI) may harm sustainable development, showing that high levels of corruption (weaker institutions) attract more FDI that pollutes the environment and contributes to high levels of pollution (Huay, Li & Shah, 2022). The Environmental Kuznets Curve (EKC) hypothesis elucidates the connection between environmental degradation and economic growth. The idea that economic advancement can lead to environmental improvements is supported by the inverted U-shaped graph, which suggests that environmental degradation worsens with economic growth and improves after a particular income level is achieved (Raymond, 2004). The EKC hypothesis is consistent with the Porter Hypothesis, which argues that regulations pertaining to the environment may stimulate technological advancement and innovation, ultimately improving business performance and productivity (Ambec et al., 2013; Yu, Ramanathan & Nath, 2017). Thus, in light of the OECD countries, this study investigates the relationship between environmental policy stringency and sustainable development, and assesses the probability of strict environmental regulations leading to sustainable growth. The following hypotheses are put forth in this study based on the previously discussed literature.

H_1: The environmental stringency policy positively influences sustainable development.

H_2: The institutional quality positively moderates the relationship between environmental stringency policy and influences sustainable development.

Methodology

Data

The effect of environmental regulation on sustainable development in 33 OECD countries caused by institutional quality, technological innovation, population density, economic growth, and foreign direct investment (FDI) is examined in this study using annual data spanning from 1990 to 2022. The data is collected from secondary sources such as the World Bank (WDI) and OECD statistics.

The variables used are very important for understanding the relationship between environmental regulation and sustainable development. We used adjusted net savings as a proxy for the dependent variable, sustainable development. Gnègnè (2009) proposes that the World Bank has devised Adjusted Net Savings (ANS), a macroeconomic indicator used to assess sustainable development. Proxy variables are chosen according to accepted empirical procedures and their applicability to the topic under inquiry. Adjusted net savings is used to gauge sustainable development because it provides a comprehensive yet measurable metric by accounting for environmental degradation, human capital investment, and pollution impact. As a measurable and consistent measure of creative activity across countries, patent counts are used to depict technological advancement.

The environmental stringency index, which measures environmental regulation, considers the multi-dimensional aspect of environmental regulation and also addresses the shortcomings of other indicators (Martínez-Zarzoso et al., 2019). Other studies assessing environmental regulation by environmental stringency index include, for instance, the work of Albulescu, Boatca-Barabas, and Diaconescu (2022), Ahmed (2020), and Ahmed et al. (2022). The quantity of patents filed serves as a proxy for technological innovation, which gives insight into the nation's ability to create and implement innovative technologies that support sustainable development. According to Kwon, Cho, and Sohn (2017), there is a direct connection between green technologies and patent applications, as well as between GDP and FDI, which shows the growth and development of a country's economy. Meyer, Van Kooten, and Wang (2003) propose that GDP is a standard for economic and financial development. Population density, on the other hand, provides information about the geographical distribution of economic activity and its impact on the environment. The metric of institutional quality is assessed using the World Governance Indicators (WGI), which serves as an indicator of how effectively and efficiently institutions promote sustainable development. It is measured using six (6) global governance factors that include government effectiveness, voice and accountability, political stability and absence of violence, regulatory quality, rule of law, and corruption effectiveness.

The variables, symbols and proxies, and sources are demonstrated in Table 1. In this paper, we employed the panel quantile regression fixed-effects as described below:

$$y_{it} = a_i + \beta(q)x'_{it} + u_{it} \quad (1)$$

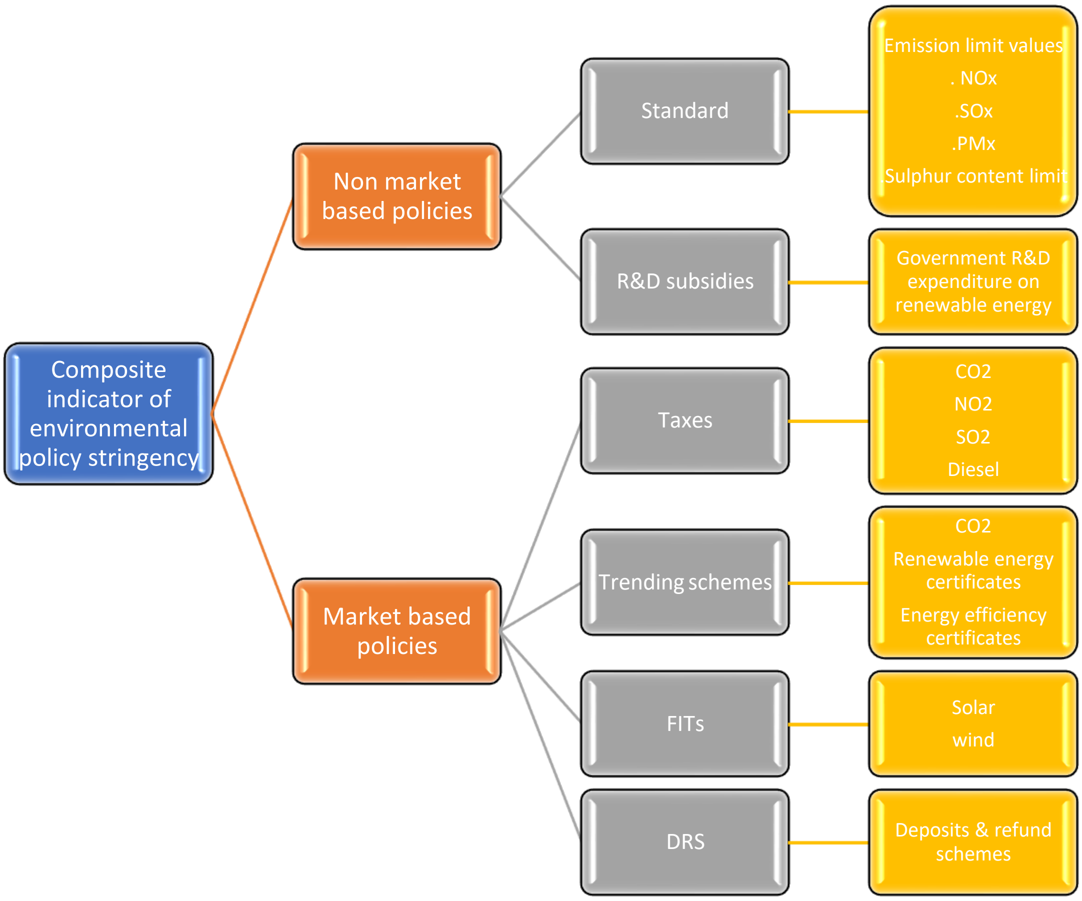
The econometric methods of the study were selected carefully and considered the properties of the data and objectives of the research. Panel quantile regression enables the study to identify dynamics that could not have been identified in the standard mean-based estimators because this approach is more resilient in measuring the heterogeneity of effects across different levels of sustainable development. This method is particularly effective when the array of correlations among variables is non-linear or when the non-probabilistic relations are based upon a conditional distribution. The reliability of the calculated parameters was further improved by using Generalized Least Squares (GLS) regression as a robustness test since it takes into consideration panel-specific problems like serial correlation and heteroscedasticity. The methods have been selected due to the preference for methodological precision and the personalized focus on the data arrangement. We opted for a linear interpolation approach to find the missing values of variables. According to a study by Chen et al. (2015), linear interpolation is a simple interpolation technique. In contrast to non-linear interpolation, Gnauck (2004) proposes that linear interpolation is considered one of the effective techniques that yields missing values that are more reliable.

Table 1: Definition and Sources of Variables

Variable	Proxy	Symbol	Unit of measurement	Source
Environmental regulation	Environmental policy stringency index	EPSI	15 different Non-Market Based (NMB) and Market Based (MB) environmental policy instruments implemented in OECD	OECD stat
Sustainable development	Adjusted net saving	ANS	Adjusted net national income per capita (constant 2010 US$)	WDI
Technological Innovation	Patents	PTNT	Applications of patents by residents	WDI
Foreign Direct Investment	Foreign direct investment, net inflows	FDI	(% of GDP)	WDI
Economic growth	GDP	GDP	(constant 2010 US$)	WDI
Population	population density	PD	(people per sq. Km of land area)	WDI
Institutional Quality	World governance indicators	WGI	Six Worldwide Governance Indicators	(WGI, WDI)

The composite indicator of environmental policy stringency is composed of market and non-market-based policies. Market-based polices are comprised of taxes, trading schemes, feed-in-tariffs (FITs), and deposit rerun schemes (DRS). The non-market-based polices include standards, R&D with subsidies, and taxes. The flow chart below (Figure 1) shows further classification of market and non-market based policies of the environmental policy stringency index.

Figure 1: Composition of EPSI



Source: Authors' draw based on OECD Statistics

Cross-sectional dependency test

In general, it is thought that the panel data should be independent, and the errors in panel data across the cross-sections are heteroscedastic. However, this assumption is not always true because of different factors such as shocks, diverse policies, hidden and unobserved factors contributing to CSD. In panel regression modelling, failing to consider cross-sectional dependence into account can lead to a decrease in estimator efficiency and may invalidate the impact of test statistics (Wang et al., 2021). To check for cross-sectional dependency, several tests are carried out; one such test is the Pesaran scaled LM test (Pesaran, 2021). Dzwigol et al. (2023) and Wenlong et al. (2023) both employed this technique to check the cross-dependence. According to the null hypothesis, cross-section dependence CD~N (0,1) exists. Disturbances in various cross-sectional units are assumed to be independent of one another in panel regression.

$$CD = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right)} \sim N(0,1)ij. \quad (2)$$

CD = 1, 2, 3, 4 … N

$$M = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right)\frac{(T-k)\hat{\rho}_{ij}^{2}E(T-k)\hat{\rho}_{ij}^{2}}{Var(T-k)\hat{\rho}_{ij}^{2}}} \quad (3)$$

$\hat{\rho}^2$ is the pairwise correlation coefficient of the ordinary least squares residual.

Slope homogeneity test.

After assessing the cross-sectional dependency, the study explores the uniformity of the coefficients using the slope heterogeneity test proposed by Hashem Pesaran & Yamagata (2008). To find the slope heterogeneity and homogeneity, this test is used. According to Atasoy (2017), other tests, like seemingly unrelated regression equations, are also used for slope heterogeneity, but it is not preferred as it does not consider cross-sectional dependence. There is a chance that panel estimators could be influenced by variation in the economic, demographic, and social fabric of OECD countries. Ignoring the slope homogeneity may result in biased results; therefore, this study applies the approach proposed by (Pesaran, 2007).

$$\tilde{\Delta}_{SH} = N_2^1 (2K) \frac{-1}{2} (\frac{1}{N}\tilde{S} - k) \quad (4)$$

$$\tilde{\Delta}_{ASH} = (N)\frac{1}{2} \frac{(2k(T-k-1)}{T+1})^{\frac{-1}{2}} (\frac{1}{N}\tilde{s} - k) \quad (5)$$

$\tilde{\Delta}_{SH}$ represents the delta tilde, and $\tilde{\Delta}A_{SH}$ represents the adjusted delta tilde heterogeneous slope coefficients, which are assumed as the alternative hypothesis (homogeneous slope coefficients are represented as the null hypothesis.

Unit root tests

The paper has used a panel unit root test to check the data stationarity. According to Maddala & Wu (1999), different unit root tests are used, each having its own strength. This study employs Pesaran (2007)'s cross-sectionally augmented Dickey-Fuller (CADF) and cross-sectionally augmented IPS (CIPS) tests. To check the integration among the variables after CSD and homogeneity, a unit root test is used, but first-generation unit root tests give bogus results if CSD exists in the data (Dogan & Seker, 2016). To mitigate this problem, Khan et al. (2020) suggest using both parametric and non-parametric tests, incorporating the IPS(CIPS) test proposed by (Pesaran, 2007). Wenlong et al. (2023) and Alharthi, Dogan, and Taskin (2021) have also employed this method in their research. CIPS is particularly adept at addressing cross-sectional dependence (CD) and heterogeneity, thereby enhancing the reliability of its results. Levin, Lin, and James Chu (2002) recommend accessing stationarity from multiple unit root tests. According to Raza et al. (2023) and Dogan & Seker (2016), for more robust analysis, a combination of parametric and non-parametric tests is more advisable. The equation of the panel unit-root test is:

$$\Delta Yi_{i,t} = \emptyset_i + \phi\phi_i z_{t-1} + \phi_i \tilde{z}_{t-1} + \sum_{i=0}^{p} \phi_{il} \Delta\bar{Y}_{t-1} + \sum_{i=0}^{p} \phi_{il} \Delta\bar{Y}_{i,t-1} + \mu_{it} \quad (6)$$

Cointegration test

After cross-sectional dependence and stationarity, the Cointegration test has been applied, which is vital for determining the long-term equilibrium relationship between selected variables. This study tries to find the link between sustainable development and environmental regulation, institutional quality, technological innovation, population density, economic growth, and foreign direct investment (FDI) for OECD countries in the long term. Two tests are employed to identify cointegration: Pedroni cointegration test (2004) and CSD robust Westerlund (2007) test. Relying on a single test may not provide sufficient robustness for policy control analysis (Ahmed et al., 2022). The Pedroni test requires the order of the series to be either at level I (0) or at first difference I (1) to determine the long-term relationship by taking into account cross-sectional heterogeneity. Kapetanios, Pesaran, and Yamagata (2011) propose that the Westerlund panel cointegration test is employed due to its statistical validity and its capability to handle cross-sectional dependence of the error term.

Quantile regression

To analyse panel data for this study, we mainly utilized quantile regression analysis. Due to several advantages, quantile regression has been used. Firstly, unlike quantile regression, which estimates the parameter at various quantiles, mean regression does not consider the heterogeneous relationship between the dependent and independent variables. The QR approach helps to produce the best results and, more importantly, for those countries that lie at the distribution's boundaries. Second, the assumption of normality is not considered by the quantile regression (Sherwood &

Wang, 2016). Quantile regression is preferred over conditional mean when the variables do not have a normal distribution. According to Zhu et al. (2016), in quantile regression, the outliers do not have an impact on the results, and the outcomes of the analysis are robust. Third, while quantile regression is based on the median, regression is based on the mean. Regression on mean can result in overestimation or underestimation when the data distribution is not normal; however, the median estimation remains reliable. Lastly, panel quantile regression with fixed effects, according to Koenker (2004) and Canay (2011), helps in recognising and avoiding the issue of unobserved individual heterogeneity. Considering these reasons, panel quantile regression is employed in this study.

$$Q_{y(q|x)} = \beta_0(q) + X^q\beta_1(q) + \varepsilon_{it} \quad (7)$$

Where q represents the related quantile (0 < q <1), $Q_{y(q|x)}$ indicates dependent variable (sustainable development), X^q denotes independent variable (EPSI and other control variables) at a certain quantile, and $\beta^0(q)$ and $\beta(q)$ measures the intercept and slope coefficients of QR model.

Dumitrescu and Hurlin causality test

The Granger causality test (Dumitrescu & Hurlin, 2012) is used to find the linkage and causality between different variables. The null hypothesis of this test is that there is no causal link between variables, while the alternative hypothesis suggests there is a link between variables.

$$Z_{it} = a_i + \sum_{j=i}^{p} \beta_i^j Z_{i,t-j} + \sum_{j=1}^{p} \gamma_i^j T_{i,t-j} \quad (8)$$

β_i^j and j are parameters of autoregression and lag length.

Results and Discussion

Before proceeding with data analysis, the summary statistics. (Mean, Standard Deviation, Kurtosis, etc.) are presented in Table 2. ANS has a mean value of $517.61 and a standard deviation of $294.855. With a mean of $4.972 and a sizable standard deviation of $15.221, foreign direct investment shows greater variability. The GDP varies greatly, with a mean of $1.390e+12. The population density averages 522.108. The WGI has a substantial skewness and kurtosis, with a mean of $1.190e+09. The average EPSI is 2.49, with a moderate degree of variability. Patents exhibit noteworthy variation between observations, with an average of 415.662. This statistical data offers a thorough overview of the variability and simple distribution in the data set.

Table 2: Descriptive Statistics

Variables	Mean	Std. Dev.	Min	Max	Skew.	Kurt.	Obs
ANS	517.61	294.855	1	1015	-.056	1.77	651
FDI	4.972	15.221	-117.375	234.466	5.787	94.424	651
PD	522.108	326.569	2	1150	.231	1.935	651
GDP	1.390e+12	3.000e+12	1.391e+10	1.993e+13	4.511	24.067	651
WGI	1.190e+09	6.350e+09	33.89	6.012e+10	6.345	45.408	651
EPSI	2.49	1.002	.056	4.889	-.493	2.528	651
PTNT	415.662	277.264	1	924	.094	1.764	651

Note: (ANS represents adjusted net saving, EPSI represents environmental policy stringency index, FDI represents Foreign direct investment, PD represents population density, GDP represents gross domestic product, PTNT represents patents, WGI represents world governance indicator.)

The correlation between variables is presented in Table 3, indicating both positive and negative correlations. However, the data does not demonstrate any problem of multicollinearity because all values of correlation coefficients between independent variables are below 80 percent. A significant positive correlation (0.159) has been shown between EPSI and ANS, and between economic growth and sustainable development. Furthermore, sustainable development (ANS) and population density (PD) have a positive correlation (0.085). On the other hand, ANS shows a significantly negative connection (-0.102) with patents (PTNT) and the World Governance Indicator (WGI) (-0.114). Additionally, ANS shows a marginally positive correlation with foreign direct investment (FDI) (0.077), indicating a potential relationship between foreign investment and savings (ANS). These findings indicate that environmental policy stringency, GDP, population density, and FDI are positively related, while the number of patents and institutional quality (WGI) are negatively associated with sustainable development (ANS) in OECD economies. However, the correlation is a weak technique when variables are non-stationary, and, therefore, it does not provide enough evidence to establish the long-run equilibrium relationship.

***Table 3*: Correlation Table**

Variables	**ANS**	**EPSI**	**PTNT**	**WGI**	**GDP**	**PD**	**FDI**
ANS	1.000						
EPSI	0.087**	1.000					
PTNT	-0.102***	0.019	1.000				
WGI	-0.114***	0.064*	-0.043	1.000			
GDP	0.159***	0.066*	0.016	-0.012	1.000		
PD	0.085**	-0.129***	0.131***	0.171***	0.144***	1.000	
FDI	0.077**	-0.031	0.030	-0.031	-0.047	0.011	1.000

Note: *** p<0.01, ** p<0.05, * p<0.1

The cross-sectional dependence of the data is shown using the CD-test results in Table 4. It denotes the interdependence of OECD nations, meaning that adjustments to one country's variables will have an impact on the data of neighboring countries in the OECD block.

Table 4: Cross-Sectional Dependence Test.

	ANS	**FDI**	**PD**	**WGI**	**GDP**	**PTNT**	**EPSI**
CD-test	28.123***	18.271***	35.768***	62.210***	20.984 ***	11.976***	96.873***
Corr	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Abs(corr)	0.421***	0.231***	0.436***	0.676***	0.600***	0.326***	0.775***

Note: *<0.01; **<0.05; ***<0.10

Following these results and to verify if the relationships between the variables differ throughout OECD nations, we ran a heterogeneity test. The results in Table 5 indicate that data are heterogeneous, as indicated by the significant values of adjusted delta and delta from Pesaran's slope heterogeneity test. This suggests that environmental regulation, sustainable development, institutional quality, technological innovation, population density, economic growth, and foreign direct investment (FDI) exhibit variations among OECD countries.

Table 5: Slope Heterogeneity

	Delta	p-value
	23.782***	0.0000
Adj	27.324***	0.0000

Note: *<0.01; **<0.05; ***<0.10

Data heterogeneity impacts cointegration and unit root tests. In our data, both cross-sectional dependence and slope heterogeneity are present. To address this issue, relevant unit root tests were employed. Due to the interdependence between different variables in OECD countries, we examined the integration order of variables through CADF and CIPS. These tests are efficient when the data has cross-sectional dependence. Particularly in panel data analysis, these tests are used to detect the cross-sectional dependence and stationarity among variables. In time series data, lag is used to control the possibility of serial correlation, which improves the estimation accuracy and ensures the model assumptions. The incorporation of drift and trend into these tests enables the detection of downward and upward movement in the data and captures long-term movement in the data. Table 6 presents the result of the unit root test. The results reveal that all variables are stationary at the level except PD, GDP, and PTNT based on both CIPS and CADF tests. However, all variables have no unit-root problem at first difference (at 5% level of significance).

Table 6: Unit Root Tests

Variables		**CIPS Test**		**CADF Test**	
		Without trend	With trend	Without trend	With trend
ANS	0	-2.360**(-2.11)	-2.361**(-2.6)	-2.334* (0.000)	-2.188***(0.840)
	1	-5.124**(-2.11)	-5.140**(-2.6)	-2.839*(0.000)	-2.806* (0.001)
FDI	0	-3.497**(-2.11)	-3.807**(-2.6)	-2.056**(0.040)	-2.278 (0.657)
	1	-6.020**(-2.11)	-6.168**(-2.6)	-3.767*(0.000)	-3.754*(0.000)
PD	0	-0.873**(-2.11)	-1.868**(-2.6)	-1.200 (1.000)	-1.738(1.000)
	1	-3.243**(-2.11)	-3.171**(-2.6)	-2.141**(0.012)	-2.168 (0.869)
WGI	0	-2.190**(-2.11)	-1.869**(-2.6)	-2.078**(0.030)	-1.889(0.998)
	L	-4.612**(-2.11)	-4.812**(-2.6)	-2.493*(0.000)	-2.636**(0.027)
GDP	0	-2.483**(-2.11)	-2.954**(-2.6)	-1.489(0.957)	-1.797(1.000)
	L	-5.490**(-2.11)	-5.787**(-2.6)	-2.788*(0.000)	-3.016* (0.000)
PTNT	0	-2.230**(-2.11)	-2.456**(-2.6)	-1.973(0.107)	-2.069(0.962)
	L	-5.299**(-2.11)	-5.542**(-2.6)	-3.075** (0.000)	-3.324*(0.000)
EPSI	0	-2.908**(-2.11)	-2.923**(-2.6)	-2.719*(0.000)	-2.695 *(0.010)
	L	-5.610**(-2.11)	-5.670**(-2.6)	-3.539* (0.000)	-3.665*(0.000)

Note: *<0.01; **<0.05; ***<0.10 *The ( ) represent τ statistics critical value*

Two distinct methods were applied to ascertain the long-term co-integration between the variables. The Westerlund test is the first method used to determine cointegration in panel data. It considers both cross-sectional dependency and heterogeneity. The second test is the Pedroni Panel Cointegration Test, which is used to account for heterogeneous slope coefficients and error processes in panel data and determine the long-term relationship across cross-sectional units. Table 7 presents the results of Westerlund and Pedroni's Cointegration tests, respectively.

Table 7: **Cointegration Results**

Westerlund Test				**Pedroni Test**			
Statistic	Value	Z-value	P-value	Common coefficient	AR	Panel	Group
G_t	-2.591	-0.929	0.176	**v**		-0.9097	.
G_a	-9.346	3.107	0.999	**rho**		2.594**	4.312***
P_t	-18.549***	-5.311	0.000	**t**		-2.428**	-2.358**
P_a	-11.993	-1.302	0.096	**adf**		-1.733	-0.6536

Note: * $p<0.05$, ** $p<0.01$, *** $p<0.001$

The G_t, G_a, P_t, and P_a statistics and their accompanying Z- and P-values from the Westerlund test with lag (0) are insignificant except the Pt value. This suggests that, at conventional significance levels, there is insufficient evidence to support the occurrence of cointegration among the variables. Similarly, Pedroni's tests yielded mixed results as two out of four statistics (the coefficients for v and adf, along with the associated t-values <1.96) fail to reject the null hypothesis, indicating relatively weak evidence for cointegration among variables.

To provide a complete picture of the different relationships among interested variables, we choose nine quantiles (10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, 90th). The Quantile regression results are presented in Table 8, which indicates that, except for the lower two quantiles, the influence of EPSI on sustainable development is positive and significant. Thus, indicating that an increase in EPSI will result in an increased level of sustainable development. This result supports (Porter & Linde, 1995) proposed that more stringent regulations on the environment encourage investment in green innovation research, reduce waste, boost efficiency, and promote sustainable development. Across all quintiles, the influence of GDP on sustainable development is positive and significant, indicating that increased economic growth is a prerequisite for sustainable development. Higher quantiles experience a bigger influence than lower quantiles. In addition, FDI and population density coefficients all have significantly positive effects that support sustainable development. The beneficial effect of FDI lends support to the pollution halo hypothesis, instead of the PHH, because multinational companies may have introduced cleaner and environmentally friendly technology in these countries to foster sustainable and green development. A significant positive impact of technological innovation is observed, except for a negative influence caused by the lower quantile. It's interesting to note that, in contrast to most of the existing literature, institutional quality has a detrimental effect on sustainable development in a few lower and intermediate quantiles. This surprising result might reflect real-world constraints on the ways that institutional quality appears in various countries within the OECD. There may be limited direct benefits for sustainability in particular situations where stronger institutions prioritize political or economic stability over environmental goals. Another factor can be the disparity between institutional frameworks and their actual enforcement or execution. Effective environmental governance may not be achieved by well-structured institutions in countries with high levels of bureaucratic rigidity or corruption. These findings imply that facilitating favorable sustainability outcomes requires institutional efficacy rather than only institutional existence.

Table 8: Quantile Regression Results

	(.1)	(.2)	(.3)	(.4)	(.5)	(.6)	(.7)	(.8)	(.9)
ESI	-0.0183	0.130***	0.0707***	-0.00505	0 .0605***	0.0880***	0.0679***	0.0804***	0.102***
	(0.0454)	(0.00753)	(0.00605)	(0.0128)	(0.0 0489)	(0.00301)	(0.00488)	(0.00353)	(0.00749)
LPD	0.104***	0.231***	0.102***	0.0585***	0.124***	0.0943***	0.0998***	0.0964***	0.0984***
	(0.00677)	(0.00956)	(0.00920)	(0.0117)	(0.00320)	(0.00360)	(0.00417)	(0.00252)	(0.00276)
LGDP	0.110***	0.199***	0.134***	0.171***	0.198***	0.140***	0.139***	0.136***	0.146***
	(0.0289)	(0.00716)	(0.00406)	(0.00588)	(0.00266)	(0.00135)	(0.00188)	(0.00484)	(0.00124)
LPTNT	-0.0242***	-0.0337***	-0.00396	-0.0309***	-0.0346***	0.0271***	-0.00323	0.0182**	0.0124*
	(0.00419)	(0.00858)	(0.00533)	(0.00493)	(0.00221)	(0.00278)	(0.00303)	(0.00596)	(0.00484)
WGI	-2.33e-11***	-3.49e-11***	-1.05e-11***	-2.23e-11***	-1.04e-11***	-6.55e-12***	-1.12e-11***	-7.71e-12***	1.41e-11***
	(2.14e-12)	(6.22e-12)	(2.22e-12)	(2.39e-12)	(8.91e-13)	(4.63e-13)	(8.65e-13)	(2.24e-13)	(8.50e-13)
LMWGI	0.0410***	0.0526***	0.0207***	0.0462***	0 .0208***	0.00891***	0.0219***	0.00912***	0.0167***
	(0.00339)	(0.00640)	(0.00535)	(0.00603)	(0.0 0180)	(0.000847)	(0.00200)	(0.000611)	(0.00293)
LFDI	0.0735**	0.0773***	0.141***	0.00829	0.175***	0.146***	0.137***	0.132***	0.140***
	(0.0239)	(0.0113)	(0.00543)	(0.0132)	(0.0 0211)	(0.00234)	(0.00287)	(0.00269)	(0.00271)

Note: Standard errors in parentheses; * p<0.05, ** p<0.01, *** p<0.001.

Table 9 tabulates the findings of DH Granger causality test, and it demonstrates that sustainable development (ANS) has a unidirectional causal relationship with FDI, income level (GDP), and technological innovation (PTNT) in OECD countries. The one-way causal relationship runs from sustainable development to FDI, which indicates that higher levels of ANS bring long-term investment in education, health and long-term investment. These trends boost the confidence of foreign investors in macroeconomic stability and expected higher long-term returns (Hayat, 2018; Le, 2021). On the other hand, income level has a unidirectional causal effect on ANS, which indicates the significant role of GDP in shaping the pro-environmental behavior of countries in the OECD. The findings suggest that a higher GDP level accelerates the investment in human capital development, environmental protection, and ecologically efficient allocation of resources. These results are aligned with prior studies that support the positive role of economic growth in enhancing sustainable development (Pardi, Čihák, & Šíma, 2020; Shumaker & Clark, 2009). Our main variable, the environmental policy stringency index (ESPI), has a bidirectional causal nexus with sustainable development. The findings imply that EPSI causes sustainable development by promoting green investments, environmentally friendly innovations, and responsible and efficient resource use.

However, enhanced sustainability in terms of human capital development, energy-efficient infrastructure, and inclusive growth further facilitates the implementation of stringent environmental regulations and increased public and institutional support (Alola, Bekun, & Sarkodie, 2019; Botta & Kozluk, 2014; Le, 2021). Moreover, population density and institutional quality also have a feedback relationship with sustainable development. Higher population density places greater pressure on ecological resources, demanding effective governance and institutional reforms to improve environmental sustainability, which in turn fosters green urban planning and designing smart cities to manage the population density. Similar results have been documented for institutional quality, which has a mutual connection with sustainable development. On one hand, higher institutional quality promotes sustainability by imposing effective laws, regulations related to the environment, human capital, and green infrastructure, while improvement in sustainability metrics further strengthens these pro-environmental policies and protection regulations. These results are also supported by Acemoglu et al. (2001) and Zhou, Wu, & Wang, 2021). Lastly, technological innovation Granger-cause sustainable development in OECD economies; it implies the pivotal role of innovation in promoting sustainable development in these countries. The results are aligned with Asongu and Odhiambo (2020), who documented the strong support for the technology-sustainability nexus.

Table 9: Heterogeneous Causality

Pair No	Null hypothesis	Z-bar	P-value	Direction of Causality
1	EPSI does not cause ANS	2.8056*	0.0050	Bidirectional
	ANS does not cause EPSI	6.9446***	0.0000	
2	FDI does not cause ANS	1.3724	0.1700	Unidirectional
	ANS does not cause FDI	2.1498*	0.0316	
3	PD does not cause ANS	3.5248**	0.0004	Bidirectional
	ANS does not cause PD	3.0878**	0.0020	
4	GDP does not cause ANS	2.0279*	0.0430	Unidirectional
	ANS does not cause GDP	1.0725	0.2835	
5	WGI does not cause ANS	2.6391**	0.0083	Bidirectional
	ANS does not cause WGI	9.1465***	0.0000	

6	PTNT does not cause ANS	12.7885***	0.0000	Unidirectional
	ANS does not cause PTNT	1.4049	0.1601	

Note: * p<0.05, ** p<0.01, *** p<0.001

Robustness Test

In this section, a GLS regression robustness test was conducted to validate our results. The assessment of quantile regression has been authenticated by GLS regression, indicating that the coefficients collected from quantile regression have the same findings as those of GLS regression. TABLE 10 illustrates that output from quantile regression is effective and suitable for the decision. The internal consistency and dependability of our conclusions are improved by this alignment of outcomes. In particular, the Porter Hypothesis is supported by the positive and significant coefficient of EPSI in GLS, and the quantile regression-identified complexity is confirmed by the consistency in the mixed impact of institutional quality. GLS regression enhances the study's overall robustness and supports the validity of our primary findings by validating these associations using a different approach.

Table 10: GLS regression

ANS	**Coeff**	**Std. Err.**	**z**
EPSI	.140727***	.0363489	3.87
PD	.4681669***	.0281192	16.65
GDP	.13908***	.0318075	4.37
PTNT	.1313612***	.0211154	6.22
FDI	.1375537***	.0296177	4.64
WGI	-1.60e-11*	7.76e-12	-2.06

Note: * p<0.05, ** p<0.01, *** p<0.001; The log of variables with positive values have been taken to smoothen and normalize the data.

Discussion

The analysis presented above demonstrates how environmental regulations can significantly improve sustainable growth. One of the reason is that increase in EPSI will lead to a higher degree of sustainable growth. This outcome confirms Porter's (1995) suggestion that stricter environmental regulations should stimulate investment in green innovation research, decrease waste, increase productivity, and support sustainable development. Our findings are aligned with the findings of Wu et al. (2022), Li et al. (2019), and Li et al. (2022) and confirm the beneficial relationship between strict environmental regulations and green development. The results are also congruent to those of Mihai et al. (2023) and Oteng-Abayie et al. (2022), who documented the crucial role that environmental regulatory factors play in boosting sustainability, lends more weight to this.

Although technological innovation is often viewed as a driver of sustainable development, it sometimes fails to achieve sustainability objectives for a variety of reasons. One of these reasons is the chance of unpredictable effects (or game-offs) when it comes to new technologies. Our results are in line with prior studies, such as Ambec et al. (2013), who contend that some innovations may inadvertently have an adverse effect on the environment or make pre-existing problems worse. Also, the rapid advance in technical progress can contribute to the decrease of resources and rising consumption, which can damage the sustainability efforts. The emphasis on technology fixes could also take resources and attention away from tackling the underlying causes of sustainability problems, like unethical consuming habits or socioeconomic inequality (Schiederig et al., 2012).

Our results also confirm the findings of Acemoglu et al. (2001) and Besley & Persson (2011) who evidenced a significant connection between environmental preservation, economic growth, and good governance. The beneficial effects of highly esteemed institutions on environmental sustainability are confirmed by Xaisongkham & Liu (2022), particularly in terms of encouraging the use of green technologies and lowering CO_2 emissions.

Nevertheless, our results reveal that although strong institutions ideally can play an enabling role in the achievement of sustainable development, there are many reasons why they should not. One of the primary causes is the potential discrepancy in the priorities of the institutions and sustainability targets. Institutions may adopt unsustainable practices as a result of prioritizing short-term financial benefit over long-term environmental concerns (Gore, 1993). The lack of capacity or knowledge to respond to issues associated with sustainability might also be present in institutions, thus may have a challenge in designing and implementing an effectively functioning policy. The political intervention can be a severe hindrance to institutional sustainability programs. Political limitations can challenge institutions to minimize long-term social and environmental sustainability in favor of immediate financial gains. All these factors can hinder organizations from achieving their optimum potential in attaining the goal of sustainability.

Although the results are strong, there are a few things to keep in mind. First, even though the OECD countries provide a nearly homogeneous sample for comparative research, there are still limitations on how broadly the findings can be applied to non-OECD or developing economies. Second, while distributional heterogeneity is captured by the panel quantile regression, it might not completely address the underlying structural breaks or biases caused by omitted variables.

To better understand causal mechanisms, future research could build on this study by using mixed-method approaches, sectoral dynamics analysis (e.g., energy or transportation), or qualitative institutional indicators. Understanding institutional dynamics in various development contexts would also be enhanced by a comparative analysis between OECD and non-OECD economies.

Conclusions

The empirical findings of the study show the positive effects of strict environmental regulations on sustainability across various domains, emphasizing the importance of well-designed regulatory frameworks in promoting sustainable outcomes. Moreover, the study sheds light on the substantial beneficial impacts of economic growth, foreign direct investment, population density, technological innovation, and institutional quality on the achievement of Sustainable Development goals. These results thoroughly support the theory frameworks that have been characterized earlier. Sustainable development (ANS) is positively impacted by strict environmental policies (EPSI) in the majority of quantiles, supporting the Porter Hypothesis (Porter & Van Der Linde, 1995). This is especially true in higher quantiles (60th to 90th), suggesting that more stringent regulations promote efficiency and innovation, which in turn produce sustainable results. As strong institutions increase the effectiveness of environmental policies, as supported by literature (Acemoglu et al., 2001; Besley & Persson, 2011), institutional quality (WGI) plays a critical moderating function, supporting H_2. Technological innovation (PTNT) shows a varied impact, positively affecting ANS in higher quantiles while negatively influencing it in lower ones. This observation aligns with the Environmental Kuznets Curve (EKC) hypothesis, which states that innovation may initially lead to environmental degradation but ultimately fosters sustainability as economies develop.

Economic growth (GDP) and foreign direct investment (FDI) consistently demonstrate beneficial impacts on sustainable development, highlighting the significance of economic prosperity and global investments. However, our findings refute the pollution haven hypothesis (PHH), as FDI shows a positive effect on adjusted net savings, suggesting that foreign investments in OECD countries enhance sustainability rather than causing environmental damage. In conclusion, the study significantly enhances the current literature by providing a comprehensive understanding of the multifaceted factors influencing sustainable development in OECD countries. The information arising out of this study gives a clear guideline to policymakers and researchers in developing better policies on how to create a balance between environmental protection and sustainable development. As we go on to face a more environmentally friendly future, it will be extremely important that we further analyze the intricacies of such interrelationships and upgrade the research methodologies so that they can specifically meet the needs of academicians as well as the entire society.

The advantages related to the environmental regulations are that they promote sustainability, innovation, and good governance, which bear an impact on the economy, society, public policy, and services. They enhance the accountability of institutions, boost the economy by enhancing green investments, and also improve the health of the population by reducing pollutants. These rules affect the public services by facilitating green and environmentally friendly transportation, sustainable infrastructure, and effective management of resources. Although it might cause some short-term challenges, the long-term benefits, i.e., social justice and environmental conservation, are much more important than the regulatory costs. The concept of a sustainable and resilient future will only occur through the strengthening of legislative frameworks, the enforcement of green technologies, and ensuring governance transparency.

According to the beneficial effects of environmental regulations on sustainability, policymakers need to focus on the establishment and enforcement of powerful regulations as the key objective. They are, therefore, supposed to formulate regulations aimed at effectively curbing environmental degradation in the various sectors, accompanied by mechanisms of their compliance and enforcement. Although there is recognition across the world on the positive impact of economic growth expansion, foreign direct investments, population densities, and technological innovations on the sustainable development objectives, policies have a role to play in establishing a desirable environment towards these expansions and innovations. This may involve the promotion of green technologies, green business methods, or investments in research and development programs aiming at environmental sustainability.

In understanding the effect that the institutional quality has on sustainability, policymakers must subject the governance structure to critical scrutiny and bring it in line with the intended conference on the environment. This can incorporate enhancement in terms of transparency, accountability, and also anti-corruption among institutions that are involved in the management of environmental issues. In addition, institutional capacity ought to be enhanced. There has to be an appreciation by policymakers who have to see the correlation between the political and the environmental results. This will involve the adoption of an integrated framework that will consider social, economic, and environmental aspects of sustainability. This involves multi-stakeholder engagement in collaboration as well as fostering collaborative decision-making processes and policy coherence in various sectors in order to achieve the Sustainable Development Goals. Continuous monitoring and evaluation of policies is crucial to determine their effectiveness in the long term. It means collecting relevant data sets, performing impact assessments as well as engaging feedback from these stakeholders. These steps would allow evidence-based policymaking, which can lead to continual improvement in green governance. Thus, if such policy implications were put into place by the policymakers, there could be an improved level of environmental sustainability together with other related benefits that would eventually result in a more resilient future that is both socially equitable and just.

The future study may consider other regions with distinct socio-economic and institutional situations. To further understand how environmental rules may affect sustainable development, future research might include developing countries and emerging economies. Furthermore, to provide policymakers more relevant information, future work might examine environmental regulatory design and implementation, such as policy instruments (taxes, subsidies, or standards), enforcement methods, and stakeholder engagement processes to enhance the validity and generalizability of our empirical findings.

Declaration of Competing Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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