DOI: 10.52131/pjhss.2024.v12i2.2261

Pakistan Journal of Humanities and Social Sciences

Volume 12, Number 02, 2024, Pages 1537–1548
Journal Homepage:
https://journals.internationalrasd.org/index.php/pjhss

Exploring the Combined Impact of Environmental Policy Stringency and Institutional Quality on Sustainable Energy: Evidence from Top 14 Green Economies

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ARTICLE INFO

Article History:

Received:	April 26, 2024
Revised:	May 25, 2024
Accepted:	May 27, 2024
Available Online:	May 28, 2024

Keywords:
Sustainable Energy
Environmental Policy Stringency
Institutional Quality

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

The growing concern for a green economy increases the demand for sustainable energy. Previous studies massively concentrate on solutions to achieve the target of sustainable energy. However, limited studies focus on the contribution of stringency to sustainable energy. This study explores the contribution of environmental policy stringency and institutional quality on sustainable energy for the top 14 green economies by utilizing data from 1990 to 2022. In empirical analysis, the study applies the PMG-ARDL and CS-ARDL models to obtain the short- and long-run estimates. The study's findings indicate that after controlling the impact of technological innovation, foreign direct investment, population, economic globalization, and gross domestic product per capita environmental policy stringency and institutional quality significantly promote sustainable energy in the long run. Based on the results, the study recommends strictness in implementing policies is more critical than just designing environmental policies.

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1. Introduction

Sustainable energy has been the subject of the most attention in the 21st century, especially among oceans with ecological problems caused by the necessity of reducing the harmful effects of greenhouse gases. No less than the policymakers and the researchers have been focusing on figuring out how the regulations that have been put in place concerning the environment, alongside the technical capacity of the institutions, play a significant role in pushing the agenda and successful implementation of the sustainable energy policies (Godawska & Wyrobek, 2021; Sibt-e-Ali, Xiqiang, Javed, Javaid, & Vasa, 2024). A section is presented here focusing on energy consumption levels worldwide and drawing attention to the need to shift to reusable options. It addresses the critical point of demonstrating the participation of both bodies with capable organizations and sustainable environmental rules to meet the sustainable energy goal. A study also illustrates that green technology significantly promotes green or sustainable growth (Zaman et al., 2023). This research aims to unveil the suggested link between ecological rules and institutional capability as key to achieving sustainability in the energy field. Identifying the links between institutional capacity and regulatory frameworks is essential since the planet is currently experiencing a challenge to move the world toward cleaner and sustainable means of obtaining energy (Marinescu, 2020). This study aims to describe the current status of policies, highlight the factors that affect this relationship negatively, and provide suggestions for rules that would help balance institutional capacities for sustainable energy and environmental regulations (Bersalli, Menanteau, & El-Methni, 2020).

There is a significant shift at the global level seen in the share of renewables in energy mixes. Renewables have become more accentuated recently, especially in Western countries, the US, and the EU. Because renewable energy such as wind, solar, and wave power eliminates air pollution, it's known that the reduction in carbon dioxide (CO2) emissions is also linked to the emission of sulfur and nitrogen oxides. One of the main priorities for a low-carbon economy is using renewable resources (De Atholia, Flannigan, & Lai, 2020; Song, Anees, Rahman, & Ali, 2024). On the one hand, renewable energy investments counteract the negative impacts of fossil-fuel emissions on the environment. Also, it ensures energy security in periods of volatile markets. An adequately framed policy is needed to expand renewable sources to replace the expensive production of fossil fuel and renewable energy. According to the record of the last forty years, industrialized countries with their renewable energy developing policies can be pointed out specifically. Even in today's economy, many emerging economies try to mimic these policies. Even if creating renewable energy is already less expensive in certain nations than producing conventional energy (such as Australia for solar and wind energy), these nations still maintain their government assistance programs (Schmidt & Sewerin, 2019). Promoting renewable energy through environmental policies includes financial and fiscal incentives, regulatory actions, and strategy development. The two most widely utilized of these tools, either at the federal, state, or provincial levels, are renewable portfolio requirements and feed-in tariffs (Galeotti, Salini, & Verdolini, 2020; Iram, Zameer, & Asghar, 2024).

Figure 1: (Average behavior of EPS and REC for three decades)

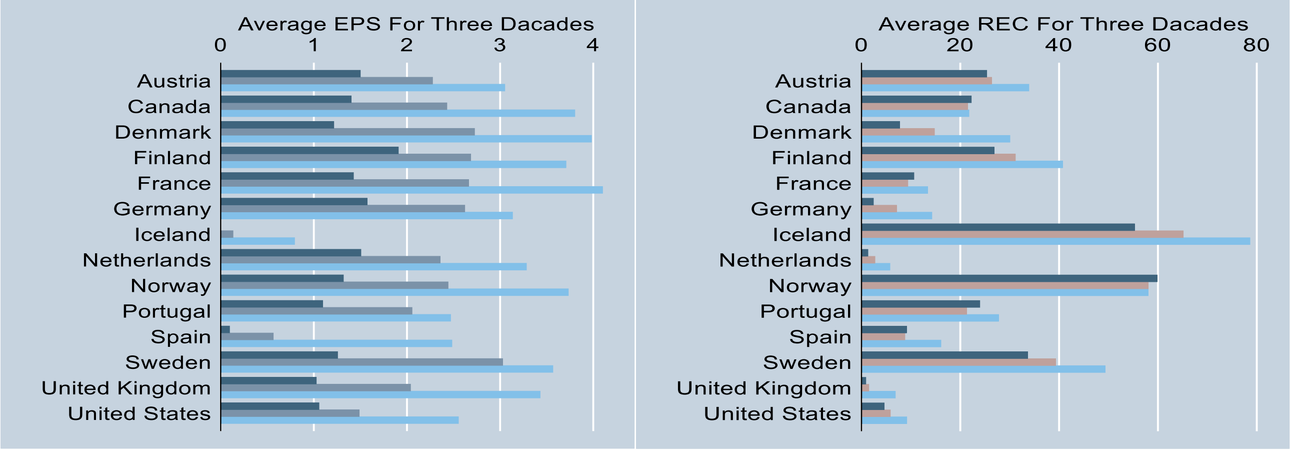

Figure 1 presents the average behavior of the EPS index for three decades. EPS_1999 indicates the average value of the EPS index from 1990 to 1999, EPS_2009 indicates the average value of the EPS index from 2000 to 2009, and EPS_2019 shows the average value of the EPS index from 2010 to 2019. The graph explains that with time, as environmental challenges increase, each country's EPS index value increases from decade to decade. It makes sense that economies have a positive attitude towards a sustainable economy in response to growing environmental issues. Similarly, the graph on the right shows the average behavior of renewable energy consumption for three decades. For each country, there is a significant positive increase in average renewable energy consumption from the first decade to the last decade. Over time, on average, the environmental policies became stricter, and usage of renewable energy consumption also increased. Similarly, figure 2 is constructed by using the renewable energy supply as a measure of sustainable energy and it is interesting to know that this measure also represents the same link with environmental policy stringency. For clarification, figure 2 is placed in the appendix. Therefore, we will explore its actual impact in the empirical analysis section. A similar comparison of the average value of the environmental policy stringency index with the average value of renewable energy supply for three decades indicates a positive association in the appendix. It should be highlighted that policies targeted at attaining other environmental goals, like lowering emissions, may also impact the usage of renewable energy in addition to those directed explicitly at its growth. Renewable energy is often considered an ecologically beneficial energy source, and developing renewable energy may be strongly encouraged in nations with generally strict environmental laws (Jobert, Karanfil, & Tykhonenko, 2019).

This study aims to examine the impact of institutional quality and stringency of environmental policies on sustainable energy for the top 14 (Sweden, Denmark, Norway, Finland, Iceland, France, Australia, Netherlands, Germany, United States, United Kingdom, Portugal, Spain, and Canada) green economies. After adjusting for the effects of population growth, economic globalization, technological innovation, foreign direct investment, and gross domestic product per capita, this study uses data from 1990 to 2022 to examine. To the best of our knowledge, this study adds to the body of literature by examining the significance of an overall degree of environmental policy restrictiveness in promoting renewable energy. In summary, the effectiveness of environmental governance is greatly influenced by the dynamic and intricate link between institutional capability and ecological rules. While regulations are necessary as change agents, their implementation and enforcement must be matched by institutional capacity. Acquiring desired results with these stumbling blocks, such as misalignment, bureaucracy, and lack of cooperation, is difficult. Recognizing noteworthy differences among regions and developing essential lessons from case studies play central roles in shaping flexible regulatory mechanisms suited for particular problems. Future studies might be a way to test new topics or discover knowledge gaps to build a better understanding and counter environmental challenges toward successful sustainable and well-managed governance. The research on the policy lanes for sustainable energy is a prevailing and evolving sector of scientific study. In making and implementing sustainable energy policies, the contribution of researchers' diverse views is vital to authorities, academics, and stakeholders responsible for the complex consequences of introducing these policies. The rest of the paper is structured as follows: The literature review on the effects of environment policy tools on renewable energy and the control variables incorporated into our models are presented in section 2. Section 3 discusses the research methodology and materials. The findings of our study are presented in section 4, and the discussion and recommendation for policy directions leading to sustainable energy are presented in section 5.

2. Literature Review

Good policy frameworks become more crucial as concerns about sustainable energy go international due to pressing environmental issues. This literature review researches the impact of institutional capacity and ecological legislation on policy routes for sustainable energy in the last few years (Sadik-Zada & Ferrari, 2020). The global shift of the world energy system to a sustainable mode is a choice of time in the context of resource misuse and climate change. These issues will question society's readiness and the regulative capacity to build the proper framework. Such literature also draws attention to the key results by examining the connections between ecological regulations and institutional capacity as significant factors in shaping future policies promoting sustainable energy. Environmental standards are vital in the infrastructural planning of future energy. The researchers argue that environmental regulations like greenhouse gas emission level reduction and energy efficiency promotion can stimulate the growth of the clean energy industry. These are the kinds of laws that encourage innovation and consumer-friendly markets coherent with renewable energy sources (Aldy, 2016). Environmental law provides sound footing for sustainable energy policies by creating legislative and economic plans supporting clean energy transformation. Institutional capacity is defined as government bodies, regulatory agencies, and other institutions successfully forming, performing, and enforcing regulations (Wolde-Rufael & Mulat-Weldemeskel, 2021). Some studies underscore strong institutions' capability to convert green regulations into scalable, transparent technology solutions. The presence of well-functioning institutions is the sine qua non of the designing, implementing, and overseeing the energy policy. Effective institutional capabilities can bridge targets and practices and accelerate energy transition (Sandri, Hussein, & Alshyab, 2020). Environmental constraints and institutional capacity are tight-rope walking ways. They are constantly changing and ceaselessly changing. Although tighter control is necessary, specialists believe the effectiveness of these control programs hinges on the institutional settings (Neij, Sandin, Benner, Johansson, & Mickwitz, 2021).

The role of institutions in developing and enacting these policies is to ensure that they are adaptive and well-equipped to supervise and implement the policies successfully. Policy disparity could be due to the misalignment of institutions' capacities with overly ambitious government goals. It is paradoxical, but several business cases are documented to show how Environmental rules may be affected by institutional capabilities and vice versa. For instance, Spangenberger, Kapp, Kruse, Hartmann, and Narciss (2018) provide the case of Germany's "Energiewende" transformation into renewable energy. These showcase the significance of holistic environmental regulations and the feasibility of leveling the playing field with German system functions. Also, studies of California's tight environmental regulations by Sovacool et al. (2020) reemphasize the essential function of an excellent magical authority that can implement the law. Several types of research indicate the fact that legal ordinances play a crucial role in how sustainable energy adoption takes place. Scholars like R. Wang, Hsu, Zheng, Chen, and Li (2020) underscore this issue as trying to make companies more eco-friendly with their guidelines. These regulations regularly lead to the creation of a sustainable environment that can withstand time and a certain amount of creativity. Furthermore, Zhang and Kong (2022) continue by addressing whether green innovation in the renewable energy sector responds to more or less strict environmental policies and how different levels of ecological law affect the green innovation process. Through analysis of panel data from 33 countries in the years 1990-2015, stark environmental regulations were shown to be the critical success factor for green innovations in renewable energy technologies, which led to the most favorable results with holders of the OECD and the high-income countries (Brown & Reichenberg, 2021). Also, inventions intended to enhance the implementation of strict nonmarket-based environmental regulations may result in more patents for renewable energy production. The findings of a study demonstrate that an increase in technological innovation measured through patents and trademarks significantly enhances environmental quality (Nanli et al., 2022). The findings of another study illustrate that ecological regulations, contrary to those on hydropower, wind power, and marine renewables, tend to induce innovative approaches in geothermal, hydro, and hydraulic energy. Currently, renewable energy technologies are vital for barring pollution from the global exploitation and combustion of fossil fuels (BankWHO, 2021).

Similarly, S. Wang, Abbas, Sial, Álvarez-Otero, and Cioca (2022) examine the 19th-century industrial revolution as effective in lifting millions out of poverty. However, a byproduct of this prosperity has been the subsequent degradation of the environment and resources. The natural resources found in developing economies are vulnerable to the effects of global warming, which puts their economic growth at risk (Mukhtarov, Humbatova, Hajiyev, & Aliyev, 2020). Throughout the years, authorities worldwide have been keen to establish regulations and standards for goods and services that are almost entirely environmentally safe. Governments promoted the development of feasible targets for reducing greenhouse gas emissions. To safeguard and enhance society and the environment, the United Nations also established the Sustainable Development Goals (SDGs) (United Nations, 2021). As a result, businesses began to recognize the value of a green environment, which inspired them to focus on revamping their management and operations processes (Bayar, Sasmaz, & Ozkaya, 2020). Ahmed, Ahmad, Murshed, Shah, Mahmood, and Abbas (2022) focus on one goal of the SDGs, which is to use the concept of "green innovation" to assist businesses in developing environmentally friendly products for social sustainability; companies need to prioritize both technical and management innovation. They also need to differentiate between two forms of green innovation: green technology innovation (GTI) and green management innovation (GMI). It combines state-of-the-art technology with sustainable knowledge (McGee & Greiner, 2018). In addition to improving the environmental, economic, and manufacturing processes, it assists businesses in creating new or enhanced products or processes with the least raw materials and other resources. Among the most essential functions of organizations in IBE are increased production and supervision processes and lower environmental pollution (Li & Ullah, 2022).

One can name structural interactions between institutional capacity and ecological legislation. Gaps in implementation might yield less effective environmental outcomes when deliberately loose regulatory framework intentions are not aligned with institutional capacities (Yang, Ali, Hashmi, & Shabir, 2020). Meanwhile, the coordination among the necessary regulatory authorities is made even more complex by the scarcity of resources and bureaucratic inefficiencies (Peng et al., 2021). Policymakers should instead focus their attention on designing policies that set inspiring environmental goals and outline the capacity of institutions to carry out these tasks efficiently. If these problems are properly understood, such goals would be more easily achieved. The research showed how regional variations must be tackled together with the two in question variables. In a way, case studies taken from different parts of the globe, including the work of Chen, Shi, and Zhao (2022), considered Southeast Asian countries and showed that the effectiveness of institutional responses and regulatory frameworks depends on circumstances. Cultural, political, and economic issues hammer whether the environmental campaigns are moving correctly or suffering from failure.

Instructional writing reveals how the author combines institutional capacity and ecological rules. Universities have to find a delicate balance in this case to achieve regulations that are both inspirational and concrete enough so they can be implemented (Bigerna, D'Errico, & Polinori, 2020). Sustainable and durable policies should expand and strengthen this interconnection because, otherwise, society cannot meet the demands of environmental problems. These case studies show the role of problem-specific methods in environmental governance through the valuable information given about the particular problems of those different world areas (Khan, Sisi, & Siqun, 2019). The literature is also not exhaustive, as there are many unanswered questions and developing regions. However, the literature is comprehensive in closely examining the interrelationship between institutional capability and environmental regulation. For the following studies to improve the sustainability of interactions, they should seek to explore the function of technology, outcomes of global connectivity, and possibilities of governing structures that will allow for partnership among countries (Ai, Zhou, Li, & Kang, 2021).

2.1. Literature Gap

Previous studies exploring the impact of environmental policy stringency on sustainable energy are nearly neglectable. Further, studies in this dimension use minimal data. To the best of our knowledge, no analysis is available to analyze the impact of environmental policy stringency on both proxies (renewable energy consumption and renewable energy supply) of sustainable energy. Further, no study is available that explores the impact of environmental policy stringency for the top 14 economies with the combination of variables that ongoing investigation uses.

3. Data and Methodology

This study mainly focuses on the influence of environmental policies and institutional quality on sustainable energy for the top 14 green economies in the world by utilizing data from 1990 to 2022. The green economies are selected based on the energy transition index score reported in 2023. A list of countries along with their energy transition index score is presented in Appendix Table 9. The higher the value of energy transition indexes, the greener the economy. This indicates that a country is making significant progress to a more sustainable and environmentally friendly or low carbon emission economy. Initially, we were interested in the top 20 green economies. Still, due to the unavailability of data for some countries, this study uses the 14 green economies out of the top 20in the empirical analysis. The list of selected green economies and their energy transition index value is in the appendix. As mentioned, the current study explores the nexus between environmental policy stringency, institutional quality, sustainable energy, and other correlating factors. The list of variables under consideration and their sources are presented in Table 1. In the next step, it is pretty relevant to understand the nature of the variables. For this purpose, we go for the summary statistics of variables in Table 2.

Table 1: Variables description

Variable	Definition	unit	source
REC	Renewable energy consumption in percentage form	Percentage	WDI
RES	Renewable energy supply percentage of total energy supply	Percentage	OECD
EPS	Environmental policy stringency	Index	OECD
IQ	Institutional Quality	Index	WGI
R&D	Research and development budget	Percentage	OECD
Patent	Number of patents with country's frictional values	Number	OECD
GDPPC	Gross domestic product per capita	Percentage	WDI
POP	Total population	Number	WDI
FDI	Foreign direct investment	Percentage	WDI
ECGI	Economic globalization	Index	KOF

Table 2: Summary Statistics

	REC	EPS	IQ	R&D	GDPPC	POP	FDI	ECGI
Mean	24.97244	2.427994	0.032719	2.241453	42639.07	9.694854	4.098742	76.67151
Median	21.17500	2.560000	0.338625	2.170000	42683.06	9.265839	2.402520	78.00000
Maximum	81.57000	4.890000	1.301431	5.520000	76712.29	12.71139	86.47915	90.00000
Minimum	0.850000	0.000000	-3.929158	0.000000	16280.94	5.594414	-36.14035	59.00000
Std. Dev	20.25319	1.109920	1.083793	1.211213	12731.54	1.624483	8.617931	6.590009
Skewness	0.937414	-0.380414	-2.148192	0.284270	0.370765	-0.500809	3.654662	-0.363548
Kurtosis	2.996340	2.321556	7.298983	2.444356	3.580956	3.482905	33.46159	2.415204
Jarque-	50.38160	14.89445	529.4757	9.058358	12.71905	17.72226	14065.79	12.47939

Bera								
Probability	0.000000	0.000583	0.000000	0.010790	0.001730	0.000142	0.000000	0.001950
Sum	8590.520	835.2300	11.25532	771.0600	14667842	3335.030	1409.967	26375.00
Sum sq. Dev	140695.7	422.5493	402.8901	503.1939	5.56E+10	905.1578	25474.17	14895.88
Observations	344	344	344	344	344	344	344	344

The descriptive statistics show that the mean value of economic globalization is the largest, indicating that economic globalization has the largest deals in the data set. Moreover, the skewness values suggest that some variables are positive while others are negatively skewed. Further, the Jarque Bera test is used to test the data's normality; here, the test's probability values are less than 0.05, which firmly rejects the null hypothesis that variables are normally distributed.

3.1. Model and Methodology

The growing challenges to sustainable energy due to the increase in global temperature and variation in climate attract researchers and regulatory authorities for a significant contribution towards sustainability. Government authorities often shape environment-friendly policies to curb harmful actions. But policies without implementation are useless. Therefore, we are interested in analyzing the influence of the strictness of policies on sustainable energy. For this purpose, the study uses environmental policy stringency (EPS) as a focus variable that compromises 13 ecological policy instruments mostly related to climate and air pollution. Stringency can be defined as the degree to which environmental policies put an explicit or implicit price on environmentally harmful behavior. A higher value of EPS indicates stricter policies to regulate environmental issues. Similarly, institutional quality is another vital variable in preventive environmental degradation. Ameer, Amin, and Xu (2022) clarifies that institutional quality reduces pollution in the long run. The variable institutional quality is also an index that combines control on corruption, government effectiveness, law and order, voice and accountability, political stability, and regulatory quality. Generally, it is considered that countries with higher institutional quality are more effective in policy implementation. Azam, Liu, and Ahmad (2021) explain the positive impact of institutional quality for developing countries. Besides these two variables, other correlating factors are essential and can significantly influence sustainable energy. Therefore, we have also included the relevant variables like technological innovation, GDP per capita, population, foreign direct investment, and economic globalization. By utilizing these variables, we estimate the following panel models:

$$RECit = \alpha it + \beta 1EPSit + \beta 2(IQ)it + \beta 3R\&Dit + \beta 4GDPPCit + \beta 5POPit + \beta 6FDIit + \beta 7ECGIit + \varepsilon it \quad (1)$$

$$RESit = \alpha it + \beta 1EPSit + \beta 2(IQ)it + \beta 3PATENTit + \beta 4GDPPCit + \beta 5POPit + \beta 6FDIit + \beta 7ECGIit + \varepsilon it \quad (2)$$

Here, equation 1 is for model 1, which takes the dependent variable as renewable energy consumption (REC) as a proxy for sustainable energy. Equation 2 is for model 2, which takes renewable energy supply (RES) as a proxy variable for sustainable energy. In these equations, R&D and PATENT are proxy variables for technological innovation. Further, the definition of the other variable can be accessed from Table 1.

4. Results and Discussion

Before proceeding with model estimation, it is necessary to explore the hidden characteristics of the variables. For this purpose, we first apply the cross-sectional dependence test to clarify whether variables have the cross-sectional dependence among cross-sectional units. Secondly, to identify the appropriate model for estimation, we apply the panel unit root test, which explains the stationary order. Finally, we use the co-integration and slope heterogeneity test to understand whether the variables have long-run relationships or heterogeneous slopes across cross-sectional units.

4.1. Cross-Sectional Dependence

A cross-sectional dependence test is used to identify the interdependence among the cross-section units. The existence of cross-sectional dependence ensures that a significant change in any cross-sectional team will influence the other selected cross-sectional groups. Table 3 presents Pasaran CD test results. This test assumes no cross-sectional dependence. The results obtained from the trial indicate that most of the variables have cross-sectional support among the cross-sectional units. This reveals that observations of different cross-section units are not independent.

Table 3: Cross-sectional dependence test

	RES	REC	EPS	IQ	R&D	GDPPC	POP	FDI	ECGI
Pasaran test	33.82***	34.480***	48.590***	-0.890***	1.50	52.070***	45.750***	17.930***	49.930***
Prob value	0.000	0.000	0.000	0.000	0.133	0.000	0.000	0.000	0.000
Off the diagonal element		0.649	0.915	-0.018	0.024	0.961	0.848	0.327	0.940

4.2. Panel Unit Root

We have applied the first-generation (LLC & IPS) and second-generation (CADF & CIPS) panel unit root tests to identify whether the variables under consideration are stationary or nonstationary. These tests assume that the variable has a unit root.

Table 4: Unit root test

	LLC		IPS		CADF		CIPS	
Variables	$I_{(0)}$	$I_{(1)}$	$I_{(0)}$	$I_{(1)}$	$I_{(0)}$	$I_{(1)}$	$I_{(0)}$	$I_{(1)}$
REC	8.8019	-3.2162 ***	10.0873	-6.3960***	-2.250	-2.250 ***	-1.306	-5.156 ***
RES	4.1515	-12.1534***	8.8520	-8.0311***	-2.250	-2.250***	-1.529	-4.963***
EPS	0.6178	-9.3511***	4.4658	-10.7151***	-2.250***		-3.253***	
IQ	-3.3329***		-2.2253***		-2.250	-2.250***	-1.762	-4.507***
R&D	-4.0232 ***		-1.3053*		-2.260	-4.642***	-1.925	-5.443***
Patent	-4.7242	-12.8862***	-0.0911	-7.9615***	-2.250	-2.250***	-2.003	-5.107***
GDPPC	-4.4531***		1.2501	-10.4613***	-0.792	-6.332***	-1.737	4.155***
POP	-3.2269***		0.3338	-4.4895***	-2.250***		-1.411	-3.875***
FDI	-4.8546 ***		-5.2292***		-2.250***		-4.215***	
ECGI	-7.2265***		-4.6076***		-2.250 ***		-3.081***	

Table 4 presents the estimated results of unit root tests. Here, the first-generation panel unit root test LLC indicates that IQ, R&D, GDPPC, POP, FDI, and ECGI are stationary at level while REC, EPS, Patent, and GDPPC are stationary at first difference. Similarly, the IPS test result indicates that IQ, R&D, FDI, and ECGI are stationary at I(0). Meanwhile, REC, EPS, Patent, GDPPC, and POP are stationary at I(1). Further, the second generation CADF unit root test indicates that EPS, POP, FDI, and ECGI are stationary at I(0), and REC, IQ, R&D, Patent, and GDPPC became stationary at I(1). Finally, the results of the CIPS test indicate that EPS, FDI, and ECGI are stationary at I(0) while REC, IQ, R&D, Patent, GDPPC, and POP became stationary at I(1). From first- and second-generation panel unit root test results, the variables under consideration have mixed order of stationarity, which guides us to use the ARDL model for estimation.

4.3. Slope Heterogeneity

Testing whether the slopes are homogeneous or heterogeneous across the cross-section units is crucial. This test provides information on whether the effect of independent variables across different entities is consistent. Table 5 presents the slope heterogeneity test results for model 1 and model 2. The statistically significant results for both models verify that slops are heterogeneous among the selected countries.

Table 5: Slope heterogeneity test

	Model 1	Model 2
Delta	9.042***	10.415***
P-value	0.000	0.000

4.4. Co-integration Test

The co-integration test assumes that there is no co-integration among the variables. The cointegration among the variables indicates that variables have long-run relationships. Table 6 presents the co-integration test results. Here, it can be shown that the coefficients are statistically significant for most of the variables, which implies that the variables are co-integrated. This ensures that in empirical analysis, we will have to estimate the short-run as well as long-run results of the model.

Table 6: Westerlund and padroni co-integration test

	EPS	IQ	RD	GDPPC	POP	FDI	ECGI
Value	-2.0843***	4.1030***	2.4998***	-1.0368	-1.2018	6.6916***	1.3712***
P-value	0.0186	0.0000	0.0062	0.1499	0.1147	0.0000	0.0851

By looking at the characteristics of the data, it is relevant to apply the PMG-ARDL technique for estimation. This model is applicable when variables are co-integrated and have a mixed order of stationarity. This model also performs well when the sample size is small and one is interested in estimating variables' short-run and long coefficients.

Table 7 presents the short-run and long-run estimates of the PMG-ARDL model. The table shows the empirically estimated results of the two models. Model 1 uses renewable energy consumption as a dependent variable, while model 2 utilizes renewable energy supply as a dependent variable for robust analysis of variables. It can be shown that most of the variables are statistically significant in the short run and long run for both models.

Table 7: ARDL PMG

	Model 1 **Dep variables (REC)**		**Model 2** **Dep variable (RES)**	
Variable	**Short run**	**Long run**	**Short run**	**Long run**
EPS	-0.302***	8.769***	-0.204	1.226***
	(0.592)	(1.498)	(0.467)	(0.554)
IQ	-0.475**	6.089***	-0.543	4.641***
	(0.249)	(1.797)	(0.761)	(0.878)
RD-Budget	-0.630	4.552***	.003	.003
	(0.483)	(1.111)	(.003)	(.003)
Patent			1.132	5.165***
			(1.986)	(1.059)
GDPPC	-.0002697***	.0002284	-0.00028***	0.00025
	(.0001284)	(.000258)	(.0001284)	(.0001284)
POP	-58.699	124.482***	28.460	11.682
	(40.234)	(18.544)	(74.133)	(11.858)
FDI	-0.028	-1.134***	0.005	0.327***
	(0.025)	(0.215)	(0.032)	(0.109)
ECGI	0.175***	-0.869***	0.104	-0.141
	(0.082)	(0.313)	(0.114)	(0.119)
ECT(-1)	-0.107***		-0.182***	
	(0.043)		(0.079)	
N	329		336	

In model 1, the statistically significant estimated coefficient value -0.302 of EPS and -0.47 of institutional quality indicates that one index point increase in EPS and institutional rate lowers renewable energy consumption by 30% and 47% respectively in the short run. This negative relation is possible in the short run because countries with higher environmental policy scores or institutional quality may already have relatively cleaner energy systems in place, reducing the immediate pressure to transition to renewable sources. Additionally, technological readiness and infrastructure for renewable energy production and distribution may lag in these countries compared to those with lower EPI scores or weaker institutional quality. Further Political and economic interests may influence policy decisions in ways that prioritize long-term gains over long-term sustainability. In some cases, powerful vested interests, such as fossil fuel industries, may exert influence to maintain the status quo and resist the transition to renewable energy sources in the short run. In the long run, EPS has a positive association with the energy transition, and the coefficient value 8.769 indicates that one index point increase in EPS increases the 876% renewable energy consumption. Similarly, the estimated significant coefficient value 6.089 of institutional quality reveals that one index point increase in institutional quality increases renewable energy consumption by 608 percent in the long. This is quite similar to the findings of (Sandri et al., 2020). The results of other correlating factors, such as GDPPC and ECGI, indicate the statistically significant negative and positive association with the energy transition in the short run. While research and development expenditure and population positively affect the energy transition in the long run, FDI and ECGI are negatively linked with energy transition. In the same way, Model 2 presents robustness in variables. In this model, the estimated coefficient of 1.226 of EPS indicates that one index point increase in EPS upsurges the renewable energy supply by 122% in the long run. The estimated coefficient of institutional quality of 4.641 suggests that one index point increase in institutional rate promotes renewable energy supply by 464% in the long run. It is interesting to know that the empirically estimated results of both models are very consistent in the long run. Further, in the long run, paten represents technological innovation, and foreign direct investment is also significantly and positively associated with sustainable energy.

4.5. Robustness check

Robust analysis is crucial for the generalization of results and ensures the reliability and credibility of findings. By looking at the characteristics of our data set, this study will apply the CS-ARDL technique for robust analysis. First, it is suitable and reliable when the variables under consideration have a mixed order of stationarity. Second, it also considers the problem of cross-sectional dependence and slope heterogeneity. Third, it provides the short-run and long-run estimates of a single equation more efficiently and is applicable when we have more cross-sectional units than the time series. This study estimates both models for robust analysis by applying the CS-ARDL technique. Again, model 1 contains renewable energy consumption as a dependent variable, while model 2 takes renewable energy supply as a dependent variable.

Table 8: CS-ARDL

	Model 1 **Dep variable (REC)**		**Model 2** **Dep variable (RES)**	
Variable	**Short run**	**Long run**	**Short run**	**Long run**
EPS	1.563*	0.982*	1.268*	0.688*
	(0.917)	(0.587)	(0.685)	(0.385)
IQ	-1.314*	-0.683	-0.429	-0.204
	(0.738)	(0.377)	(0.685)	(0.330)
RD-Budget	-0.295	-0.199		
	(0.487)	(0.236)		
Patent			.2.379	1.160
			(1.678)	(0.981)
GDPPC	.0000943	.0000652		
	(.0002847)	(.0001373)		
GDPGR			-0.049	-0.025
			(0.064)	(0.039)
POP	30.031	12.923	.966*	.118***
	(33.949)	(16.860)	(.549)	(.027)
FDI	0.071	0.032	-.001	-.001
	(0.059)	(0.027)	(.002)	(.003)
ECGI	-0.114	-0.061	-0.261***	-0.122***
	(0.105)	(0.053)	(0.115)	(0.057)
ECT(-1)				
N	1275		350	
	.285		.285	

Standard errors are in parentheses
*** p<.01, ** p<.05, * p<.1*

In model 1, the empirically estimated coefficient value of 1.56 of EPS indicates that one index point increase in environmental policy stringency increases renewable energy consumption by 156% in the short run. In the long run, it increases by 98%. The estimated coefficient of institutional quality is only significant in the short run. The estimated coefficient -1.314 indicates that one index point increase in institutional rate lowers renewable energy consumption in the short run. Similarly, in model 2, the estimated coefficient values of EPS are statistically significant and positive. This explains that one index point increase in EPS leads to a rise in the renewable energy supply of 126% and 68% in the short and long run, respectively. Among other correlating factors, population significantly and positively influences renewable energy supply. At the same time, economic globalization is significantly negatively related to renewable energy supply both in the short run and long run.

5. Conclusion and Policy Implications

The Growing concern towards sustainable development attracts the researcher to address the key factors contributing to or hindering progress toward a sustainable economy. The recent literature highlights that sustainable energy is highly influential for sustainable development; therefore, it is essential to understand how sustainable various economic factors influence energy. Many countries have taken different measures for sustainable energy.

Environmental regulation can be categorized as the leading among the criteria. Recently, the OECD developed an index containing thirteen ecological policies mainly related to pollution and climate change. The value of ecological policies stringency index explains the degree of strictness of environmental policies. This study explores the impact of environmental policy stringency and institutional quality on sustainable energy, along with other correlating factors. To select the suitable estimation technique, the study explores the hidden characteristics of the data by applying the cross-sectional dependence, panel unit root, co-integration, and slope heterogeneity test. Based on the pre-estimation test results, this study uses the PMG-ARDL and CS-ARDL techniques for empirical analysis. The findings of the survey are pretty meaningful. In the empirical analysis, the study does robust analysis in two ways. One is variable, and the second is methodology-based. The findings of the study can be explained in four steps. First, the PMG-ARDL results for model 1, which takes renewable energy consumption as a proxy for sustainable energy, indicate that the environmental policy stringency (EPS) and institutional quality significantly promote sustainable energy in the long run but lower it in the short run. Second, in model 2, where the study takes renewable energy supply as a proxy for sustainable energy, the environmental policy stringency (EPS) and institutional quality have significant positive associations with sustainable energy in the long run. Third, the estimated results obtained from CS-ARDL for model 1 show that environmental policy stringency (EPS) promotes sustainable energy both in the long and short run. Fourth, for model 2, the estimated results again show the significant positive association between environmental policy stringency and sustainable energy in the short and long run. These results also hold by controlling the essential correlating factors like technological innovation, GDP per capita, population, foreign direct investment, and Economic globalization for both models.

The findings of this study help in explaining some policy recommendations. The economies are always in the interest of sustainable development. First, the evidence of the supportive role of environmental policy stringency and institutional quality in promoting sustainable energy, in the long run, suggests that the regulatory authority of economies should implement environmental policies to achieve a sustainable economy. Second, the findings also suggest that the strictness in the implementation of policies is more effective than just designing the environmental policies. For this purpose, the institutions can play a central role because, without proper checks and balances on environmental policies, it is very difficult to tackle environmental challenges. Therefore the economies should have to improve the quality of institutions. This study also contains some limitations that can be addressed in future studies. First, for empirical analysis, this study considers only the top 14 green economies which is a small sample. Secondly, this study focuses on the influence of environmental policy stringency on sustainable energy and does not separately analyze the impact of different environmental policies on sustainable energy. This study is limited in analyzing the different environmental policies separately to identify which policy is more effective in achieving sustainable energy. In the future, the analysis can be done by selecting a large sample size where one can differentiate the results of developed and developing countries.

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