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Green Innovation and Environmental Quality in Regional Comprehensive Economic Partnership (RCEP) Countries: Moderating Effect of Institutional Quality

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Abstract

This study examines the role of institutional quality in the relationship between green innovation and environmental quality in RCEP countries, using a panel dataset covering the period from 2000 to 2021. Through two-way fixed effects (TWFE) estimation, the analysis reveals that green innovation significantly reduces carbon dioxide emissions, with institutional quality amplifying its environmental benefits by supporting the implementation of green technologies. Countries with higher institutional quality are able to utilize resources more efficiently, resulting in substantial pollution reduction. Robustness tests confirm these findings, underscoring the importance of a strong governance framework for maximizing the environmental potential of green innovation. These insights highlight the need for institutional reforms and strategic policy support in RCEP countries to promote sustainable development, providing valuable guidance for policymakers.

Keywords: Green Innovation, Institutional Quality, CO_2, RCEP countries, TWFE

Introduction

In recent years, growing global concern over climate change and environmental degradation has underscored the urgency of sustainable development. The traditional model of economic growth, which often prioritizes gross domestic product (GDP) growth at the expense of the environment, has proved inadequate in addressing escalating environmental challenges (Fernandes et al., 2021). The Regional Comprehensive Economic Partnership (RCEP), officially signed in 2020, is now one of the world's largest regional trade agreements. This agreement includes 15 member countries, comprising the ten ASEAN nations as well as China, Japan, and South Korea, and spans both developed and developing economies. RCEP creates new growth opportunities for Southeast Asia, East Asia, and Oceania by promoting regional economic integration while simultaneously placing greater demands on member countries to balance economic expansion with environmental protection (Choi & Park, 2022; Itakura, 2022).

Most RCEP member countries are classified as developing economies, and their economic development is still associated with high carbon emissions. In 2021, approximately 40 percent of global carbon dioxide (CO_2) emissions from fuel combustion originated from RCEP member countries, with CO_2 emissions in these countries increasing from 6,098,970 $MtCO_2e$ in 2000 to 14,834,782 $MtCO_2e$ in 2021 (Tian et al., 2022). Trade, economic development, and globalization have undoubtedly exacerbated CO_2 emissions within RCEP countries and globally (see Figure 1). Long-term high carbon emissions not only have irreversible impacts on the local environments of RCEP member countries but also exert far-reaching negative effects on the global climate. If not addressed, the carbon-intensive development pathways of RCEP countries will accelerate climate change, further threatening the stability of the global ecosystem and the health and well-being of humanity.

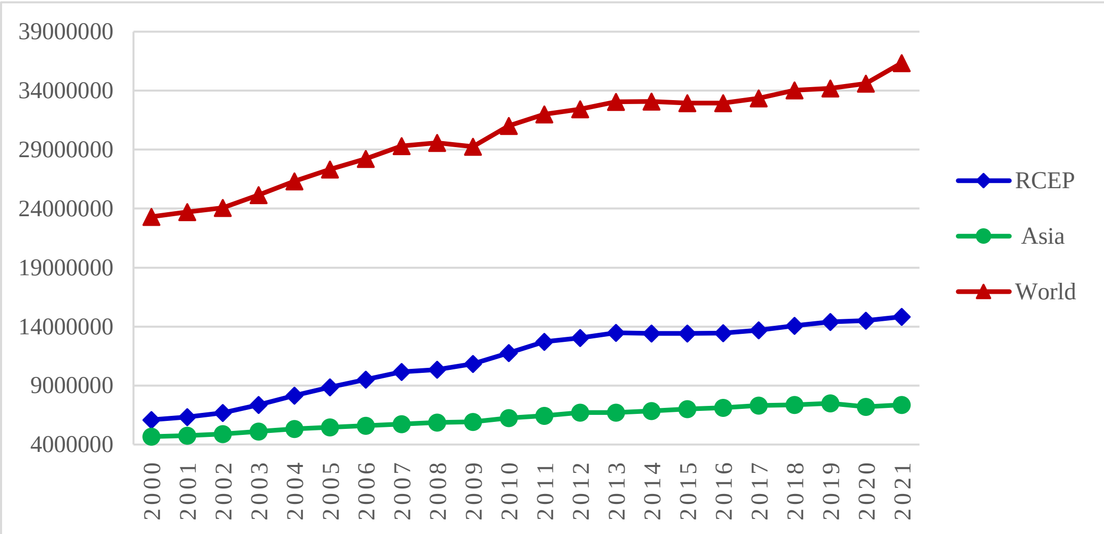

Figure 1: CO_2 Emission in RCEP Countries, Asia and World (2000-2021)
Source: World bank indicators, Online World Bank Database (2022)

In this context, green innovation has received increasing attention and, in recent years, has gradually been recognized as a key strategy for mitigating environmental degradation through technological means. Compared to traditional technological innovation, green innovation has a significantly positive impact on reducing pollution, improving resource utilization efficiency, and promoting economic growth through the development and application of environmentally friendly technologies (Hashmi & Alam, 2019). Specific forms of green innovation include clean energy technologies, energy efficiency technologies, and waste recycling technologies, all of which show considerable potential for reducing carbon emissions. In recent years, as countries have placed greater emphasis on green technology, the overall trend of green patent applications in RCEP member countries has been steadily increasing (see Figure 2), with particularly significant growth in environment-related patents after 2009. In 2017, the annual number of applications in the 15 member countries was close to 20,000, showing the importance countries place on green technology R&D and technological competition. Despite a slight decline in 2018 and 2019, the annual number of applications remained around 18,000.

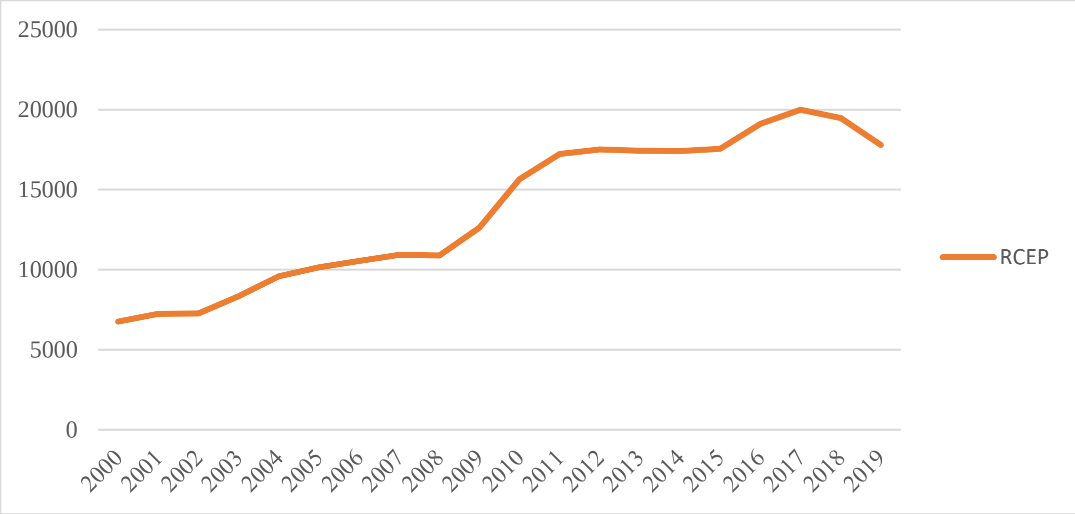

Figure 2: Green patents application trend for RCEP countries (2000-2019)
Source: OECD (2022), patents on environment technologies indicator

However, despite the steady growth in green patent applications in RCEP countries, the correlation between green innovation and environmental quality shown in Figure 3 suggests that environmental quality in these countries has not improved rapidly as a result of green technology development. This may be because environmental quality deterioration stems from the long-term accumulation of greenhouse gas emissions, and even with green technology advancements, it takes an extended period to significantly improve the environment. Additionally, sustained economic growth has increased demand for resources and energy, which may have partially offset the short-term environmental benefits of green technologies (Hussain & Dogan, 2021). This also suggests that other factors (e.g., institutional quality, regulatory strength, and policy support) may limit the diffusion of green technologies, so that their effects typically take longer to materialize.

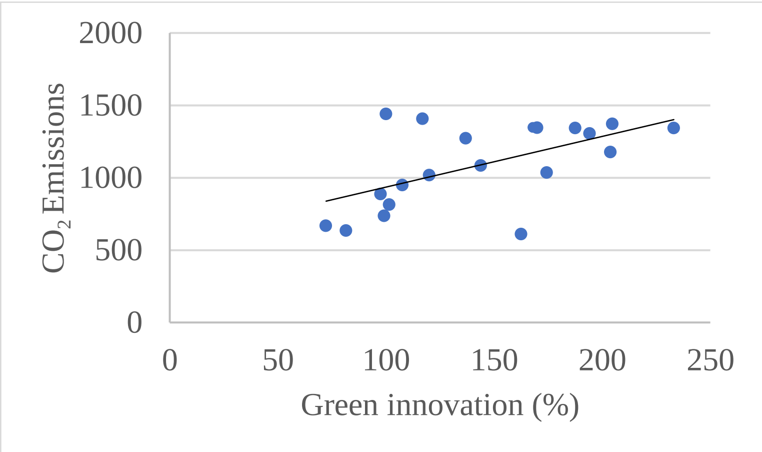

Figure 3: Green Innovation and Environmental Quality
Source: Author’s own calculation

Studies have shown that the effectiveness of green innovation in reducing CO_2 emissions depends on key external conditions (Bai et al., 2023). Institutional theory suggests that external environmental factors, such as legal rules and governance structures, shape firm behavior (DiMaggio & Powell, 1983). Institutional quality is typically measured through different dimensions such as corruption control, government efficiency, and political stability (WDI, 2022). Higher institutional quality indicates that the government implements effective measures to promote economic development and environmental protection, reducing transaction costs, improving economic efficiency, and minimizing environmental damage (Yuan et al., 2022). For example, developed RCEP economies such as Australia, New Zealand, and Singapore excel in corruption control, government effectiveness, and rule of law (see Figure 4), and are therefore more effective in promoting green technologies and environmental governance. In contrast, many RCEP member countries with weaker institutions often implement environmental policies selectively, especially when controls over corruption and rule of law are limited. This institutional weakness leads to a tendency for these countries to overlook environmental responsibilities, thereby reducing the potential of green innovation to improve environmental quality. Therefore, examining the moderating role of institutional quality in the relationship between green innovation and environmental quality is not only crucial for RCEP member countries to achieve sustainable development but also for providing new perspectives on the effects of environmental improvement across different institutional contexts.

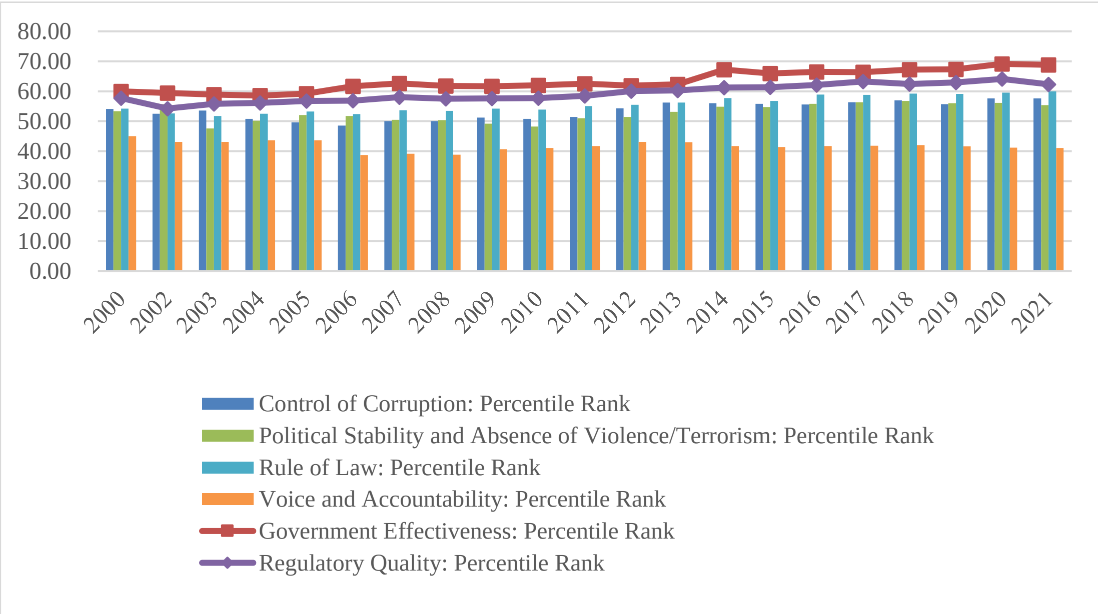

Figure 4: Institutional trend performance in RCEP countries (2000-2021)
Source: World Bank Indicators, Online World Bank Database (2022)

This study aims to address a gap in the existing literature by analyzing the role of institutional quality in influencing green innovation and environmental degradation in RCEP countries, offering a new perspective on the effectiveness of environmental policies within the region. We adopt the STIRPAT model (i.e., a random-effects model incorporating population, affluence, and technology regressions) as the analytical framework and apply two-way fixed-effects (TWFE) estimation to conduct an in-depth analysis of panel data from RCEP countries over the period 2000 to 2021. This study contributes in the following ways: First, using a sample of RCEP member countries, we explore the moderating role of institutional quality in green innovation and environmental impacts. Second, we utilize a two-way fixed-effects estimation methodology that effectively controls for fixed characteristics and time effects across the different countries over the sample period, thereby reducing interference from these factors and ensuring the robustness of our analysis. Finally, our findings provide important insights for future policy directions. The rest of the paper is organized as follows: Section 2 reviews the relevant literature, Section 3 outlines the data and methodology, Section 4 presents the empirical results and discussion, and Section 5 concludes with policy recommendations.

Literature Review

Theoretical Review

Ecological Modernization Theory and Environmental Sustainability

In the 1980s, German scholar Josef Huber proposed the ecological modernization theory (EMT), whose core idea is that ecological factors can drive economic development and should be integrated into the modernization process (Huber, 1982; Huber, 1985). EMT suggests that industrialization can be transformed through a new institutional framework and technological progress, achieving ecological rationality in production systems by incorporating environmental protection into economic decision-making to create a win-win situation (Spaargaren & Mol, 1992; Fisher & Freudenburg, 2001). EMT emphasizes that through the application of green technology and policy innovation, society and the economy can achieve steady economic growth while maintaining environmental sustainability (Mol, 2003; York et al., 2010). This theory provides a critical theoretical foundation for green innovation, especially in industrialized countries, where green innovation is increasingly regarded as an essential pathway to sustainable development.

Sustainable Transformation Theory

Sustainable transformation theory originated in the 1990s and advocates that social and technological systems should achieve sustainable development through comprehensive innovation. Geels (2011) pointed out that system innovation involves transforming socio-technical systems from high-resource-consumption production modes to resource-friendly production modes. In recent years, this theory has been widely applied in the fields of production and consumption patterns and design to explain how to achieve socio-technical change through eco-design, system innovation, and other approaches (Brezet, 1997; Gaziulusoy, 2010; Joore, 2010; Ceschin, 2013). The core of this theory is to transition from unsustainable to more sustainable practices, emphasizing the key role of green innovation in promoting ecological sustainability and resource efficiency (Gaziulusoy & Erdoğan Öztekin, 2019).

Circular Economy Theory

Circular economy theory emphasizes achieving economic sustainability through resource recycling and pollution minimization. In recent years, it has been combined with green innovation to promote ecological innovation and business model innovation (De Jesus et al., 2018, 2019). Typical models of eco-innovation within the circular economy include reducing resource consumption, extending product life cycles, and following the 6R principles (reduce, reuse, recycle, etc.) to reduce pollution in the production process (Sehnem et al., 2022). Additionally, realizing the circular economy relies on the dynamic capabilities of enterprises, which enable them to efficiently integrate resources by continuously enhancing their innovation capabilities. Dynamic capabilities include behaviors, learning mechanisms, and knowledge management, which help enterprises achieve ongoing innovation and green transformation in a circular economy context (Meirelles & Camargo, 2014; Scarpellini et al., 2018). Within the circular economy framework, green innovation is considered a key pathway to ecological modernization.

Environmental Innovation Theory
Environmental innovation theory focuses on the role of technological innovation in addressing environmental issues, positing that innovative design can effectively tackle environmental challenges. Jacob et al. (2005) proposed that innovative design can address specific environmental needs in a dominant market context and achieve international diffusion through market mechanisms. Rennings and Smidt (2010) suggested that pioneer countries promote technological innovation and create a demonstration effect for other countries by implementing strict environmental policies. This interaction between policy and market forces has gradually positioned environmental innovation at the core of green transformation, driving global ecological change through technological advancement and policy support (Quitzow et al., 2014). Thus, environmental innovation theory provides a framework for applying green innovation from a global perspective.

Environmental Kuznets Curve (EKC)
The Environmental Kuznets Curve (EKC) hypothesis proposes an inverted U-shaped relationship between environmental quality and economic growth. Environmental quality declines in the early stages of economic development but improves after reaching a certain income level (Grossman & Krueger, 1991, 1995; Antweiler et al., 2001). This theory offers a framework for understanding the environmental impact of green innovation at various stages of economic development. The EKC model suggests that in the early phases of economic expansion, pollution from industrialization increases environmental burdens. However, as income grows and green technologies develop, economic growth begins to support environmental protection (Mrabet & Alsamara, 2017). In the global economy, the EKC model not only provides a theoretical basis for the notion of “pollution first, governance later” but also reveals the complex relationship between economic development and green innovation (Uddin et al., 2017; Alola et al., 2019).

Empirical Review
Green Innovation and Environmental Quality
In the past 20 years, green innovation has received widespread attention for its potential to alleviate environmental issues. Green innovation generally refers to production and processing technologies with positive environmental benefits, aiming to reduce environmental costs and achieve sustainable development through environmentally friendly technologies (Shahzad et al., 2020). It introduces environmentally friendly technologies and reduces environmental costs. By minimizing environmental hazards, it supports environmental sustainability (Ekins & Zenghelis, 2021).

Carrión-Flores and Innes (2010), used patent applications as an indicator of green innovation to study its environmental impact in 127 manufacturing industries from 1989 to 2004, finding a bidirectional causal relationship between innovation and air pollution. Weina et al. (2016)

analyzed data from 95 provinces in Italy from 1990 to 2010, showing that green innovation improved environmental productivity but did not significantly reduce CO_2 emissions for environmental protection; however, green patents did significantly reduce carbon emissions in East China. Ali et al. (2022) found that green innovation in BRICS countries had a significant negative impact on CO_2 emissions based on data from 1990 to 2014, with a two-way causal relationship between CO_2 emissions and green innovation. Nan et al. (2022) used a panel smooth transition regression model to study the relationship between green innovation, economic growth, and carbon emissions in China, revealing that green innovation has contributed significantly to reducing carbon emissions while promoting economic growth, underscoring its key role in sustainable development. Zhang et al. (2024) applied an autoregressive distributed lag (ARDL) model to examine green innovation's impact on environmental sustainability in South Korea from 1995 to 2022, finding that green innovation significantly reduced CO_2 emissions in the long run, highlighting the role of technological progress in supporting environmental sustainability.

Institutional Quality and Carbon Dioxide Emissions
In recent years, the importance of institutional quality in environmental governance has become increasingly prominent. High-quality institutions typically have sound governance structures, strong rule of law, and effective regulatory quality and accountability mechanisms, which can mitigate environmental degradation, especially in carbon emission control (Yuan et al., 2022). Effective institutions ensure the formulation and implementation of environmental policies that not only reduce CO_2 emissions but also attract investment that complies with environmental regulations, further strengthening environmental protection (Gani, 2012). Bilgili et al. (2020) noted that improved governance quality supports environmental law enforcement and encourages investment in green technologies, playing a key role in environmental improvement. Hussain and Dogan (2021) analyzed data from BRICS countries from 1992 to 2016 to study the impact of institutional quality on pollution, finding that improved institutional quality can reduce environmental degradation. Warsame et al. (2022) used data from 1990 to 2017 and found, through an ARDL model and Granger causality analysis, that renewable energy use and institutional quality improvement benefit environmental quality. Sheng et al. (2023) examined the influence of institutional quality and various energy production types on environmental quality in BRICS countries, revealing that improved institutional quality significantly reduced CO_2 emissions from 2000 to 2020.

Moderating Role of Institutional Quality
Beyond its direct impact on environmental quality, institutional quality also plays a crucial role in the relationship between green innovation and environmental quality. Effective institutions and the rule of law are core factors that shape innovation (Dasgupta & Cian, 2018). Strong institutions facilitate the dissemination of new patents, knowledge, and law enforcement, reducing uncertainty (Azam et al., 2021). High-quality institutions promote the effective implementation of green innovation by improving policy execution and enhancing access to innovation resources. Bekhet and Latif (2018), in a study on Malaysia, highlighted that institutional quality and technological innovation are equally essential for economic growth and environmental protection, noting that good governance fosters the promotion and application of green technologies, thus supporting sustainable environmental development. Yuan et al. (2022) further observed, in a study on China, that higher institutional quality enhances green innovation's emission reduction effect, with this moderating effect

varying across regions and periods. Bekhet and Latif (2018) underscored the importance of technological innovation and governance quality for Malaysia's sustainable growth from 1985 to 2015, advocating for policies that encourage technological advancement. Yuan et al. (2022) analyzed the impact of green innovation and institutional quality on CO_2 emissions in China from 2005 to 2017, focusing on institutional quality's moderating role, and found that while green innovation significantly reduces CO_2 emissions, high institutional quality strengthens this reduction effect, with differences across regions and time periods.

Research Gaps

While existing research has explored green innovation's positive impact on environmental quality, there remains a significant gap in understanding how institutional governance mediates this relationship. Most studies primarily focus on green innovation's direct effects, such as pollution reduction, resource conservation, and sustainable development, often overlooking the complex role institutional governance plays in shaping and potentially mitigating these impacts. Institutional governance, such as policies, regulations, regulatory mechanisms, and social norms, can influence firms' motivations, capabilities, and strategic choices regarding green innovation. However, relatively few studies examine how institutional governance modifies green innovation's environmental impact through incentives, constraints, or guidance. This study aims to fill this gap by investigating how institutional governance affects the relationship between green innovation and environmental quality, introducing it as a key moderating variable and revealing specific mechanisms through which it interacts with green innovation.

Research Methodology and Data Collection

Model Specification

In the early 1970s, Commoner et al. (1971) and Ehrlich & Holdren (1972) proposed the IPAT model (Impact = Population x Affluence x Technology), which regards environmental impact (I) as the combined effect of population (P), affluence (A), and technology level (T), providing an early framework for assessing environmental pressure. The ImPACT framework proposed by Waggoner & Ausubel (2002) further refines the IPAT model by decomposing the technological factor into consumption per unit of GDP (C) and environmental impact per unit of consumption (T). However, these models still have certain limitations in applicability. To address these limitations, the STIRPAT model (Stochastic Impacts by Regression on Population, Affluence, and Technology) was developed. The model assumes potential causal relationships among population, affluence, and technology and incorporates factors such as culture, institutions, and politics as determinants of environmental impact, thus providing a more comprehensive explanatory framework (Vélez-Henao et al., 2019).

Based on the STIRPAT framework, this study examines the impact of green innovation on environmental quality, with particular attention to the moderating role of institutional quality. Using the number of green patents as a proxy for technological progress, green innovation is considered a key factor in reducing pollution, improving resource efficiency, and lowering carbon dioxide emissions. Institutional quality, in turn, influences the effectiveness of green innovation through governance and oversight (Dasgupta & Cian, 2018). Following the approach of Liddle (2015), we assume that population elasticity is 1, thus excluding the population variable and expressing the dependent variable in per capita terms, as shown in equation (1):

$$\ln(\frac{1}{p})_{it} = \gamma_i + \delta_t + \alpha_1 \ln(A)_{it} + \alpha_2 \ln Z_{it} + \varepsilon_{it} \quad (1)$$

This study uses CO_2 emissions as the dependent variable, introduces green innovation as the core independent variable, and includes interaction terms to examine the moderating effect of institutional quality on the relationship between green innovation and CO_2 emissions (Yuan et al., 2022). Therefore, the extended STIRPAT model is expressed as:

$$\begin{aligned} LNCO2_{it} &= \alpha_0 + \alpha_1 LNGI_{it} + \alpha_2 LNIQ_{it} + \alpha_3 LNGI_{it} \times LNIQ_{it} + \alpha_4 LNGDP_{it} \\ &+ \alpha_5 FDI + \alpha_6 LNURN_{it} + \alpha_7 LNENU_{it} + \mu_{it} \end{aligned} \quad (2)$$

Where $LNCO_2$, LNGI, LNIQ, LNGI*LNIQ, LNGDP, LNFDI, LNURN, LNENU represent log of emission of carbon dioxide, log of green innovation, log of institutional quality, log of green innovation*log of institutional quality, log of GDP per capita, log of FDI, log of urbanization, log of energy use and error term, respectively.

To examine the relationship between green innovation and environmental quality and explore the moderating role of institutional quality, this study employs a two-way fixed effects (TWFE) model for estimation. The concept and application of the TWFE model developed gradually from the late 1970s to the early 1980s and was later expanded and refined by Baltagi (1985) and Justman and Dominic (1988). This model is selected for its significant advantages in controlling for heterogeneity across countries and over time, thereby enhancing the robustness of the estimation results. Specifically, the TWFE model can simultaneously control for unobserved country-specific and time-specific effects, reducing bias caused by these factors and thus offering superior explanatory power compared to alternative models (Baltagi, 2005; Wooldridge, 2021). Additionally, the TWFE model effectively mitigates omitted variable bias, as it controls for individual and time-invariant characteristics, improving the reliability and precision of the estimation results (Hasan et al., 2023; Sharif et al., 2023).

Data Collection

This study uses a balanced panel data set covering 15 RCEP countries from 2000 to 2021. The description and data source of each variable are shown in Table 1 below.

Table 1
Description of Variables and Data Sources

Variables	Description	Unit of Measurement	Data Sources
CO_2 emissions	emissions of carbon dioxide	metric tons per capita	World Development Indicator (WDI)
Green innovation	environmental-related patents	number of green patents related to environment	Organization for Economic Co-operation and Development (OECD)
Institutional quality	percentile rankings for corruption control, government efficiency, political stability and	Percentile ranks are used for each of the six dimensions (0 being	World Development Indicator (WDI)

	absence of violence/terrorism, regulatory quality, rule of law and voice and accountability	the lowest ranking and 100 the highest)	
Economic growth	GDP per capita	constant 2015 US$	World Development Indicator (WDI)
Foreign direct investment (FDI)	Knowledge spillover	constant 2015 US$	World Development Indicator (WDI)
Urbanization	total population who living in urban areas	percentage	World Development Indicator (WDI)
Energy use	usage of primary energy	thousand metric ton of oil equivalent	World Development Indicator (WDI)

Empirical Results and Discussions

In this study, we use the two-way fixed effects (TWFE) model to analyze the relationship between green innovation and environmental quality, as well as to examine the moderating effect of institutional quality. This model effectively reduces the influence of unobserved factors on the estimation results by controlling for both country-specific and time-specific effects. The analysis results are presented in Table 2 below.

Table 2

Estimation Results for Green Innovation-Environmental Quality: Institutional Quality as the Moderating Variable

	Model (1) $LNCO_2$	Model (2) $LNCO_2$	Model (3) $LNCO_2$	Model (4) $LNCO_2$
LNGDP	0.496***	0.170*	0.207**	0.164*
	(0.078)	(0.087)	(0.087)	(0.086)
LNURN	0.900***	1.295***	1.284***	1.179***
	(0.235)	(0.232)	(0.230)	(0.226)
LNFDI	0.008	-0.004	-0.004	0.005
	(0.030)	(0.029)	(0.028)	(0.028)
LNENU	1.037***	0.878***	0.945***	0.925***
	(0.082)	(0.075)	(0.079)	(0.077)
LNGI	-0.105***	-	-0.059***	-0.130***
	(0.023)		(0.023)	(0.029)
LNIQ	-	0.539***	0.473***	0.451***
		(0.073)	(0.076)	(0.075)
LNGI*LNIQ	-	-	-	-0.086***
				(0.023)
_cons	-15.341***	-17.328***	-17.890***	-15.794***
	(3.569)	(3.411)	(3.384)	(3.352)

Year	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes
N	330	330	330	330
R-sq	0.827	0.844	0.848	0.855
F-test	53.28	53.04	54.59	60.45

Note: The dependent variable is carbon dioxide emissions. GI = number of green patent applications, GDP= GDP per capita, FDI =foreign direct investment, URN= urbanization rate, ENU = energy use, IQ = institutional quality, GI*IQ is the interaction term between green innovation and institutional quality. All variables are estimated in logarithmic form. *, ** and *** refer to significance at 10%, 5% and 1% respectively and parentheses indicate standard errors.

It can be concluded that green innovation (LNGI), GDP per capita (LNGDP), energy use (LNENU), urbanization rate (LNURN), institutional quality (LNIQ), and the interaction term (LNGI*LNIQ) all have significant effects on environmental quality.

Specifically, the suppression effect of green innovation on $LNCO_2$ aligns with theoretical expectations, suggesting that an increase in the number of green patent applications can effectively reduce carbon emissions in RCEP countries. Additionally, the negative effect of green innovation remains significant when institutional quality (LNIQ) and its interaction term (LNGI*LNIQ) are added to model (3) and model (4), respectively. This result is consistent with the Schumpeterian growth theory hypothesis, which posits that green innovation can enhance productivity and resource utilization efficiency while reducing carbon emissions. According to Schumpeterian growth theory, innovation-driven technological progress is a key driver of both economic and environmental performance (Schumpeter, 1942). This finding is also supported by existing studies. For example, some studies have highlighted that green innovation plays a crucial role in energy saving and emission reduction (Ekins & Zenghelis, 2021; Bashir et al., 2022; Ali et al., 2022). In addition, model (2) - (4) reveal that the coefficient of institutional quality is positive and statistically significant, suggesting that institutional quality positively affects CO_2 emissions in RCEP countries. This result may be attributed to the ineffective functioning of institutions due to weak legal and regulatory enforcement and lax environmental enforcement in some developing member countries. For instance, widespread corruption and bureaucracy have severely constrained the ability of government officials to formulate and implement effective environmental policies, leading to continued deterioration of environmental quality (Wang et al., 2018). Weak institutional quality also creates conditions for other countries to invest in highly polluting industries. Low institutional quality hinders environmental policies from fully achieving their intended environmental objectives, resulting in limited effectiveness in reducing pollution and improving environmental quality. Our findings are consistent with Dasgupta and Cian (2018), Yamineva & Liu (2019), and Hassan et al. (2020).

However, the inclusion of the interaction term between green innovation and institutional quality in model (4) shows a negative and significant effect on environmental quality, suggesting that strong institutions mitigate the negative environmental impacts of green innovation. This result supports theories that emphasize institutional quality not only enhances the effectiveness of green innovations (Hussain & Dogan, 2021), but also ensures that the outcomes of green innovations are effectively translated into environmental benefits. Specifically, there are at least three reasons to support the conclusion that institutional quality plays a crucial role in the relationship between green innovation and environmental quality. First, the trade-off between green innovation and environmental quality diminishes as stricter environmental standards are implemented and regulatory controls are strengthened. This implies that green innovations are more likely to contribute to environmental protection in a high-quality institutional environment. Second, strong institutions can enhance the spillover effects of green innovation by improving resource allocation efficiency in various ways, such as strengthening environmental regulation enforcement, raising emission standards, and encouraging the development and application of cleaner technologies. Finally, a higher level of institutional quality can promote corporate investment in green innovation to maintain market competitiveness and ensure compliance. Therefore, with sound institutions and effective regulatory mechanisms, the adoption of green innovations can minimize CO_2 emissions and thus improve environmental quality (Bekhet & Latif, 2018; Yuan et al., 2022; Raza et al., 2023).

The positive effect of GDP per capita (LNGDP) suggests that economic growth is typically associated with increased energy consumption and CO_2 emissions in RCEP countries. This result is consistent with previous studies (Güler & Yildirim, 2020; Aslam et al., 2021; Awan & Azam, 2022). This phenomenon may be attributed to the fact that economic development in these countries often comes at the expense of the environment, particularly in the context of rapid industrialization and urbanization. Many RCEP member countries remain highly dependent on traditional manufacturing and fossil fuel energy sources, which are highly polluting and energy-intensive, in order to achieve short-term economic growth targets. This result validates the early stages of the Environmental Kuznets Curve (EKC) hypothesis, which posits that environmental quality tends to deteriorate with economic growth in the early stages of development. This is primarily because, in the early stages of development, countries typically prioritize economic expansion over environmental protection. This phenomenon is particularly evident in countries at the early stages of industrialization (e.g., Cambodia, Laos, and Myanmar). As a result, the lack of strong institutional support, policy orientation, and environmental awareness has led to negative environmental consequences driven by economic growth in RCEP member countries.

Moreover, the positive and significant effect of urbanization (LNURN) on environmental quality in RCEP countries is also consistent with theoretical expectations. Urbanization is typically accompanied by industrial expansion and population growth, leading to greater demand for national resources, which can significantly increase energy demand and environmental degradation. At the same time, if the rapid pace of urbanization outstrips the level of infrastructure development, it can lead to inefficient energy use and increased pollutant emissions. Together, these factors contribute to rising environmental pressures. Our findings further validate previous literature that suggests urbanization processes tend to be associated with environmental degradation (Behera & Dash, 2017; Pazienza, 2019; Talib et al., 2021). Similarly, energy use (LNENU) shows a positive and significant effect in all models, indicating that increased energy consumption in RCEP member countries significantly contributes to the rise in CO_2 emissions. This finding aligns with theoretical expectations and is supported by previous studies that suggest rising energy consumption directly contributes to increasing CO_2 emissions (Khan et al., 2022; Paramati et al., 2022; Ramzan et al., 2023; Mohsin et al., 2023).

Robustness Tests

It should be noted that the results of studies based on two-way fixed effects model may not be reliable because the independent variables may be endogenous. For example, green innovation is endogenously determined because government environmental policies, corporate environmental responsibilities, and public environmental awareness all contribute to the development and application of green technologies. Simultaneously, green innovation also directly affects environmental quality. Therefore, green innovation and environmental quality are jointly determined. To mitigate endogeneity problems caused by omitted variables, measurement error, or reverse causality, we employed an instrumental variable (IV) approach within a 2SLS estimation framework to eliminate possible simultaneity bias. The instrumental variable was selected based on two key criteria: First, it must be highly correlated with the endogenous explanatory variables (Stock & Watson, 2011). Second, it should not directly affect the dependent variable but instead influence it indirectly through the explanatory variables (Bellemare et al., 2015). Furthermore, the use of lagged independent variables as instrumental variables has practical advantages, as it reduces the need to collect additional data (Anderson & Hsiao, 1981). Specifically, the lagged one-period value of green innovation is an appropriate choice as an instrumental variable because it is highly correlated with current green innovation while remaining uncorrelated with the model's error term, thereby effectively mitigating estimation bias due to endogeneity (Roodman, 2009). The results of the 2SLS estimation reported in Table 3. The table shows that the first-stage IV is significant at the 1% level, indicating a strong correlation between the IV and the endogenous explanatory variables. Additionally, the p-value is 0.000, which is less than 0.1, indicating that we reject the null hypothesis and the model is identifiable. In other words, the chosen instrumental variable is sufficiently correlated with the endogenous variables. In the weak identification test, the CD-F statistic is 127.908, which is far greater than the critical value of 16.38. Therefore, the model passes the non-identifiable test and the weak identification test, verifying the validity of the chosen IV. The second-stage regression results show that the coefficient of green innovation (LNGI) is significantly negative at the 1% level, indicating that the conclusion holds after mitigating potential endogeneity. This further validates the effectiveness of green innovation in reducing carbon dioxide emissions.

Table 3
2SLS Estimation

	Model (5) LNGI	Model (6) $LNCO_2$
L.LNGI	0.519***	-
	(0.046)	
LNGI	-	-0.108***
		(0.024)
LNGDP	-0.146	0.537***
	(0.174)	(0.083)
LNFDI	0.002	0.003
	(0.062)	(0.030)
LNURN	0.427*	0.867***
	(0.524)	(0.250)
LNENU	0.590***	1.053***
	(0.169)	(0.083)
N	315	330
R-sq		0.683
Under identification test	100.001	
Weak identification test	127.908	

Table 4
Robustness Tests

	Model (7) $LNPCCO_2$	Model (8) $LNPCCO_2$	Model (9) $LNCO_2$_w	Model (10) $LNCO_2$_w	Model (11) $LNCO_2$	Model (12) $LNCO_2$
LNGI	-0.100***	-0.121***	-0.090***	-0.130***	-0.076***	-0.083***
	(0.021)	(0.026)	(0.023)	(0.030)	(0.020)	(0.025)
LNGDP	0.552***	0.252***	0.506***	0.225**	0.358***	0.009**
	(0.071)	(0.078)	(0.090)	(0.092)	(0.070)	(0.074)
LNFDI	0.013	0.009	0.046	0.071	0.006	-0.001
	(0.027)	(0.025)	(0.150)	(0.135)	(0.026)	(0.024)
LNURN	0.414*	0.668***	1.042***	1.047***	0.878***	1.158***
	(0.214)	(0.207)	(0.210)	(0.208)	(0.210)	(0.195)
LNENU	1.111***	1.010***	0.911***	0.823***	1.076***	0.947***
	(0.075)	(0.070)	(0.085)	(0.077)	(0.073)	(0.066)
LNIQ	-	0.408***	-	0.529***	-	0.493***
		(0.068)		(0.076)		(0.064)
LNGI*LNIQ	-	-0.076***	-	-0.110***	-	-0.072***
		(0.021)		(0.027)		(0.019)
LNFD	-	-	-	-	0.243***	0.252***
					(0.027)	(0.024)
LNR	-	-	-	-	-0.029*	-0.01*
					(0.017)	(0.015)
_cons	-18.725***	-19.180***	-17.881***	15.097***	14.834***	15.128***

	(3.253)	(3.064)	(5.530)	(5.089)	(3.194)	(2.898)
Year	Yes	Yes	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes	Yes	Yes
N	330	330	330	330	330	330
R-sq	0.811	0.841	0.806	0.845	0.868	0.897

To further assess the reliability of the findings, we conducted several robustness tests. First, replacing the dependent variable is a common method for evaluating model stability under different measures, helping to avoid biases from reliance on a single indicator and enhancing result generalizability (Stern, 2004; Ekins, 2010). Specifically, we re-estimated the model by substituting total carbon emissions with carbon emissions per capita. The results, shown in models (7) and (8) of Table 4, indicate that in the base regression model (7), the coefficient for green innovation is negative and statistically significant. In model (8), which includes the interaction term between institutional quality and green innovation, this interaction remains negative and statistically significant.

Second, percentile trimming was applied to reduce the influence of extreme values, which is a widely used method for addressing outliers and enhancing model robustness (Huber, 1964; Barro, 1991). In this study, we trimmed all variables by removing the top and bottom 2.5% of values, retaining the central 95% of the data. After trimming, model (9) still shows a negative effect of green innovation on carbon emissions, with this negative relationship remaining significant in model (10) even after adding the interaction term. These results reaffirm the robustness of our earlier findings, highlighting the significant role of institutional quality in moderating the relationship between green innovation and environmental quality.

Lastly, as an additional sensitivity check, we introduced supplementary variables, such as financial development and the number of R&D personnel, to control for potential omitted variable bias and verify consistency across different model specifications (Aghion et al., 2005; Grossman & Krueger, 1995). The results, reported in models (11) and (12), confirm that the main conclusions remain stable across various configurations, reinforcing the robustness of our findings.

Overall, these robustness tests underscore the importance of green innovation in sustainable development, with institutional quality enhancing this effect. Specifically, by reducing corruption, improving government efficiency, and fostering a stable regulatory environment, institutional quality ensures the effective deployment of green technologies. Furthermore, stable political and legal frameworks support long-term green innovation initiatives, while robust accountability and regulatory quality encourage both corporate and public adherence to environmental standards. Through these mechanisms, institutional quality plays a vital role in amplifying green innovation's effect on mitigating environmental degradation.

Conclusion

This study provides valuable insights into the moderating role of institutional quality in promoting green innovation to enhance environmental quality in RCEP countries. Findings from an analysis of RCEP countries using a two-way fixed effects (TWFE) model show that green innovation significantly reduces carbon dioxide emissions, highlighting its potential to improve environmental quality. At the same time, the robustness of institutional quality effectively amplifies the environmental benefits of green innovation by enhancing regulatory enforcement, ensuring policy stability, improving transparency, and reducing corruption risks.

Countries with higher institutional quality are better able to support the effective implementation of green technologies, promoting efficient resource use and pollution reduction. This finding further emphasizes the central role of institution building in the green transition process in RCEP countries, suggesting that a strong governance framework is critical for achieving long-term environmental goals.

This study also carries significant policy implications. First, improving institutional quality is crucial for maximizing the environmental benefits of green innovation. RCEP countries should develop a governance system that supports green innovation by strengthening anti-corruption measures, enhancing government efficiency, optimizing regulatory quality, reinforcing the rule of law, and encouraging public participation. Additionally, interregional cooperation and the promotion of green technology R&D will further enhance the effectiveness of green innovation across the region. Robustness tests confirm the reliability of the findings, supporting the positive spillover effect of institutional quality in the relationship between green innovation and environmental protection. Overall, this study suggests that an effective combination of institution building and technological innovation will help RCEP countries make substantial progress in achieving the Sustainable Development Goals (SDGs) and advancing long-term environmental protection. This provides an important reference for policymakers in shaping future environmental and economic strategies.

Declaration of competing interest
There is no conflict of interest associated with this manuscript.

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