Journal of Risk Analysis and Crisis Response, 2025, 15(4), 787-806
https://jracr.com/
ISSN Print: 2210-8491
ISSN Online: 2210-8505

Article

Renewable Energy Consumption, Governance Quality, and CO_2 Emissions in Asia-Pacific Region: Evidence from the MMQR Approach

Anwar Hossain [1,*], Ishtiaq Mainuddin [1], Partha Acharjee [2] and Md. Arafat Rahman [1]

[1] School of Business Administration, East Delta University, Chattogram (4209), Chattogram, Bangladesh
[2] Department of Management, Humanities and Social Sciences, National Institute of Technology Agartala, Agartala (799046), Tripura, India
* Correspondence: anwar.h@eastdelta.edu.bd; Tel.: +8801834816740

Received: July 21, 2025; Received in revised form: October 13, 2025; Accepted: November 23, 2025; Available online: December 31, 2025

Abstract: Transitioning from fossil fuels to renewable sources unquestionably contributes significantly to reducing carbon emissions and is the way forward to achieving sustainable development goals. This study, thus, aims to empirically investigate the effects of renewable energy consumption on environmental sustainability (carbon emissions) in the Asia-Pacific region, with a specific emphasis on governance quality as a moderator. Using the MMQR approach for 25 Asia-Pacific countries over the period 1998-2022, the analysis reveals that renewable energy consumption is significantly and negatively correlated with CO_2 emissions across all quantiles, with the effect becoming more evident between the 0.20 and 0.90 quantiles. The results further highlight that effective governance significantly impacts the inverse linkage between renewable energy consumption and carbon emissions. Such a moderating effect is most pronounced in the middle and upper quantiles, where better institutions will have a higher probability of converting renewable energy policies into positive environmental results. In addition, this study employs income-segmented MMQR analysis to highlight the extent to which the drivers of carbon emissions differ across economic groups. These findings emphasize the need for a multidimensional policy approach that unites renewable energy promotion and institutional quality enhancements. Thereby, the study contributes to the existing body of literature by offering quantile-specific insights for formulating focused and effective emission-reduction policies.

Keywords: Renewable Energy Consumption; Environmental Sustainability; CO_2 Emissions; Governance Quality; MMQR; Asia-Pacific Region

1. Introduction

One of the most significant ongoing difficulties facing the globe today is keeping the environment sustainable without impeding economic progress [1, 2]. The recognition of ecologically sustainable economic advancement as a critical component of worldwide endeavors to enhance and safeguard environmental and socioeconomic circumstances is growing since the world is likely to experience a severe environmental challenge sooner than anticipated [3].

Promoting economic expansion is linked to higher levels of energy consumption, as noted by [4], since it increases the productivity of goods and services. However, this in turn suggests a conflict between growth and the goal of environmental sustainability. It is theorized that the kind and

quantity of energy utilized to support national output are thought to have an impact on the likelihood of attaining environmentally sustainable economic growth. Global economic expansion and human well-being in recent decades have been accompanied by the rapid depletion of natural resources and fossil fuels, which have resulted in elevated CO_2 emissions [5]. Since fossil fuels are the main source of greenhouse gases (GHGs), primarily CO_2 emissions, into the atmosphere and subsequently pollute the environment, the world's heavy reliance on fossil fuels intensifies environmental pollution [6].

However, in contrast to fossil fuels, GHG emissions are reduced by renewable sources of energy [7]. Notwithstanding, in order to address and create ecological sustainability, the challenges posed by a changing climate and other ecological issues have triggered the necessity to swiftly terminate the era of fossil fuels and have reinforced the need for the elevation of renewable energy consumption (REC). Meanwhile, in light of urgent global issues such as resource depletion, climate change, and environmental degradation, policymakers and decision-makers are paying close attention to the need for sustainable development and continue to search for eco-friendly solutions that will minimally affect economic indicators [8, 9, 10, 11, 12]. Nowadays, REC is leading the way in the fight against environmental deterioration and is quickly emerging as a key strategy for fostering both sustainable economic growth and environmental protection. Switching from fossil fuels to renewable sources, green and clean energy consumption that is eco-friendly unquestionably contributes significantly to reducing GHG emissions, especially CO_2, and thus has the least negative effect on climate change and is the answer to achieving sustainable development objectives [13, 14]. Indeed, the significantly constructive effects of unconventional energy sources, including REC, on lowering CO_2 emissions and alleviating climate change effects have been reported by several scholars [15, 16, 17], making them a critical strategic aspect in the global agenda for sustainability, including SDG 13 on climate change [18, 19]. Thus, the REC straightaway minimizes reliance on CO_2-intensive energy sources by promoting a clean and sustainable energy environment, which is crucial in guiding the world's energy trajectory towards a low-CO_2 future [20].

However, the formulation and application of rules and regulations specifically tailored to sustainable energy projects is made possible by the existence of robust governance, which is capital to the realization of the true and substantial effectiveness of REC for environmental quality and conservation efforts, eventually resulting in a sustainable environment [21, 22]. Researches indicate that strong governance, including political stability, accountability, openness, and democracy, can be a potent instrument for the environment and its preservation, lower different types of emissions, including CO_2, as well as for long-term sustainable economic growth [23, 24, 25]. Quality governance is critical to environmentally sustainable development because it affects the embracing of eco-friendly practices, the distribution of funds toward eco-friendly investments, and the conception of strategies that support ecological balance in the long run [26, 27, 28]. High-governance nations are frequently better able to create and implement laws that encourage the REC, which results in more notable drops in CO_2 emissions. Likewise, government efficiency [29], control of corruption [30], and political stability [31] ensure the efficacy of renewable energy projects, elevating their ability to reduce CO_2 emissions.

Even though numerous studies have examined the determinants of CO_2 emissions, several limitations still need to be addressed. Firstly, the available literature overwhelmingly agrees that the REC can lead to strategic CO_2 emissions cuts; nonetheless, the results seem to be context-linked and change considerably from regions, income categories, and levels of institutions [7, 21, 32]. These

divergences suggest that moderating factors, such as GQ, may explain the efficacy of REC in mitigating emissions; however, most studies do not investigate this interaction, particularly for Asia-Pacific nations [23, 24, 25]. Secondly, although an increasing number of studies acknowledge that GQ matters for environmental management, very few have explored the moderating effect of GQ in the relationship between REC and environmental outcomes, those that have, including [33, 34], are constrained at firm-level data, or concentrate on national governance and direct determinants rather than conditional enablement of REC effectiveness. This creates an urgent theoretical and empirical validation of how GQ realizes environmental benefits from clean energy transitions. Thirdly, most reviews of the literature focus on particular regions, such as OECD [35], BRICS [36], MENA [7], and ASEAN [32], with very little empirical research in the Asia-Pacific region [23, 29, 37], which is responsible for approximately half of the world's energy demand and the majority of GHG emissions worldwide [38]. As this region hosts a range of economies with their different level of sustainability and governance reform, it makes the region a suitable case for exploring how a constellation of REC policies and GQ can contribute to environmental sustainability. Some studies in this region explored the REC-CO_2 nexus; however, from varying aspects and considering multidimensional determinants of environmental sustainability. For instance, several variables have been investigated, including economic growth, renewable energy, foreign direct investment, trade openness, and institutional quality in curbing emissions [12, 25]. However, most of these studies investigated CO_2 emissions in terms of multiple explanatory variables, but not solely employing REC. In addition, GQ has been used as either an explanatory variable or a moderating variable with different determinants of CO_2 emissions, rather than only being utilized with REC [39]. Lastly, there are still some methodological concerns in the existing literature, for instance, the lack of sufficient endogeneity treatment, a narrow focus on interaction effects, inconsistent application of governance indicators, and impact analysis for different quantiles [23, 24, 25, 29, 37]. Accordingly, the role of REC in reducing emissions, especially in governance-sensitive environments, has been under-theorized and empirically underdeveloped. In aggregate, this study incorporates GQ as a moderator with particular emphasis on Asia-Pacific economies, thereby contributing to a more nuanced understanding of the REC-emissions nexus within the framework of the Environmental Kuznets Curve (EKC) theory.

Hence, based on the justifications and arguments presented above and using the innovative econometric technique 'Methods of Moments Quantile Regression (MMQR)' of [40], this study aims to evaluate the effects of REC on environmental sustainability through CO_2 emissions, and how these effects are modified by GQ for the Asia-Pacific context. Hence, this study makes three literary contributions. Firstly, it looks at one of the crucial factors, REC, in curbing CO_2 emissions and thus ensuring environmental sustainability over 25 years (1998–2022). Secondly, to the best of our knowledge, this study is one of the few to look at the significant role that GQ plays in transitioning the substantial impacts of REC in creating a sustainable environment in the Asia-Pacific region, thus adding to the ongoing debate on the relationship between REC and CO_2 emissions. Lastly, this study aims to contribute methodologically by using the MMQR to look at how the empirical relationships among the study variables change for different levels of carbon (CO_2) emissions. Compared to conventional panel methods like fixed effect ordinary least squares (FE-OLS), this method, using different quantile distributions, provides a comprehensive picture of the conditional distribution and offers a non-linear relationship between variables.

2. Literature Review

2.1. Theoretical Framework of the Study

The study is grounded in the Environmental Kuznets Curve (EKC) hypothesis, which argues that during the initial period of growth, large-scale industrial expansion and energy use typically lead to a rise in CO_2 emissions [41], however, as income increases, economies develop more effective institutions, find creative ways to invest in green technologies, and utilize cleaner energy, which in turn alleviate environmental deterioration [9]. The rationale for employing the EKC in this study because, particularly at higher income levels, RE can facilitate decouple environmental degradation from economic growth. To give some evidence, [21] reported the urge to implement cleaner and more sustainable forms of energy in China to abate CO_2 emissions resulting from economic growth. Similarly, [31] suggested that countries that are transitioning from reliance on fossil fuels to REC are regarded as moving along the EKC in the direction of a sustainable environment, in tandem with SDG 13. Other regional studies, including those on the BRICS economies [36], the MENA region [7], and ASEAN countries [32], also showed similar findings. However, such EKC results are also directed by the GQ. Prior research, including [24, 25], has shown that the degree of corruption control [30], stable government [31], and effective governance [29] influence how REC policies are implemented and foster a favorable investment setting for RE investments in developing nations. Consequently, to account for this dynamic in its entirety, this study also introduces GQ as a moderator in the REC-emissions nexus.

2.2. Renewable Energy Consumption and CO_2 Emissions

The interaction between REC and CO_2 emissions and the validity of the EKC hypothesis have been widely addressed in empirical literature. For instance, [42] studied 97 countries from 1995 to 2015 and found that the increase in REC per capita lowers CO_2 emissions. The authors emphasized that the nexus is significant if the countries surpass a certain level of REC. In Malaysia, [12] found the deteriorating effect of GDP on the environment, but higher REC can help to achieve environmental sustainability through emission reduction. Likewise, [24] found that the growth of REC has the potential to lower emissions in developing nations, particularly in the presence of effective governance. Showing similar results, [34, 41] stated the significance of REC in combating emissions driven by economic growth. [37] studied 16 Asia-Pacific countries between 2000 to 2021 and showed that REC is a driving factor for green energy transition in the region. [15] suggested that REC is essential to meeting the worldwide goal of reducing half of the CO_2 emissions by 2050 if the average global temperature rise is to be kept to 2-2.4 °C. The authors also argued that REC is an effective remedy to reduce emissions in light of the growing threat of climate change and global warming brought on by economic growth. Indeed, REC is particularly important for developing countries that seek to balance economic growth with environmental preservation. However, there is literature indicating that the impact of REC on efficiency might be conditional on structural and policy factors. Institutional mechanisms can either amplify or undermine the ability of REC to mitigate emissions [25]. [21] showed that the impacts of REC are influenced by the physical structure of the energy system and its governance capacity to affect CO_2 levels, whereas [19] emphasized that adopting renewable generation does not necessarily result in an immediate reduction of GHG emissions, unless it is coupled with deep decarbonization efforts. These findings suggest that REC is a crucial policy tool for environmental sustainability in the long run. Consistent with the EKC framework as well as prior empirical studies, this study hypothesizes that:

H1: Renewable energy consumption has a significant negative impact on CO_2 emissions.

2.3. Governance Quality as a Moderator in the Renewable Energy–CO_2 Nexus

Past literature shows that the existence of effective governance, in the means of quality institutions, significantly moderates the ability of REC policies on CO_2 reduction. The notion of "institutional quality" denotes to the broad concept that includes individual rights, legal frameworks, and the provision of different governmental services and laws [26]. Existing empirics showed that robust institutions ensure effective implementation of environmental rules, leading to a greater positive contribution of clean energy use toward reducing emissions [23, 24]. Mechanisms of transparency and accountability mechanisms moderate the extent to which predictors such as regulatory quality, control of corruption, and the rule of law promote REC [13]. This moderating effect of governance is particularly apparent in emerging and developing countries, since institutional failures commonly cause the potential environmental benefits from renewable energy sources to be stifled [25]. For instance, [27] observed that Nigeria's poor governance stifled the environmental gains of economic and energy reforms. [26] also showed that a strong GQ enhances the relationship between green finance and sustainable development and thus identify governance as a facilitator of green transitions in developing economies. Renewables are integral to decarbonization, but the environmental effectiveness of renewables is strongly contingent upon governance proxies, such as rule of law [36], control of corruption [28], and political stability [31]. These proxies have been found to enhance the performance of environmental policies, and ensure the efficacy of renewable energy projects in elevating their ability to reduce emissions. Empirics also support that countries with good governance structures are capable of implementing strong environmental regulations, including keeping the effectiveness of policies as well as policy compliance, so as to support the REC-emission abatement linkage. [28] demonstrated that when an EKC is moderated by good governance, emissions are suppressed at both early and mature levels of economic prosperity in Malaysia. The author also suggested that REC can result in a more sustainable and efficient decarbonization composition if the institution ensures that capital is allocated to the most effective investments, particularly in environmental or low-carbon initiatives. Conversely, weak governance could prevent the adoption of clean energy policies and lower the emissions-reducing impact of REC [13]. Therefore, drawing from the EKC's emphasis on effective governance and supported by empirical evidence, this study proposes:

H2: Governance quality moderates the relationship between renewable energy consumption and CO_2 emissions.

3. Methodology

3.1. Data

This study is grounded on secondary data for a rationally chosen panel of 25 Asia Pacific countries from 1998 to 2022, aiming to extensively investigate and understand the burning nexus between REC and CO_2 emissions. Annual data for all the variables under the study have been retrieved from the World Bank. It employs CO_2 emissions as the endogenous variable, measured as total CO_2 emissions in metric tons per capita [7, 42, 43]. Henceforth, REC, measured as the final REC in kilo tons, has been incorporated as the main exogenous variable. Hence, by investigating the empirical linkage between REC and CO_2 emissions, this study conceptualizes the REC in the sampled

countries and elucidates the potential environmental sustainability that the REC may offer. In addition to the direct relationship, this study also investigates the possible moderating effect of governance quality (GQ) [24, 34, 44, 45]. The GQ index has been constructed using the Principal Component Analysis (PCA) approach, and the components used to generate the index have been extracted from the World Development Indicators (WDI). Four out of six critical World Governance Indicators (WGI) have been accounted for in the index. This approach is extensively employed by numerous scholars to transform several highly correlated indicators into a single, minimalized multicollinearity index while capturing their shared fundamental dimensions [44]. Instead of using all six WGI dimensions of GQ, this study selected four dimensions (see Table 1), based on both theoretical and statistical relevance. These dimensions are a direct reflection of the administrative and institutional quality that affects market effectiveness, environmental regulation, and policy enactment; all of which are directly linked to CO_2 emissions. In contrast, the other two dimensions, such as political stability and voice and accountability, have been omitted since they basically reflect participatory and political dimensions of governance, which, theoretically, lack the substantiality of closeness to the regulatory and environmental aspects evaluated in this study. This study also employs population density, GDP growth, energy intensity, and urbanization as control variables, as these variables have been highlighted to have substantial effects on CO_2 emissions in several earlier studies [46, 47, 48]. However, all the variables have been converted into natural logarithmic values to ensure normalization of the data series. The data sources and measurements of the variables used in this study are summarized, along with their descriptive statistics, in Table 1. The conceptual framework of the study is presented in Figure 1.

3.2. Empirical Methods

To explore the direct empirical effects of the REC on curbing the CO_2 emissions, and the moderating effect of GQ on the linkage between the REC and CO_2 emissions, this study employs the panel MMQR with the fixed effect method based on the following econometric model:

$$CO_2 = \alpha + \beta_1 REC_{i,t} + \beta_2 GQ_{i,t} + \beta_3 GQ_{i,t}*REC_{i,t} + \beta_4 POPD_{i,t} + \beta_5 GDPG_{i,t} + \beta_6 EINT_{i,t} + \beta_7 UPOP_{i,t} + \varepsilon_{i,t} \quad (1)$$

The subscript i represents the cross-section, and t represents the time series dimensions of the data, α indicates the intercept, $\beta_{1\text{-}7}$ the coefficients of the exogenous variables, and ε is the residual term.

This study, however, employs several diagnostic tests, including autocorrelation, cross-section dependence, and multicollinearity, before investigating the relationships using the MMQR estimation. Consequently, this study draws on a three-stage analysis approach, namely fundamental analysis of the study variables to test for the applicability of the empirical method, fundamental analysis of the study model, and the econometric analysis of the model. In the initial analysis of both the endogenous and exogenous variables, cross-sectional dependence (CD) among the variables has been examined, incorporating the technique outlined by [49]. Hence, the detection of the CD supports the integration of second-generation unit root (UR) tests, such as the CIPS and CADF approaches. Consequently, these second-generation UR tests verify the integration procedure of the study variables, underpinning the justifiable empirical paradigm for further analysis. Likewise, the fundamental analysis of the model involves assessing the probable issues of multicollinearity using

the Variance Inflation Factor (VIF) [50]. Moreover, to test for the presence of a long-run relationship among the variables, a cointegration test has been conducted employing the Kao approach [51]. These preliminary tests of the model are critical for the identification of a suitable empirical methodology.

Hence, this study employs the MMQR to investigate the relationship stated in the econometric model (equation 01). As a second-generation approach, MMQR robustly tackles the issues of outliers, heterogeneity, and cross-sectional dependence of the model [52]. The strengths of this method lie in its capacity to capture heterogeneous effects across different quantiles of the conditional distribution [40], thus offering a more nuanced and sophisticated understanding of how the relationships among variables of interest differ across different states of CO_2 emissions. In addition to that, MMQR differentiates the short-run effects, usually detected in the lower quantiles, from the long-run effects, typically observed in the upper quantiles [53].

To check the robustness of the baseline MMQR findings, this study, in accordance with the World Bank classification, further employed an income-segmented MMQR analysis by splitting the entire sample into three income groups. This additional analysis allows the study to reflect on and examine whether the observed associations between the study variables are consistent across diverse phases of economic progression.

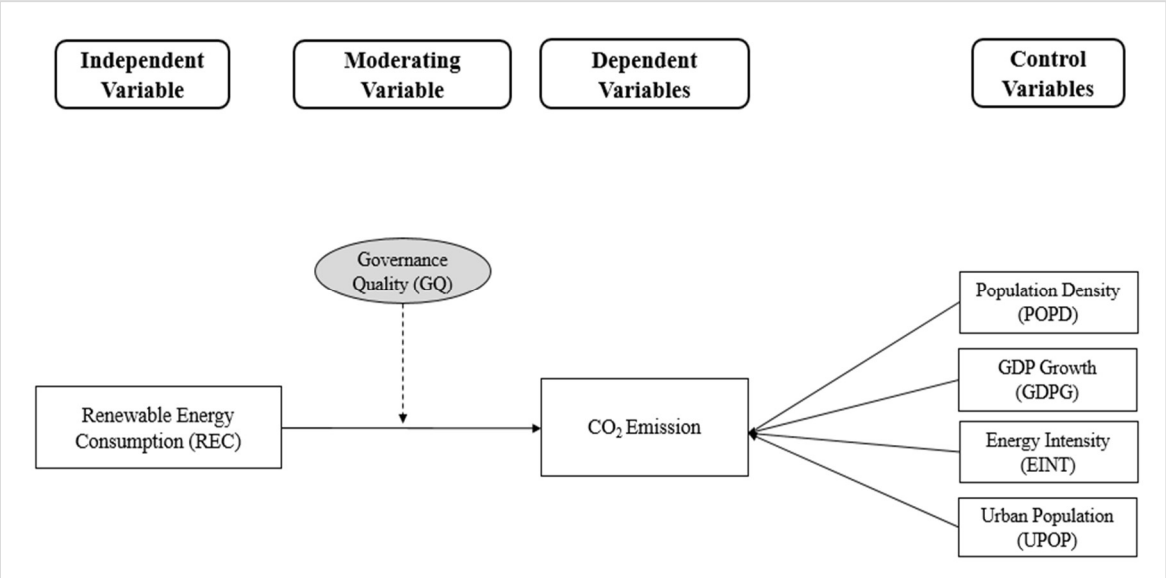

Figure 1. Conceptual Framework.

4. Findings and Analysis

4.1. Descriptive Statistics

Table 1 provides a comprehensive description of the variables and data used in this study. CO_2 emissions are a predictive variable that shows how economic and energy-related activities interact with the environment. The mean value of CO_2 emissions in the Asia-Pacific region is 6.183 metric tons; however, there is a substantial disparity, ranging from 0.098 to 47.657 metric tons. The standard deviation of 7.988 further supports the variation, indicating that certain regions are disproportionately responsible for global CO_2 emissions because of their extent of industrial development, commercial activities, and energy polices. This study considers REC as a critical

predictor of CO_2 emissions. With an average of 24.527 kilotons, the REC shows an uneven distribution, ranging from 0.01 to 93.46 kilotons, which demonstrates that although certain regions have achieved significant strides towards REC, others are still dependent on conventional forms of energy. The average GQ score is 0.438 across the Asia-Pacific countries, which varies from 0.00 to 1.00. As control variables, the population density (POPD) and urban population (UPOP) have a mean value of 4.453 and 3.867, respectively. With an extent from 0.441 to 8.981, POPD shows a skewed distribution, implying that approximately half of the observations are concentrated in low-density regions. Similarly, the standard deviation of the UPOP shows a relatively low variability, indicating consistent urbanization in the sample countries. GDP growth (GDPG) exhibits the presence of diverse economic trajectories extending from -3.738% to 3.977% within the dataset. The energy intensity (EINT) averages 1.63 with a slight variation of 0.50, signifying the efficiency of countries in using their energy in terms of their economic output.

Table 1. Variable Descriptions and Descriptive Statistics.

Variables and Measurements	Notation	Data Source	Descriptive Statistics				
			Observation	Mean	SD	Min	Max
Dependent Variable							
CO_2 Emissions (Total CO_2 emissions in metric tons/capita)	CO_2	WDI	1,192	6.183	7.988	0.098	47.657
Independent Variable							
Renewable Energy Consumption (Total final renewable energy consumption in kilo tones)	REC	WDI	1,132	24.527	26.356	0.010	93.460
Interaction Variable							
Governance Quality (An index generated through PCA based on Government Effectiveness, Regulatory Quality, Rule of Law, and Control of Corruption)	GQ	WDI	1,173	0.438	0.204	0.000	1.000
Control Variables							
Population density	POPD	WDI	1,248	4.453	1.570	0.441	8.983
GDP growth	GDPG	WDI	1,113	1.444	0.871	-3.738	3.977
Energy intensity	EINT	WDI	1,109	1.630	0.497	0.307	3.483
Urban population	UPOP	WDI	1,300	3.867	0.554	2.513	4.605

Source: Authors' computation.

4.2. Correlation and Multicollinearity

This study uses the Pearson correlation coefficient and the VIF to test for the variables' linear relationship and potential multicollinearity concerns. Table 2, hence, highlights the correlation matrix for the study. The data reveal that, as expected, CO_2 has a significant negative correlation with REC,

emphasizing the significance of REC in lowering CO_2 emissions. In contrast, the CO_2 positively correlates with UPOP, indicating that CO_2 emissions increase with urbanization. REC demonstrates a strong and negative association with UPOP, underscoring the difficulties of incorporating REC in urban settings with significant reliance on fossil fuels. However, the positive inter-linkage between REC and GDPG, as shown in Table 2, indicates the significance of economic development in stimulating investment in infrastructure for renewable energy. In the relationship between the environment and the economy, GQ plays a nuanced role. GQ shows a slight negative link with GDP and EINT, but a positive association with CO_2. This suggests that governance measures may improve energy efficiency and sustainable practices, even in the face of potential short-term financial trade-offs. Moreover, the VIF values for all explanatory variables are below the threshold level of 5, as stated by [50], which indicates that no multicollinearity issues exist across the independent variables employed in the model.

Table 2. Correlation Matrix.

Variables	VIF	CO_2	REC	GQ	POPD	GDP	EINT	UPOP
CO_2		1.000						
REC	2.23	-0.5013*	1.000					
GQ	3.15	0.4634*	-0.3121*	1.000				
POPD	1.3	-0.0751*	-0.0131	0.1613*	1.000			
GDPG	1.09	-0.0787*	0.1585*	-0.2399*	-0.0168	1.000		
EINT	1.42	0.2966*	-0.0680*	-0.1766*	-0.3686*	0.1129*	1.000	
UPOP	3.13	0.6256*	-0.7033*	0.4998*	0.0038	-0.1288*	0.1442*	1.000

Source: Authors' computation.

4.3. Cross-Sectional Dependency (CD) Test

Table 3. CD Test.

Variables	CD-test	p-value	FADF		CADF	
			Level	First Difference	Level	First Difference
CO_2	31.788	0.000	98.431	329.729***	2.445	-5.495***
REC	18.431	0.000	109.129	419.875***	1.892	-13.706***
GQ	13.629	0.000	115.012	405.087***	-2.935***	-14.700***
POPD	121.935	0.000	348.539***	284.615***	8.262	2.060
GDPG	11.254	0.000	253.719***	703.445***	-9.468***	-
EINT	39.022	0.000	138.109***	390.607***	-0.081	-13.294***
UPOP	117.146	0.000	343.311***	688.715***	4.836	-2.573***

Sources: Authors' computation.

Table 3 shows how CO_2 emissions and REC are intertwined and how GQ moderates these relationships in Asia-Pacific nations. Using the CD-test, FADF, and CADF tests, respectively, the cross-sectional dependence and stationarity of the variables have been investigated. According to the analysis, CO_2, REC, and GQ show varying degrees of dependence; lower values (such as GDPG=11.254) suggest less dependence, while larger numbers (such as POPD=121.935) indicate strong interconnection. Moreover, variables such as CO_2, REC, GQ, and EINT are non-stationary at

levels, but structural and economic shifts drive long-term trends after initial differentiation. However, the stationarity results of POPD and UPOP are inconsistent; they are continually non-stationary for CADF but stationary at the level for FADF. Control factors, including POPD, GDPG, EINT, and UPOP, have different effects, indicating their socio-economic and structural relevance.

4.4. Panel Cointegration Test

With a particular focus on the interactions among CO_2, REC, and GQ, Table 4 summarizes the Kao test's cointegration findings, which shed light on the long-term dynamics of environmental sustainability. These variables may be associated based on the Augmented Dickey-Fuller (ADF) t-statistic, depicting a significant long-run equilibrium relationship (statistic=-1.7717, p-value=0.0382). However, cointegration is not consistently demonstrated by two further Kao test variations, such as the Modified Dickey-Fuller t (p-value=0.0204) or the Unadjusted Dickey-Fuller t (p-value=0.055). This variant emphasizes how crucial methodological rigor is when evaluating panel cointegration tests and how results are sensitive to test specifications. The ADF t-statistic's significant cointegration result supports the idea that adopting renewable energy and GQ significantly shape the long-term trajectory of CO_2 emissions in the Asia-Pacific region. This information serves as a basis for focused policy interventions.

Table 4. Kao Test.

Kao test for cointegration	Statistic	P-value
Modified Dickey-Fuller t	2.0458	0.0204
Dickey-Fuller t	0.5411	0.2942
Augmented Dickey-Fuller t	-1.7717	0.0382
Unadjusted modified Dickey-Fuller t	1.598	0.055
Unadjusted Dickey-Fuller t	0.1277	0.4492

Source: Authors' computation.

4.5. Regression Results and Discussions

This study employs the MMQR method because it can address heterogeneity and mitigate the weak cross-sectional dependence (CD) issues of the dataset. The results of the MMQR analysis are presented in Table 5, offering a comprehensive examination of the explanatory factors affecting CO_2 emissions in Asia-Pacific economies, including REC, GQ, and a set of macroeconomic control variables. Additionally, a quantile plot diagram for all variables is presented in Figure 2-4.

The analysis reveals that REC is negatively and significantly associated with CO_2 emissions across all quantiles, with the effect intensifying from the 0.20 to the 0.90 quantile. Specifically, the coefficient rises from -0.0135 at the lower quantile to -0.0377 at the higher quantile. This suggests that REC contributes more effectively to CO_2 mitigation in countries with higher emission levels. Thus, the increasing impact also underscores the growing importance of clean energy in more polluted regions. These findings strongly support H_1 and are in line with recent studies [7, 21, 31]. Opposing the expectation, GQ exhibits a positive and significant relationship with emissions at the lower and middle quantiles (0.10-0.60). The outcome indicates that in comparatively cleaner nations, improved governance quality may concurrently arise with infrastructural and industrial development [24, 25], [29, 30], hence, resulting in a short-term emissions upsurge. This counterintuitive result can be a

reflection of the early phases of the environmental transformation progression, when economic activity is boosted by institutional solidification before the dominance of green measures [9, 38]. Nevertheless, this connotation turns smaller as emissions increase in higher quantiles (0.70-0.90), which is in line with the EKC. These results support H_2 and are consistent with prior studies [24, 26, 34].

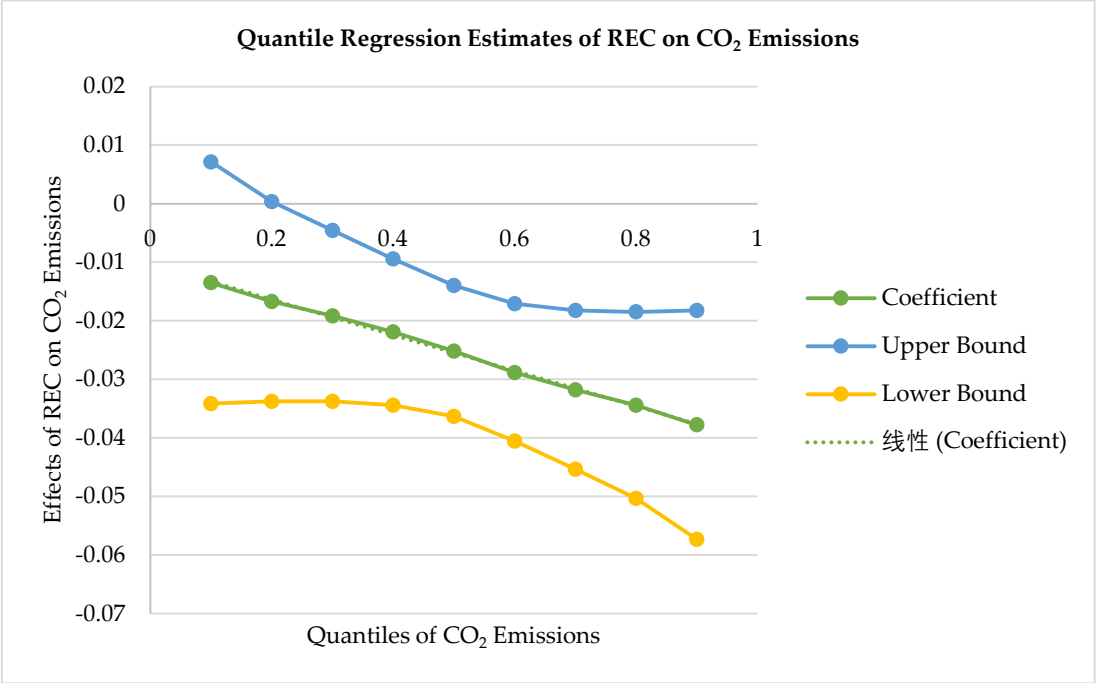

Figure 2. Quantile Regression Estimates of REC on CO_2 Emissions.

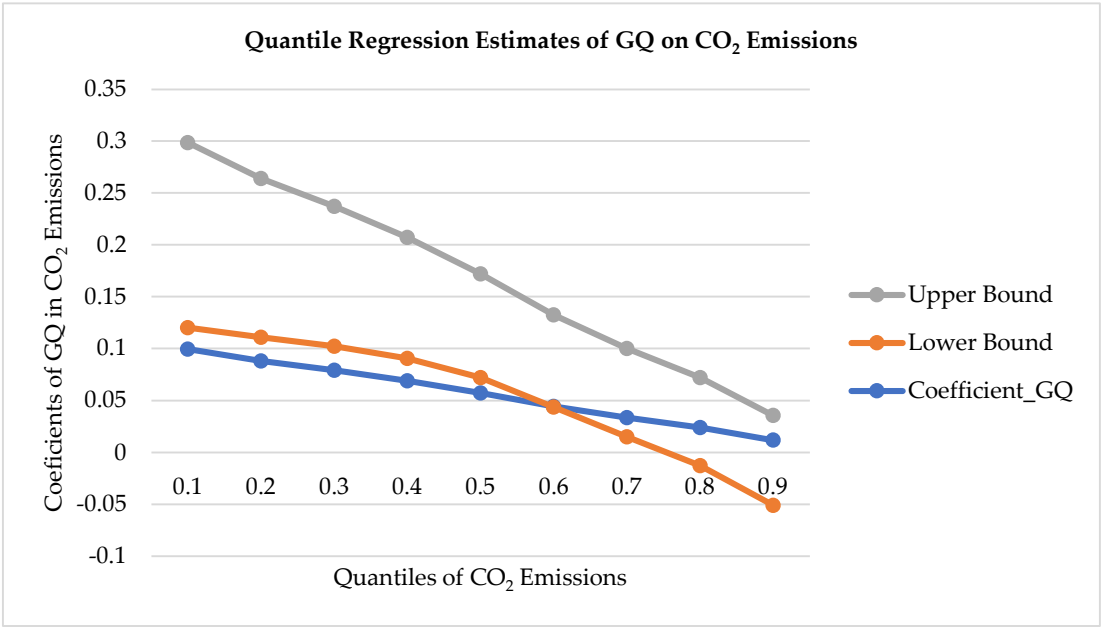

Figure 3. Quantile Regression Estimates of GQ on CO_2 Emissions.

Among the control variables, POPD demonstrates a consistent and statistically significant adverse effect on CO_2 emissions, suggesting that higher population density enhances energy efficiency through shared infrastructure and service delivery. In contrast, UPOP has a stable and significantly positive impact on emissions across all quantiles, with the coefficient increasing from

5.23 to 5.45. This indicates that urbanization exerts substantial environmental pressure due to higher consumption demands, transportation needs, and industrial activity within cities [51]. No significant relationships are identified for GDPG or EINT across the quantiles. This suggests that, in Asia-Pacific economies, neither energy use per unit of GDP nor economic growth alone reliably predicts changes in CO_2 emissions. These findings imply that structural economic factors and energy efficiency may not be linearly decoupled from emissions.

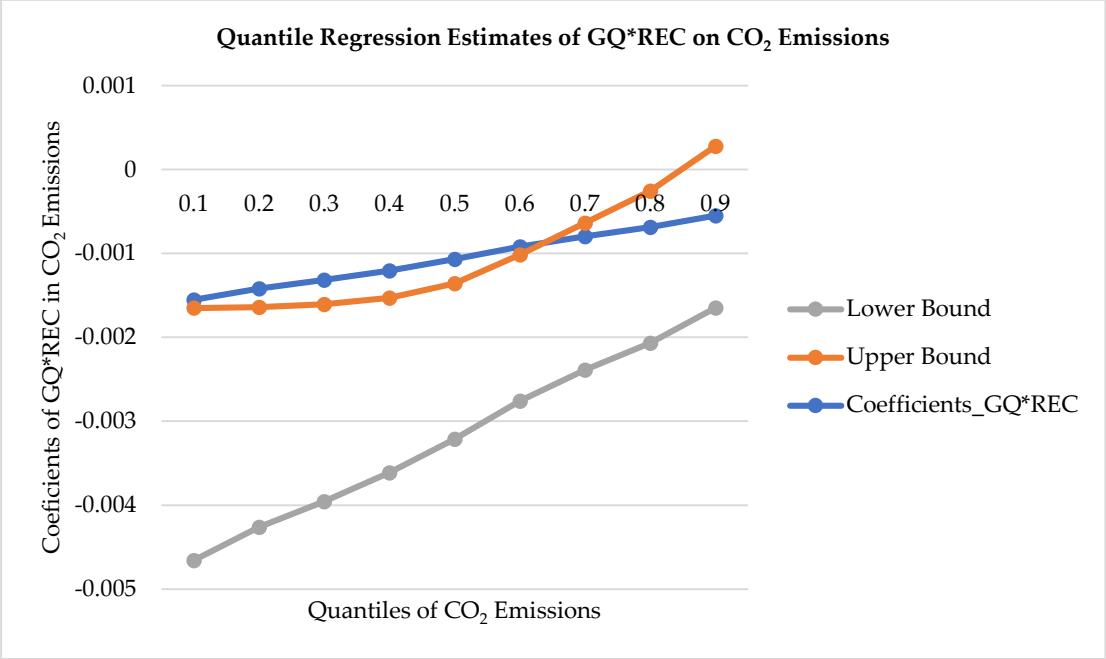

Figure 4. Quantile Regression Estimates of GQ*REC on CO_2 Emissions.

Finally, the results in Table 5 show that the interaction term GQ*REC significantly and negatively impacts emissions at the lower to mid quantiles (0.10–0.60), but this effect becomes insignificant at higher quantiles. This indicates that stronger governance enhances the effectiveness of REC in reducing emissions, particularly in low- to mid-emission countries, likely due to improved policy enforcement and institutional capacity. In higher-emission settings, however, the complex mix of emission sources may dilute this synergistic effect. Previous studies, such as [25, 27], provide further support for this observation.

Table 5. Methods of Moments Quantile Regression (MMQR) Results.

	Dependent Variable = CO_2 Emissions			
Variables/Quantiles	**0.10**	**0.20**	**0.30**	**0.40**
REC	-0.013500	-0.0166944*	-0.019170***	-0.0219263***
	(0.0105238)	(0.0086989)	(0.0074573)	(0.0063627)
GQ	0.099546**	0.088011***	0.079072***	0.0691146***
	(0.0402006)	(0.0332339)	(0.0284968)	(0.0243213)
POPD	-5.134241**	-5.152023***	-5.165803***	-5.181151***
	(1.228736)	(1.01531)	(0.8690851)	(0.7393676)
GDP	-0.025982	-0.02973	-0.032635	-0.0358697
	(0.0832911)	(0.0688242)	(0.0589137)	(0.050123)

EINT	0.025155	0.0250111	0.0248100	0.0247754
	(0.3590379)	(0.2966714)	(0.2539384)	(0.2160273)
UPOP	5.233091***	5.261847***	5.284132***	5.308953***
	(1.125791)	(0.930251)	(0.7962897)	(0.6774569)
GQ*REC	-0.001552**	-0.0014204**	-0.001318**	-0.0012042***
	(0.0007421)	(0.0006133)	(0.0005255)	(0.0004477)

Source: Authors' computation.

Table 5. Methods of Moments Quantile Regression (MMQR) Results (Continued).

	Dependent Variable = CO_2 Emissions				
Variables/Quantiles	**0.50**	**0.60**	**0.70**	**0.80**	**0.90**
REC	-0.025174***	-0.028829***	-0.0318081***	-0.034396***	-0.0377715***
	(0.0056975)	(0.0059727)	(0.0069214)	(0.0081164)	(0.009969)
GQ	0.0573863***	0.0441828*	0.0334235	0.024076	0.0118849
	(0.0217851)	(0.0228359)	(0.0264523)	(0.0310108)	(0.0380798)
POPD	-5.19923***	-5.219583***	-5.236168***	-5.25058***	-5.269369***
	(0.658584)	(0.6917176)	(0.8059422)	(0.9467538)	(1.164193)
GDP	-0.0396803	-0.0439703	-0.0474662	-0.050503	-0.0544644
	(0.0446509)	(0.0468956)	(0.0546341)	(0.0641777)	(0.0789157)
EINT	0.0246291	0.0244645	0.0243303	0.024214	0.0240617
	(0.192412)	(0.2020963)	(0.2354852)	(0.2766369)	(0.3401797)
UPOP	5.33819***	5.371104***	5.397926***	5.421228***	5.451619***
	(0.6034662)	(0.6338166)	(0.7384427)	(0.8674439)	(1.066653)
GQ*REC	-0.00107***	-0.0009189**	-0.0007959	-0.0006889	-0.0005494
	(0.0003998)	(0.0004195)	(0.0004875)	(0.0005721)	(0.000703)

Source: Authors' computation.

In addition, this study employs income-segmented MMQR analysis to highlight the extent to which the drivers of CO_2 emissions differ across economic groups. The income-segmented MMQR analysis is presented in Table 6. In the lower-middle-income group (LMIG), REC exhibits a consistently negative and statistically significant effect on CO_2 emissions across all quantiles (25th, 50th, and 75th), with coefficients ranging from -0.0309 to -0.0300 ($p<0.01$). This consistent pattern demonstrates that REC significantly reduces emissions at the early stages of industrial development by displacing coal-fired power and reducing dependence on fossil fuel imports. This underscores the environmental benefits of clean energy infrastructure in developing economies. These findings are supported by the outcomes of previous studies, such as [12]. However, GQ remains statistically insignificant in reducing CO_2 emissions across all quantiles, reflecting these countries' institutional weaknesses and limited enforcement capacity. This observation aligns with the institutional capacity argument advanced in the study conducted by [27].

Among the control variables, POPD is negatively associated with CO_2 emissions at the 25th and 50th quantiles, indicating that higher population density may contribute to marginal emission reductions, possibly through denser settlement patterns and lower per capita energy use. Likewise, GDPG exhibits a negative but less significant relationship at the lower two quantiles, suggesting that limited economic growth in these countries is initially accompanied by lower emissions, likely due

to a small industrial base or a shift toward service-oriented economies [41]. EINT shows a strong and positive correlation across all quantiles, which indicates that high energy intensity is a key driver of emissions in this group. Enhancing energy efficiency, therefore, could play a vital role in emission reduction strategies [48]. Finally, UPOP emerges as a significant and positive contributor to emissions. It is the environmental pressures from rapid urbanization in contexts where urban planning and energy infrastructure remain underdeveloped.

The MMQR results for the upper-middle-income group (UMIG) reveal that REC continues to negatively impact CO_2 emissions significantly, with coefficients ranging from -0.029 to -0.0347. This indicates that the benefits of REC remain essential in countries with higher emissions levels. This finding supports prior evidence suggesting that REC becomes increasingly crucial as countries industrialize and their emissions intensify the global climate [21]. GQ shows a statistically significant negative association with emissions at the 25th and 50th quantiles. This suggests stronger governance in countries such as Malaysia, China, or Thailand initially supports infrastructure expansion and growth-oriented policies that may temporarily increase emissions [12]. The reduced significance of GQ at the 75th quantile implies that better regulatory oversight and environmental governance may eventually begin to mitigate emissions as countries reach higher emission levels. Unlike in LMIGs, POPD is positively and significantly associated with CO_2 emissions at all quantiles in UMIGs. This indicates that densely populated urban centers, often lacking sufficient environmental safeguards, exacerbate emissions, in align with the study conducted by [45]. GDPG exhibits a mixed effect, while EINT lacks statistical significance, potentially reflecting variations in energy efficiency improvements. Finally, UPOP exerts a strong positive influence at the 75th quantile, which emphasizes the role of urbanization in intensifying emissions in the UMIG.

In high-income countries (HICs), the results show more variation and instability in statistical significance, reflecting the complexity of their advanced economies. Although REC remains negatively associated with emissions, its impact is statistically heterogeneous across quantiles. This variation suggests that the benefits of REC become more challenging to isolate once countries have diversified their energy systems or approached saturation in cleaner energy adoption. The wide standard errors point to heterogeneity across countries in this group, consistent with earlier findings [15, 19]. Similarly, GQ shows only weak significance, with marginal relevance at the median quantile. This supports prior studies suggesting high-income countries focus more on policy stability and regulatory compliance than on aggressive emissions reduction. POPD exhibits a strong negative association with emissions across all quantiles, indicating that densely populated high-income areas may benefit from more efficient resource use, superior infrastructure, and strict environmental regulations. GDPG is negatively but insignificantly associated with emissions, while the non-significant positive relationship between EINT and emissions compared with the significant positive role of UPOP points to a fragile and possibly non-linear linkage in this context.

The interaction term GQ*REC does not attain statistical significance in any quantile for LMIGs. Coefficients range from 0.0002511 at the 25th quantile to -0.0001012 at the 75th, yet none show meaningful associations with CO_2 emissions. This implies that while these countries are expanding their REC, their governance frameworks may not yet be equipped with the regulatory tools necessary to reinforce this transition. In contrast, the interaction effect is statistically significant and adverse for the 25th and 50th quantiles in UMIGs [52, 53]. This finding suggests that improvements in governance can enhance the effectiveness of REC in dropping emissions. However, the non-significance at the

75th quantile indicates diminishing marginal returns from GQ in reducing emissions as countries become more emissions-intensive. Among HICs, the interaction term remains statistically significant across all quantiles, though with modest coefficients. These results indicate that GQ contributes less to renewable energy's emissions-reduction potential in high-income countries. This is likely due to the presence of well-functioning institutions and already advanced renewable energy systems, in alignment with findings of [34]. In such contexts, emissions reductions are more likely to be driven by technological innovations, market dynamics, or consumer behavior rather than governance improvements, consistent with [22].

Table 6. MMQR Results (By Income Group).

Variables/	Lower-Middle			Upper-Middle		
Quantiles	0.25	0.50	0.75	0.25	0.50	0.75
REC	-0.030953***	-0.0305942***	-0.030076***	-0.0291266	-0.0318288**	-0.0347054*
	(0.0039602)	(0.0036553)	(0.0066574)	(0.0240375)	(0.0157834)	(0.0184547)
GQ	-0.0045947	-0.0004795	0.0054632	0.0984774**	0.0719355***	0.04368
	(0.0110399)	(0.010238)	(0.018557)	(0.0416781)	(0.0275547)	(0.0321423)
POPD	-0.4212817*	-0.2130572	0.0876357	1.991811***	1.701479***	1.392402**
	(0.2445406)	(0.230537)	(0.410947)	(0.7631258)	(0.5023415)	(0.5868542)
GDP	-0.0513932*	-0.0585184**	-0.0688079	0.0628244	0.032073	-0.0006639
	(0.0278966)	(0.0258162)	(0.046893)	(0.0735239)	(0.0483758)	(0.0565229)
EINT	0.5358604***	0.6439992***	0.8001603***	0.2566553	0.3616122	0.4733457
	(0.1263256)	(0.1197025)	(0.2122206)	(0.447215)	(0.2938535)	(0.3435052)
UPOP	0.947951 ***	1.191843***	1.544043***	-0.1036301	0.5701558	1.287444
	(0.2768112)	(0.2623564)	(0.4650491)	(2.071768)	(1.363266)	(1.592831)
GQ*REC	0.0002511	0.000107	-0.0001012	-0.0041573**	-0.0031482***	-0.002074
	(0.0002178)	(0.0002037)	(0.0003661)	(0.0018167)	(0.001199)	(0.0013994)
N		409			314	

Source: Authors' computation.

Table 6. MMQR Results (By Income Group) (Continued).

Variables/	Higher		
Quantiles	0.25	0.50	0.75
REC	-0.0513747	-0.0314242	-0.0154172
	(0.1931964)	(0.116018)	(0.1361711)
GQ	0.1130114	0.0827905*	0.0585432
	(.0810068)	(0.0489771)	(0.0570263)
POPD	-7.740502***	-7.979415***	-8.171104***
	(1.341551)	(0.8076196)	(0.9449883)
GDP	-0.0358047	-0.0542065	-0.0689709
	(0.2036787)	(0.1223497)	(0.1435438)
EINT	1.867884	1.444094	1.104073
	(1.685101)	(1.015111)	(1.186993)
UPOP	3.848054	0.9575353	-1.361633

	(9.602667)	(5.785758)	(6.765006)
GQ*REC	-0.0014484	-0.0010236	-0.0006828
	(0.0047317)	(0.002844)	(0.0033341)
N		178	

Source: Authors' computation.

Overall, the MMQR results indicate that the mitigating impact of REC is robust, since it consistently lowers CO_2 emissions across all quantiles. Furthermore, when examined by income groups (see Table 6), the findings of the MMQR approach remain largely consistent. Although the negative effects of REC are less obvious for higher-income nations, these are still noticeable for lower to upper-middle-income nations. Despite having a favorable impact on CO_2 in upper-middle-income countries, GQ, demonstrating heterogeneity, is mostly insignificant in lower-middle and higher-income nations. These findings reveal the urgency of an income-specific governance approach for environmental regulations.

5. Conclusion

This study empirically examines the dynamic relationship between renewable energy consumption (REC) and CO_2 emissions in 25 Asia-Pacific countries over the period 1998-2022, with a specific emphasis on governance quality (GQ) as a moderator. Employing the Method of Moments Quantile Regression (MMQR), the study demonstrates the heterogeneity effect across various levels of CO_2 emissions and offers a nuanced understanding of the energy-environment-institution nexus.

The results validate the first hypothesis (H_1), stating that REC significantly reduces CO_2 emissions, especially in countries with higher emissions. This indicates that investments in clean energy technologies bring greater environmental returns in high-pollution contexts. Furthermore, the second hypothesis (H_2) is supported, indicating that GQ significantly impacts the negative correlation between REC and CO_2 emissions. Such a moderating effect is most pronounced in the middle and upper quantiles, where better institutions will have a higher probability of converting renewable energy policies into positive environmental results.

These findings emphasize the need for a multidimensional policy approach that unites renewable energy promotion and institutional quality enhancements. The study adds to this body of literature by providing valuable quantile-specific insights in developing targeted and effective emission-reduction policies.

5.1. Policy Implications

The study's findings suggest various policy measures for countries aiming for low-carbon development within the Asia-Pacific region. Firstly, a statistically significant negative correlation between the REC and CO_2 emissions in most quantiles confirms the role of REC as a feasible vehicle toward environmental sustainability. Specifically, an intensive shift towards renewable sources may guarantee environmental benefits to high-emitting countries, suggesting that governmental and private funding should focus on solar, wind, and hydro energy. Secondly, the significant moderating effect of GQ on the relationship between REC and emissions reveals the crucial role of institutional strength. To maximize the environmental advantages of REC, effective regulatory frameworks, transparent public policy, accountability measures, and environmental regulation enforcement are

needed. Thus, energy policy reforms should be accompanied by broader institutional reforms to enhance policy implementation and governance capacity. Furthermore, the significantly positive impact of energy intensity and urbanization on CO_2 emissions indicates that integrated policy responses should consider energy source impacts and focus on energy efficiency and urban sustainability. Urban planning, public transportation systems, and industrial energy efficiency improvements should be prioritized in line with renewable energy adoption to reduce emissions on a larger scale. Lastly, the quantile-specific results eradicate the adoption of homogeneous policy strategies. Due to the varying nature of emissions at various development stages, environmental policies must be tailored to their institutional capacity and ecological pressures.

5.2. Limitations and Directions for Future Research

Despite offering valuable insights, this study is not without limitations. First, the GQ index applied in the survey is created based on the Principal Component Analysis (PCA) of numerous governance measures, which, though methodologically appropriate, can conceal the impacts of individual governance aspects like regulatory quality, political stability, or corruption control. Therefore, further studies can be conducted by disaggregating these factors to identify their moderate-level specificities. Second, although the inclusion of several control variables can reduce the problem of omitted variable bias, it is impossible to rule out the potential endogeneity problem, particularly due to the potential of reverse causation between the economic indicators and emissions. This could be solved by considering dynamic panel models or instrumental variables in future studies. Third, the geographical scope of this research is confined to 25 countries in the Asia-Pacific region, which can reduce the generalizability of the findings. The external validity of the results might be improved by extending the analysis to cover other areas or countries or by comparing regional blocs. Furthermore, using aggregate data on REC and emissions does not allow for sectoral analysis. That limits the scope of more detailed information on which sectors most respond to REC and GQ improvement, particularly transport, manufacturing, and residential. Future research initiatives could overcome these limitations to better comprehend the renewable energy and governance nexus for providing more effective policy interventions.

Contributions: Anwar Hossain led the study, designing and implementing the research methodology, conducting data collection and analysis, and ensuring methodological rigor. Ishtiaq Mainuddin significantly contributed by playing a key role in interpreting the findings, providing valuable feedback, which refined the results and enhanced the research quality, and preparing the manuscript. Md. Arafat Rahman contributed by writing the literature review. Partha Acharjee contributed by helping with the interpretation of the findings, drafting concluding remarks, and policy implications of the study.

Funding: This research received no external funding.

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

References

[1] Costa-Campi, M. T., del Rio, P., & Trujillo-Baute, E. (2017). Trade-offs in energy and environmental policy. Energy Policy, 104, 415-418. https://doi.org/10.1016/j.enpol.2017.01.053

[2] Tol, R. S. J. (2017). The structure of the climate debate. Energy Policy, 104, 431-438. https://doi.org/10.1016/j.enpol.2017.01.005

[3] Arora, N. K., & Mishra, I. (2021). COP26: more challenges than achievements. Environmental Sustainability, 4(4), 585-588. https://doi.org/10.1007/s42398-021-00212-7

[4] Lloyd, P. J. (2017). The Role of Energy in Development. Journal of Energy in Southern Africa, 28(1), 54-62. https://doi.org/10.17159/2413-3051/2017/v28i1a1498

[5] Schandl, H., Hatfield-Dodds, S., Wiedmann, T., Geschke, A., Cai, Y., West, J., Newth, D., Baynes, T., Lenzen, M., & Owen, A. (2016). Decoupling global environmental pressure and economic growth: scenarios for energy use, materials use and carbon emissions. Journal of Cleaner Production, 132, 45–56. https://doi.org/10.1016/j.jclepro.2015.06.100

[6] He, G., Pan, Y., & Tanaka, T. (2020). The short-term impacts of COVID-19 lockdown on urban air pollution in China. Nature Sustainability, 3(12), 1005–1011. https://doi.org/10.1038/s41893-020-0581-y

[7] Omri, A., & Saidi, K. (2022). Factors influencing CO_2 emissions in the MENA countries: the roles of renewable and non-renewable energy. Environmental Science and Pollution Research, 29(37), 55890–55901. https://doi.org/10.1007/s11356-022-19727-5

[8] Abbasi, K. R., Kirikkaleli, D., & Altuntaş, M. (2022). Carbon dioxide intensity of GDP and environmental degradation in an emerging country. Environmental Science and Pollution Research, 29(56), 84451–84459. https://doi.org/10.1007/s11356-022-21679-9

[9] Hunjra, A. I., Bouri, E., Azam, M., Azam, R. I., & Dai, J. (2024). Economic growth and environmental sustainability in developing economies. Research in International Business and Finance, 70, 102341. https://doi.org/10.1016/j.ribaf.2024.102341

[10] Zhou, Z., Chau, K. Y., Sibghatullah, A., Moslehpour, M., Tien, N. H., & Nizomjon Shukurullaevich, K. (2024). The role of green finance, environmental benefits, fintech development, and natural resource management in advancing sustainability. Resources Policy, 92, 105013. https://doi.org/10.1016/j.resourpol.2024.105013

[11] Shen, Y., & Zhang, X. (2023). Intelligent manufacturing, green technological innovation and environmental pollution. Journal of Innovation & Knowledge, 8(3), 100384. https://doi.org/10.1016/j.jik.2023.100384

[12] Raihan, A., & Tuspekova, A. (2022). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. Resources, Conservation & Recycling Advances, 15, 200096. https://doi.org/10.1016/j.rcradv.2022.200096

[13] Khan, H., Weili, L., & Khan, I. (2022). Environmental innovation, trade openness and quality institutions: an integrated investigation about environmental sustainability. Environment, Development and Sustainability, 24(3), 3832–3862. https://doi.org/10.1007/s10668-021-01590-y

[14] Santosh, M., Groves, D. I., & Yang, C.-X. (2024). Habitable planet to sustainable civilization: Global climate change with related clean energy transition reliant on declining critical metal resources. Gondwana Research, 130, 220–233. https://doi.org/10.1016/j.gr.2024.01.013

[15] Apergis, N., Payne, J. E., Menyah, K., & Wolde-Rufael, Y. (2010). On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. Ecological Economics, 69(11), 2255–2260. https://doi.org/10.1016/j.ecolecon.2010.06.014

[16] Chen, H. H., & Lee, A. H. I. (2014). Comprehensive overview of renewable energy development in Taiwan. Renewable and Sustainable Energy Reviews, 37, 215–228. https://doi.org/10.1016/j.rser.2014.04.055

[17] AlFarra, H. J., & Abu-Hijleh, B. (2012). The potential role of nuclear energy in mitigating CO_2 emissions in the United Arab Emirates. Energy Policy, 42, 272–285. https://doi.org/10.1016/j.enpol.2011.11.084

[18] Fant, C., Adam Schlosser, C., & Strzepek, K. (2016). The impact of climate change on wind and solar resources in southern Africa. Applied Energy, 161, 556–564. https://doi.org/10.1016/j.apenergy.2015.03.042

[19] Nunes, L. J. R. (2023). The Rising Threat of Atmospheric CO_2: A Review on the Causes, Impacts, and Mitigation Strategies. Environments, 10(4), 66. https://doi.org/10.3390/environments10040066

[20] Hassan, R., Das, B. K., & Hasan, M. (2022). Integrated off-grid hybrid renewable energy system optimization based on economic, environmental, and social indicators for sustainable development. Energy, 250, 123823. https://doi.org/10.1016/j.energy.2022.123823

[21] Butt, H. M. M., Khan, I., & Xia, E. (2023). How do energy supply and energy use link to environmental degradation in China? Environmental Science and Pollution Research, 30(40), 92891–92902. https://doi.org/10.1007/s11356-023-28960-5

[22] Zheng, S., & Jin, S. (2023). Is corporate green investment a determinant of corporate carbon emission intensity? A managerial perspective. Heliyon, 9(12), e22401. https://doi.org/10.1016/j.heliyon.2023.e22401

[23] Danish, Baloch, M. A., & Wang, B. (2019). Analyzing the role of governance in CO_2 emissions mitigation:

The BRICS experience. Structural Change and Economic Dynamics, 51, 119–125. https://doi.org/10.1016/j.strueco.2019.08.007

[24] Haldar, A., & Sethi, N. (2021). Effect of institutional quality and renewable energy consumption on CO_2 emissions–an empirical investigation for developing countries. Environmental Science and Pollution Research, 28(12), 15485–15503. https://doi.org/10.1007/s11356-020-11532-2

[25] Danish, & Ulucak, R. (2020). The pathway toward pollution mitigation: Does institutional quality make a difference? Business Strategy and the Environment, 29(8), 3571–3583. https://doi.org/10.1002/bse.2597

[26] Sun, X., Meng, Z., Zhang, X., & Wu, J. (2025). The role of institutional quality in the nexus between green financing and sustainable development. Research in International Business and Finance, 73, 102531. https://doi.org/10.1016/j.ribaf.2024.102531

[27] Maduka, A. C., Ogwu, S. O., & Ekesiobi, C. S. (2022). Assessing the moderating effect of institutional quality on economic growth—carbon emission nexus in Nigeria. Environmental Science and Pollution Research, 29(43), 64924–64938. https://doi.org/10.1007/s11356-022-20346-3

[28] Abd Razak, F. D., Khalid, N., & Ali, M. H. (2021). Asymmetric Impact of Institutional Quality on Environmental Degradation: Evidence of the Environmental Kuznets Curve. Sustainability, 13(22), 12507. https://doi.org/10.3390/su132212507

[29] Wawrzyniak, D., & Doryń, W. (2020). Does the quality of institutions modify the economic growth-carbon dioxide emissions nexus? Evidence from a group of emerging and developing countries. Economic Research-Ekonomska Istraživanja, 33(1), 124–144. https://doi.org/10.1080/1331677X.2019.1708770

[30] Sahoo, M., Sethi, N., & Angel Esquivias Padilla, M. (2023). Unpacking the dynamics of information and communication technology, control of corruption and sustainability in green development in developing economies: New evidence. Renewable Energy, 216, 119088. https://doi.org/10.1016/j.renene.2023.119088

[31] Behera, B., Behera, P., & Sethi, N. (2024). Decoupling the role of renewable energy, green finance and political stability in achieving the sustainable development goal 13: Empirical insight from emerging economies. Sustainable Development, 32(1), 119–137. https://doi.org/10.1002/sd.2657

[32] Nasir, M. A., Duc Huynh, T. L., & Xuan Tram, H. T. (2019). Role of financial development, economic growth & foreign direct investment in driving climate change: A case of emerging ASEAN. Journal of Environmental Management, 242, 131–141. https://doi.org/10.1016/j.jenvman.2019.03.112

[33] Han, A., Yu, T., Ke, Y., Liu, C., & Liu, Y. (2024). Study on the effect of carbon trading on the carbon emission intensity of enterprises—a mechanism test based on ESG performance. Frontiers in Environmental Science, 12, 1406577. https://doi.org/10.3389/fenvs.2024.1406577

[34] Khan, M., & Rana, A. T. (2021). Institutional quality and CO_2 emission–output relations: The case of Asian countries. Journal of Environmental Management, 279, 111569. https://doi.org/10.1016/j.jenvman.2020.111569

[35] Akpanke, T. A., Deka, A., Ozdeser, H., & Seraj, M. (2024). Ecological footprint in the OECD countries: do energy efficiency and renewable energy matter? Environmental Science and Pollution Research, 31(10), 15289–15301. https://doi.org/10.1007/s11356-024-32151-1

[36] Padhan, L., & Bhat, S. (2025). The relevance of renewable energy and green innovation in environmental sustainability: evidence from BRICS countries. International Journal of Sustainable Economy, 17(1), 52–74. https://doi.org/10.1504/IJSE.2025.142926

[37] Kilinc-Ata, N., & Proskuryakova, L. N. (2024). The contribution of energy policies to green energy transition in the Asia-Pacific region. Renewable Energy, 237, 121797. https://doi.org/10.1016/j.renene.2024.121797

[38] Kostakis, I., Armaos, S., Abeliotis, K., & Theodoropoulou, E. (2023). The investigation of EKC within CO_2 emissions framework: Empirical evidence from selected cross-correlated countries. Sustainability Analytics and Modeling, 3, 100015. https://doi.org/10.1016/j.samod.2023.100015

[39] Kousar, S., Ahmed, F., López García, M. de las N., & Ashraf, N. (2020). Renewable Energy Consumption, Water Crises, and Environmental Degradation with Moderating Role of Governance: Dynamic Panel Analysis under Cross-Sectional Dependence. Sustainability, 12(24), 10308. https://doi.org/10.3390/su122410308

[40] Machado, J. A. F., & Silva, J. M. C. S. (2019). Quantiles via moments. Journal of Econometrics, 213(1), 145–173. https://doi.org/10.1016/j.jeconom.2019.04.009

[41] Bulut, A., & Tekdemir, N. (2025). The inverted n-shaped relationship between economic growth and CO_2 emissions: Evidence from OECD countries. Economic Annals, 70(244), 7–33. https://doi.org/10.2298/EKA2544007B

[42] Chen, C., Pinar, M., & Stengos, T. (2022). Renewable energy and CO_2 emissions: New evidence with the panel threshold model. Renewable Energy, 194, 117–128. https://doi.org/10.1016/j.renene.2022.05.095

[43] Abdouli, M., Kamoun, O., & Hamdi, B. (2018). The impact of economic growth, population density, and FDI inflows on CO_2 emissions in BRICS countries: Does the Kuznets curve exist? Empirical Economics, 54(4), 1717–1742. https://doi.org/10.1007/s00181-017-1263-0

[44] Karim, S., Appiah, M., Naeem, M. A., Lucey, B. M., & Li, M. (2022). Modelling the role of institutional quality on carbon emissions in Sub-Saharan African countries. Renewable Energy, 198, 213–221. https://doi.org/10.1016/j.renene.2022.08.074

[45] Akpolat, A. G., & Bakırtaş, T. (2024). The nonlinear impact of renewable energy, fossil energy and CO_2 emissions on human development index for the eight developing countries. Energy, 312, 133466. https://doi.org/10.1016/j.energy.2024.133466

[46] Hassan, M. I. U., Wu, M., Rasool, Y., Sohu, J. M., & Ali, S. (2025). The Role of the Blue Economy, Renewable Energy, and Energy Intensity in Mitigating CO_2 Emissions: Evidence from China Using MMQREG Analysis. Geological Journal, 60(11), 2790-2807. https://doi.org/10.1002/gj.5224

[47] Iqbal, K., Hassan, S. T., Geng, Y., & Cai, C. (2024). Impact of Green Technological Innovations, ICT, and Renewable Energy on CO_2 Emissions in Emerging Economies. International Journal of Energy Research, (1), 5594324 . https://doi.org/10.1155/er/5594324

[48] Shabani, Z. D. (2024). Renewable energy and CO_2 emissions: Does human capital matter? Energy Reports, 11, 3474–3491. https://doi.org/10.1016/j.egyr.2024.03.021

[49] Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. Empirical Economics, 60(1), 13–50. https://doi.org/10.1007/s00181-020-01875-7

[50] Hair, J. F., Hult, G. T. M., Ringle, C. M., Sarstedt, M., Danks, N. P., & Ray, S. (2021). Partial Least Squares Structural Equation Modeling (PLS-SEM) Using R. Springer International Publishing. https://doi.org/10.1007/978-3-030-80519-7

[51] Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. Journal of Econometrics, 90(1), 1–44. https://doi.org/10.1016/S0304-4076(98)00023-2

[52] Kadir, M. O., Deka, A., Seraj, M., & Ozdeser, H. (2024). Capitalizing on natural resources rent and renewable energy in enhancing economic growth—New evidence with MMQR method. Natural Resources Forum. https://doi.org/10.1111/1477-8947.12536

[53] Deka, A. (2024). The role of natural resources rent, trade openness and technological innovations on environmental sustainability–Evidence from resource-rich African nations. Resources Policy, 98, 105364. https://doi.org/10.1016/j.resourpol.2024.105364

(Executive Editor: Yan Li)