

“The effect of oil, coal and renewable energy consumption, economic growth and trade on carbon emissions in ASEAN-5: Insights from panel ARDL and method of moments quantile regression (MMQR) analysis”

AUTHORS	Ciler Sigeze 
	Esra Ballı 
	M. Sedat Uğur 
	Abdurrahman Nazif Çatık 
	Gulnoza Matyakubova
	Bekhzod Kuziboev 
	
	Jamshid Pardaev
	O'g'iljon Artiqova
ARTICLE INFO	Ciler Sigeze, Esra Ballı, M. Sedat Uğur, Abdurrahman Nazif Çatık, Gulnoza Matyakubova, Bekhzod Kuziboev, Jamshid Pardaev and O'g'iljon Artiqova (2026). The effect of oil, coal and renewable energy consumption, economic growth and trade on carbon emissions in ASEAN-5: Insights from panel ARDL and method of moments quantile regression (MMQR) analysis. <i>Environmental Economics</i> , 17(3), 290–310. doi: 10.21511/ee.17(3).2026.17
DOI	http://dx.doi.org/10.21511/ee.17(3).2026.17
RELEASED ON	Wednesday, 30 September 2026
RECEIVED ON	Tuesday, 17 February 2026
ACCEPTED ON	Thursday, 23 July 2026
LICENSE	
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JOURNAL	"Environmental Economics"
ISSN PRINT	1998-6041
ISSN ONLINE	1998-605X
PUBLISHER	LLC “Consulting Publishing Company “Business Perspectives”
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”


NUMBER OF REFERENCES
119


NUMBER OF FIGURES
1


NUMBER OF TABLES
7

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BUSINESS PERSPECTIVES



LLC "CPC "Business Perspectives"
Hryhorii Skovoroda lane, 10,
Sumy, 40022, Ukraine
www.businessperspectives.org

Type of the article: Research Article

Received on: 17th of February, 2026

Accepted on: 23rd of July, 2026

Published on: 30th of September, 2026

© Ciler Sigeze, Esra Balli, M. Sedat Uğur, A. Nazif Çatik, Gulnoza Matyakubova, Bekhzod Kuziboev, Jamshid Pardaev, O'g'iljon Artiqova, 2026

Ciler Sigeze, Dr., Associate Professor,
Department of Econometrics,
Çukurova University, Türkiye.

Esra Balli, Dr., Associate Professor,
Department of Economics, Erzincan
Binali Yıldırım University, Türkiye.

M. Sedat Uğur, Dr., Associate Professor,
Department of Economics, Çankırı
Karatekin University, Türkiye.

A. Nazif Çatik, Dr., Professor,
Department of Economics, Ege
University, Türkiye.

Gulnoza Matyakubova, Associate
Professor, Department of Education
Economics, Urgench State Pedagogical
Institute, Uzbekistan.

Bekhzod Kuziboev, Associate
Professor, Department of Economics,
Urgench State University, Uzbekistan.
(Corresponding author)

Jamshid Pardaev, Dr., Associate
Professor, Termez University of
Economics and Service, Uzbekistan.

O'g'iljon Artiqova, Lecturer, Termez
University of Economics and Service,
Uzbekistan.



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Conflict of interest statement:

Author(s) reported no conflict of interest

Ciler Sigeze (Türkiye), Esra Balli (Türkiye), M. Sedat Uğur (Türkiye),
A. Nazif Çatik (Türkiye), Gulnoza Matyakubova (Uzbekistan),
Bekhzod Kuziboev (Uzbekistan), Jamshid Pardaev (Uzbekistan),
O'g'iljon Artiqova (Uzbekistan)

THE EFFECT OF OIL, COAL AND RENEWABLE ENERGY CONSUMPTION, ECONOMIC GROWTH AND TRADE ON CARBON EMISSIONS IN ASEAN-5: INSIGHTS FROM PANEL ARDL AND METHOD OF MOMENTS QUANTILE REGRESSION (MMQR) ANALYSIS

Abstract

This paper investigates the impact of oil, coal, renewable energy consumption and CO₂ emissions in the ASEAN-5 countries for the period from 1971 to 2020 utilizing the panel ARDL and MMQR models. The panel autoregressive distributed lag (ARDL) model estimates average short- and long-run effects, whereas the method of moments quantile regression (MMQR), a panel quantile technique, estimates how these effects vary across the distribution of emissions. The MMQR results shed light on the impacts of variables on CO₂ emissions estimated at different emission levels. The results show that oil, coal consumption, and GDP are significant factors influencing CO₂ emissions. Conversely, renewable energy sources contribute significantly to reductions in CO₂ emissions. Also, the results reveal that trade activities have a significant impact on emissions in countries exhibiting high emission levels. In particular, the effects of GDP and renewable energy become stronger at higher quantiles, whereas those of oil and coal remain relatively stable. Furthermore, the panel causality tests reveal bidirectional causality between CO₂ emissions and oil consumption and economic growth. The results also support unidirectional causality from coal consumption to emissions, and causality from emissions to renewable energy. The results indicate the need for comprehensive efforts across various policy areas to reduce emissions and address climate change. Reducing coal and oil dependence should be a priority for all ASEAN-5 countries, while faster renewable deployment matters most for high emitters.

Keywords

CO₂, coal consumption, oil consumption, MMQR,
ASEAN-5

JEL Classification

C23, O53, Q43, Q53, Q54

INTRODUCTION

Climate change is one of the major issues confronting our planet today. Scientific consensus is that anthropogenic greenhouse gas (GHG) emissions, primarily CO₂ emissions, are a significant driver of global temperature increase and climate change. Since the energy industry accounts for a considerable amount of CO₂ emissions, it is imperative to seek ways to cut down emissions from this industry to mitigate the effects of climate change.

Coal is also a widely utilized fossil fuel, and its associated CO₂ emissions grew by 15% from 2020 to 2021 (EPA, 2023). Coal use is known to intensify environmental destruction (Bloch et al., 2012; Govindaraju & Tang, 2013; Tiwari et al., 2013; Shahbaz et al., 2017a; Ansari et al., 2022). Oil consumption, which is the second-largest source of fossil fuel reserves in the world (Our World in Data, 2023), is also a major contributor to CO₂ emissions (Alkhathlan & Javid, 2013; Ansari et al., 2022).

In Southeast Asia, 90% of the growth in energy demand comes from fossil fuels, with demand for coal, oil, and natural gas increasing dramatically since 2000 (IEA, 2022). In 2020, the ASEAN region's energy mix was 83% fossil fuels, such as oil, coal, and natural gas, and 14.2% renewable energy (ACE, 2022). Indonesia and Singapore are ASEAN's largest oil consumers, and Indonesia is also the region's largest coal consumer (BP, 2022). Fossil fuels are projected to meet three-quarters of the region's increased energy demand by 2030, resulting in an approximately 35% increase in CO₂ emissions (IEA, 2022).

ASEAN countries' energy policies differ in terms of meeting increasing demands for energy, developing new energy sources, and achieving low CO₂ emission targets. Among the ASEAN-5 countries, Indonesia is the largest energy consumer and thus CO₂ emitter, followed by Thailand, Malaysia, Singapore, and the Philippines (Delina, 2021; BP, 2022). The drivers of increased CO₂ emissions also vary from the manufacturing expansion underlying economic development in Thailand and Malaysia to growth in the service sector in the Philippines (IEA, 2022).

Regarding energy exports and production, Indonesia contributed the majority (89%) of ASEAN's total coal exports and, together with Malaysia, was also an important exporter of natural gas, while Thailand and Singapore were importers of natural gas. These indicators suggest that the current global energy crisis has had little impact on ASEAN economies (ACE, 2023). While hydropower is a major energy contributor, other renewable energy sources, such as solar, wind, and biomass, only constitute a very small proportion of energy production (Delina, 2021).

Against this backdrop, this study focuses on ASEAN-5 (Indonesia, Malaysia, the Philippines, Thailand, and Singapore), which consists of fast-growing countries in Southeast Asia, to analyze the effect of various forms of fossil fuel consumption on CO₂ emissions. The energy demand of these countries is projected to increase in the coming decades, thereby generating even greater greenhouse gas emissions. To this end, the study combines the panel autoregressive distributed lag (ARDL) model, which estimates the average short- and long-run effects, with the method of moments quantile regression (MMQR) of Machado and Santos Silva (2019). MMQR is a panel quantile regression technique that estimates the effects of the explanatory variables at different quantiles of the conditional distribution of CO₂ emissions, that is, separately for low-, medium- and high-emission country-year observations, while controlling for unobserved country fixed effects.

1. LITERATURE REVIEW

There has been growing attention to the energy consumption – economic growth nexus since the pioneering work of Kraft and Kraft (1978). This assertion of a unidirectional causal relation running from economic growth to energy consumption, rather than the reverse, has since been challenged: Akarca and Long (1980) and Yu and Hwang (1984) find no causal relationship between energy and economic growth. Indeed, the debate over this relationship remains unresolved, with studies fre-

quently reaching contradictory conclusions. The selected studies on ASEAN countries in Table 1 also conform to the mixed results from the wider literature. Most of these studies tend to utilize either oil or coal consumption as a proxy for energy consumption and have resulted in four competing hypotheses, namely those of growth, conservation, feedback, and neutrality.

The growth hypothesis is based on the premise that consumption of energy is essential for realizing economic growth (Dunkerley, 1982; Payne,

2010) and that economic growth is a result of energy consumption growth. Such studies have focused on a single causal direction from EC to EG, including Appiah (2018) for Ghana, Pinzón (2018) for Ecuador, and Pandey and Rastogi (2019) for India. Conversely, the conservation hypothesis posits that energy consumption-reducing policies will not result in a decline in economic growth, and thus the causal relationship can be from economic growth toward energy consumption (Al-Mulali et al., 2013). Examples include Zhang and Cheng (2009) for China, Yildirim et al. (2014) for three ASEAN countries, Akadiri et al. (2019) for Iraq, Gorus and Aydin (2019) for MENA countries, and Tong et al. (2020) for the E7 countries.

The feedback hypothesis postulates that GDP growth and energy consumption share a long-term relationship (Apergis & Payne, 2010), and it is considered bidirectional in nature. This has been empirically found to be true by Shahbaz et al. (2012) for Pakistan, Tiwari (2014) for the USA, Bui (2020) for Vietnam, and Rahman (2021) for BRICS and ASEAN nations. Lastly, the neutrality hypothesis posits a minimal effect of energy use on economic development, as energy consumption constitutes only a small fraction of a nation's gross domestic product (GDP) (Squalli, 2007). That is, there is no Granger causality in either direction between EC and GDP. This is in line with several other studies, such as Śmiech and Papież (2014) covering the EU countries, Fazal et al. (2021) for Pakistan, and Otim et al. (2022) for Uganda.

These four hypotheses can be used in the same manner for investigating the relationship between renewable energy consumption and economic growth. In recent years, growing interest in this relationship has stimulated many studies. Most conclude that an increase in renewable energy consumption is linked to economic growth (Ito, 2017; Iqbal et al., 2023), although they differ in attributing the direction of causality. Khobai and Leroux (2017), for instance, suggest that there is unidirectional causality from renewable energy consumption to economic growth in the short run, which supports the growth hypothesis, but that the direction reverses in the long run, which supports the conservation hypothesis. Saidi and Mbarek (2016), Mukhtarov (2022), and Steve et al. (2022) also conclude that there is a unidirectional caus-

al relationship from renewable energy consumption to economic growth. However, other studies provide contradictory findings. Some suggest a feedback impact (Shahbaz et al., 2012; Sebri & Ben-Salha, 2014; Chang et al., 2015; Ghazouani et al., 2020; Saidi & Omri, 2020; Acheampong et al., 2021) whereas others find no causal relationship (Yildirim et al., 2012; Ummalla & Samal, 2019; Mounir & El-Houjjaji, 2022). Finally, some studies support the neutrality hypothesis by concluding that there is no significant relationship between renewable energy use and economic growth, whereas economic growth does not increase renewable energy consumption (Marques & Fuinhas, 2012; Mbarek et al., 2015). Together, these findings imply that the renewable energy-growth relationship is very context-dependent: its causality direction and significance depend on the level of renewable energy development and the time horizon, and not a-b directionality in causality.

The use of fossil fuels, such as oil and coal, has been generally found to increase CO₂ emissions (Bloch et al., 2012; Ansari et al., 2020; Joshua & Bekun, 2020; Balli et al., 2021), and higher consumption of renewable energy has a mitigating impact on CO₂ emissions (Shafiei & Salim, 2014; Zoundi, 2017; Allard et al., 2018; Bilan et al., 2019; Jebli et al., 2020; Ponce & Khan, 2021; Muhammad et al., 2022; Rahman et al., 2022; Amin & Song, 2023). Conversely, other literature finds that renewable energy consumption does not have any meaningful effect on reducing CO₂ emissions (Menyah & Wolde-Rufael, 2010; Yazdi & Shakouri, 2018; Acheampong et al., 2021); that is to say, no causal relationship exists between renewable energy use and CO₂ emissions. Overall, while the bulk of the evidence indicates that renewable energy substitutes for fossil fuel use and lowers emissions, this effect is not universal, which points to the share and maturity of a country's renewable energy sector as a likely moderating factor.

The association between economic activity and environmental degradation is also still unclear, and there is no consensus regarding the effect of increasing economic activity on environmental degradation. The impact of economic growth on CO₂ emissions led to Grossman and Krueger's (1991) well-known proposal of the Environmental Kuznets Curve (EKC), which predicts an inverted

U-shaped association between economic growth and CO₂ emissions. That is, CO₂ emissions increase with economic growth until a threshold, before starting to decrease. However, there is still no consensus regarding the curve's precise shape. While some studies have validated the inverted-U-

shaped curve (Ahmed & Long, 2013; Pata, 2018; Bekun et al., 2021; Gyamfi et al., 2021), others have reported an N-shaped curve (Poudel et al., 2009; Allard et al., 2018; Tirgil et al., 2021; Awan & Azam, 2022). That is, having fallen previously, environmental degradation starts to increase

Table 1. Selected literature on ASEAN countries

Authors	Methodology	Period	Variables	Findings
Lean and Smyth (2010)	Panel VECM, Granger causality	1980–2006	GDP, GDP ² , CO ₂ , ELE	The association between ELE and CO ₂ is statistically significant in the long run, with unidirectional causality running from CO ₂ to ELE in the short run.
Chandran and Tang (2013)	Multivariate cointegration tests, Granger causality	1971–2008	GDP, CO ₂ , TRENE, FDI	The variables are cointegrated only in Indonesia, Malaysia, and Thailand; there is no support for the EKC hypothesis.
Saboori and Sulaiman (2013)	ARDL, Granger causality	1971–2009	GDP, CO ₂ , ENE	The variables are cointegrated. Bidirectional causality between ENE and CO ₂ in all countries is found.
Heidari et al. (2015)	Panel Smooth Transition Regression	1980–2008	GDP, CO ₂ , ENE	Environmental pollution rises with economic growth in the first regime, while the opposite is true for the second regime. ENE increases CO ₂ in both regimes.
Zhu et al. (2016)	Panel Quantile Regression	1981–2011	GDP, CO ₂ , ENE, FDI, POP, TRA, FIN, IND	Variables affect CO ₂ emissions across quantiles; ENE increases CO ₂ most at higher quantiles; higher GDP reduces CO ₂ in high-emission countries.
Liu et al. (2017)*	Pedroni and Kao cointegration tests, Granger causality	1970–2013	CO ₂ , AGR, RENE	Increasing renewable energy decreases CO ₂ emissions, while non-renewable energy increases CO ₂ emissions.
Vo et al. (2019)**	Johansen, ARDL cointegration tests, FMOLS, DOLS, Granger causality	1971–2014	GDP, GDP ² , CO ₂ , ENE, RENE, POP	Variables show cointegrating relationships between selected countries, except Thailand and the Philippines, while Granger causality results differ among ASEAN countries.
Chontanawat (2020)***	Johansen cointegration test, Granger causality	1971–2015	GDP, ENE, CO ₂	Cointegration is found. There is a bidirectional causality between ENE and CO ₂ .
Guzel and Okumus (2020)	Durbin-Hausman cointegration test, CCEMG, AMG	1981–2014	GDP, GDP ² , ENE, CO ₂ , FDI	Increased FDI leads to increased CO ₂ emissions in the ASEAN-5 countries. EKC is also valid, while ENE damages the environment.
Ling et al. (2020)	Pedroni cointegration test, Granger causality	1995–2014	GDP, CO ₂ , ENE, TRA, FDI	There is short-run bidirectional causality between energy consumption, economic growth, and CO ₂ emissions.
Munir et al. (2020)	Westerlund cointegration test	1980–2016	GDP, CO ₂ , ENE	There is strong evidence of cointegration between the pairs of GDP-EC and EC-CO ₂ in all ASEAN-5 countries
Ahmad et al. (2022)	Westerlund cointegration test, PMG-ARDL	2000–2019	GDP, CO ₂ , FIN, URB, ENE	All variables positively and significantly cause environmental degradation in the long run.
Feriansyah et al. (2022)	Pedroni cointegration, Panel ARDL	1994–2018	GDP, CO ₂	GDP has a significant long-term effect on CO ₂ emissions.
Hanif et al. (2022)	CS-ARDL	1995–2020	RENE, ENE, GDP, CO ₂ , GLO	In ASEAN countries, the utilization of non-renewable energy sources exacerbates environmental degradation, whereas the adoption of renewable energy sources enhances environmental quality.
Pata et al. (2023)	ARDL, Dumitrescu-Hurlin causality test	1995–2018	GDP, TRA, RENE, CO ₂	Income and trade openness reduce pollution. Renewable energy reduces CO ₂ emissions only in the short term and has no significant impact on the environment in the long run.

Note: * This study includes all ASEAN-5 countries except Singapore. ** The study covers the ASEAN-5 countries except Singapore while including Myanmar. *** This study includes ASEAN-5 countries and Brunei, Myanmar, and Vietnam. The abbreviations below refer to the variables used in the studies summarized in this table; they do not all correspond to the variables used in the present study. ELE: electricity consumption, ENE: energy consumption, GDP: economic growth, GDP2: square of economic growth, CO2: carbon emissions, TRA: trade openness, RENE: renewable energy consumption, GLO: globalization, TRENE: transport energy consumption, POP: population, FIN: financial development, IND: industrial structure, GCF: gross capital formation.

again after the country reaches a certain income level. In short, the growth-emissions relationship is non-linear in most settings, but its exact shape, and hence the income level at which emissions begin to fall, varies with the sample and time period studied.

Another frequently used variable in recent studies of environmental quality is trade, particularly regarding whether trade is good for the environment (Copeland & Taylor, 1994). Shapiro (2016) argues that the benefits of international trade outweigh its environmental costs. Shahbaz et al. (2013) and Sebri and Ben-Salha (2014) also suggest that trade openness may help increase environmental quality by promoting renewable consumption. However, other studies suggest that trade damages environmental quality by increasing CO₂ emissions (Shahbaz et al., 2017b; Ansari et al., 2020; Dou et al., 2021; Usman et al., 2023). For example, Mahmood et al. (2019) found that increasing trade openness in Tunisia was associated with higher CO₂ emissions. Finally, several studies have investigated the causal relationships between trade openness, economic growth, and CO₂ emissions (Jamel & Maktouf, 2017; Hdom & Fuinhas, 2020; Wasti & Zaidi, 2020; Omri & Saadaoui, 2023). However, they find differing directions of causality depending on the period of study or country sample. Taken together, the trade-environment literature suggests that trade openness can either help or harm environmental quality depending on a country's export composition, technology level, and stage of development, rather than having a uniformly positive or negative effect.

Several studies have investigated the factors affecting environmental quality in ASEAN countries, such as economic growth, non-renewable and renewable energy consumption, trade, globalization, and financial development. Most conclude that many of these variables are cointegrated in the long run and have causal relationships with each other. For example, economic growth appears to be a major contributor to CO₂ emissions in ASEAN-5 countries (Chandran & Tang, 2013), while their non-renewable energy consumption damages the environment (Heidari et al., 2015; Zhu et al., 2016; Hanif et al., 2022). Conversely, renewable energy consumption improves environmental quality (Liu et al., 2017;

Ahmad et al., 2022). Whereas some studies conclude that trade openness increases CO₂ emissions in ASEAN-5 countries (Ling et al., 2020), others find that it reduces environmental degradation (Pata et al., 2023).

These studies have used various methodologies, such as second-generation cointegration tests and a range of causality tests (see Table 1). None, however, has used MMQR to analyze the relevant nexus for ASEAN countries. A few studies have used MMQR to investigate the relationship between energy consumption, economic growth, and CO₂ emissions. For instance, Miao et al. (2022) used MMQR to investigate the impacts of renewable energy sources on environmental quality in newly industrialized countries between 1990 and 2018. They concluded that for all quantiles (0.1–0.9), renewable energy consumption contributes to environmental quality, while economic growth increases the ecological footprint. Khalfaoui et al. (2023) used MMQR to investigate the environment-growth nexus in 17 MENA countries for the period 1984–2018. They found an inverted U-shaped relationship between income level and CO₂ emissions, but no statistically significant relationship between income level and ecological footprint for MENA countries as a group.

1.1. Research gap, aims and hypotheses

The above literature indicates a positive impact of economic growth, non-renewable energy consumption and trade openness, but negative effects of renewable energy consumption on CO₂ emissions, however, the magnitude and the sign of these effects depend on the countries, the time periods and the applied estimation methods (refer to Table 1). Most of these studies rely on cointegration and Granger-causality techniques that capture average effects, and none has used MMQR to examine how oil consumption, coal consumption, renewable energy consumption, GDP, and trade openness jointly affect CO₂ emissions across the full distribution of emission levels in the ASEAN-5 countries. This represents an important gap, given that the policy response required to curb emissions in a low-emission country may differ substantially from that required in a high-emission country.

Building on this gap, the study pursues three specific aims: (i) to estimate the average short- and long-run effects of oil consumption, coal consumption, renewable energy consumption, economic growth (GDP) and trade openness on CO₂ emissions in the ASEAN-5 countries over the period 1971–2020 using the panel ARDL model; (ii) to examine whether, and how, these effects differ across low-, medium- and high-emission levels using MMQR; and (iii) to identify the direction of causality between CO₂ emissions and each of its determinants using the Dumitrescu–Hurlin panel causality test, so that emission-level-specific policy recommendations can be derived.

Drawing on the theoretical framework reviewed in Section 1, the following hypotheses are tested:

- H1: *Economic growth has a positive effect on CO₂ emissions. According to the scale effect underlying the Environmental Kuznets Curve (Grossman & Krueger, 1991), rising output increases energy use and pollution in economies that have not yet reached the income turning point, which is the case for most ASEAN-5 countries (Chandran & Tang, 2013; Heidari et al., 2015).*
- H2: *Oil consumption and coal consumption have positive effects on CO₂ emissions. Because the combustion of fossil fuels releases carbon, and coal in particular has a high carbon content per unit of energy, greater use of either fuel is expected to raise emissions (Bloch et al., 2012; Alkhathlan & Javid, 2013; Ansari et al., 2022).*
- H3: *Renewable energy consumption has a negative effect on CO₂ emissions. Renewable sources substitute for fossil fuels in electricity generation and thereby reduce the carbon intensity of the energy mix (Shafiei & Salim, 2014; Hanif et al., 2022).*
- H4: *The effect of trade openness on CO₂ emissions depends on the emission level. Trade theory identifies two competing channels: a scale and pollution-haven channel that raises emissions (Copeland & Taylor, 1994; Shahbaz et al., 2017b) and a technique channel, operating through access to cleaner tech-*

nologies, that lowers them (Shahbaz et al., 2013; Shapiro, 2016). The net effect is therefore expected to be negative in low-emission and positive in high-emission settings.

- H5: *The effects of the explanatory variables differ across the conditional distribution of CO₂ emissions. Because the ASEAN-5 countries differ in their energy mix, industrial structure and stage of development (IEA, 2022), the marginal effects of growth, fossil fuels, renewables and trade are expected to vary between low- and high-emission country-year observations (Zhu et al., 2016).*

- H6: *There is feedback (bidirectional) causality between CO₂ emissions and its main determinants, in line with the feedback hypothesis of the energy–growth literature (Apergis & Payne, 2010).*

2. METHODOLOGY

2.1. Data

To test the hypotheses formulated in Section 1.1, CO₂ emissions are modelled as a function of economic growth, oil consumption, coal consumption, renewable energy consumption and trade openness. The linear version of the fixed-effects model is defined as:

$$lCO_{2it} = \alpha_0 + \alpha_1 lGDP_{it} + \alpha_2 loil_{it} + \alpha_3 lcoal_{it} + \alpha_4 shrenr_{it} + \alpha_5 trade_{it} + \varepsilon_{it}, \quad (1)$$

where the dependent variable lCO_{2it} represents the natural logarithm of CO₂ emissions, while the independent variables are the natural logarithm of GDP ($lGDP_{it}$), the natural logarithm of total final oil consumption ($loil_{it}$), the natural logarithm of total final coal consumption ($lcoal_{it}$), the share of renewable sources in electricity generation ($shrenr_{it}$), and the share of trade in GDP ($trade_{it}$).

CO₂ emission data, measured in kilotons of CO₂, were sourced from the International Energy Agency (IEA). GDP data, measured in billion USD at 2015 prices and purchasing power parities (PPPs), were obtained from the Organization for Economic Co-operation and Development

Table 2. Descriptive statistics for the study variables

Statistic	ICO2 _{it}	IGDP _{it}	lcoal _{it}	loil _{it}	shrenr _{it}	trade _{it}
Mean	11.112	5.851	5.718	9.425	0.163	1.356
Median	11.061	5.876	6.475	9.413	0.140	0.861
Std. Dev.	1.015	1.006	2.601	0.968	0.131	1.129
Skewness	0.082	-1.614	-0.480	-0.286	0.754	1.158
Kurtosis	2.213	7.606	2.121	5.903	2.782	2.964
Jarque-Bera	6.725	323.012	17.663	89.354	24.207	55.928
Probability of Jarque-Bera	(0.035)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)

(OECD). Total oil consumption and total final coal consumption data, both measured in ktoe, were sourced from the IEA. To examine the effects of renewable energy consumption on environmental degradation in the ASEAN-5 countries, the percentage share of renewable sources in electricity generation, obtained from the IEA, was used as the proxy variable. Lastly, the share of trade in GDP data, measured as a percentage, was sourced from DataStream (Refinitiv Eikon Datastream, 2023).

Before proceeding, the descriptive properties of the variables are reported in Table 2. The results indicate that they are not normally distributed. In particular, the Jarque-Bera statistics of all variables reject the null hypothesis of normality for all variables at the 5% level of significance. Because of the non-normality of the data, it can be said that MMQR can provide a more suitable analytical perspective on the data than the linear estimation methods, since MMQR enables one to estimate conditional quantiles of a dependent variable, given a set of independent variables.

2.2. MMQR

The choice of the MMQR estimator is motivated by the aims of the study and by the properties of the data. First, mean-based panel estimators such as the panel ARDL or fixed-effects OLS yield only the average effect of each regressor, which may mask substantial differences between low- and high-emitting country-year observations; MMQR, by contrast, estimates the effects at selected quantiles of the conditional distribution of CO₂ emissions and therefore allows H5 to be tested directly. Second, the variables and the model residuals are

not normally distributed (Table 2 and Figure A1), and quantile-based estimates are more robust to non-normality, heavy tails and outliers than estimates of the conditional mean. Third, unlike conventional panel quantile regression, in which individual effects act only as a location shift, MMQR allows the unobserved country fixed effects to affect the entire conditional distribution of emissions, which is important for a heterogeneous panel of countries with a long time dimension such as ASEAN-5 over 1971–2020 (Machado & Santos Silva, 2019). Fourth, MMQR is computationally simple and helps to avoid crossing quantile estimates, and it has become a standard tool in recent energy–environment studies (Miao et al., 2022; Khalfaoui et al., 2023). The panel ARDL estimates are retained as a mean-based benchmark against which the distributional MMQR results can be compared.

Given the non-normal distribution of the data (Table 2), we estimate Equation (1) using the MMQR estimator of Machado and Santos Silva (2019), which accommodates panel fixed effects and yields consistent parameter estimates across the full conditional distribution of CO₂ emissions.¹ The model is specified as (Machado & Santos Silva, 2019, p. 148):

$$ICO2_{it} = \alpha_i + X'_{it}\beta + (\delta_i + Z'_{it}\gamma)U_{it}, \quad (2)$$

Here $X'_{it} = [IGDP_{it} \text{ } loil_{it} \text{ } lcoal_{it} \text{ } shrenr_{it} \text{ } trade_{it}]'$, and β is the associated coefficient vector. α_i is the country fixed effect; δ_i is the quantile-specific scale fixed effect for country i ; Z_{it} contains known differentiable transformations of X_{it} satisfying $P\{\delta_i + Z'_{it}\gamma > 0\} = 1$. U_{it} is an unobserved inno-

¹ To further investigate the normality of the residuals of the panel data equation, the Jarque-Bera normality test was performed using the panel fixed-effect equation (1). The Jarque statistic of 81.838 strongly rejects the null hypothesis that the residuals are normally distributed. In addition, we present a Q-Q plot of the cross-sectional residuals versus the normal quantile presented in Figure A1. As can be seen, the plot departs significantly from the line corresponding to the normal distribution; hence, it can be concluded that the residuals are not normally distributed.

vation, independent of X_{it} , normalized so that: $E(U_{it}) = 0$, $E(|U_{it}|) = 1$.

Under exogeneity of X_{it} , the parameters $\alpha_i, \beta', \delta_i, \gamma'$ and $q(\tau)'$ are estimated via first moment conditions. The resulting conditional quantile function is:

$$Q_Y(\tau|X_{it}) = (\alpha_i + \delta_i q(\tau)) + X_{it}'\beta + Z_{it}'\gamma q(\tau). \quad (3)$$

The term $(\alpha_i + \delta_i q(\tau))$ is the quantile- τ fixed effect for unit i .

Estimation proceeds via Hansen's (1982) one-step GMM in five steps:

- Step 1: Estimate $\hat{\beta}$ by regressing demeaned $(Y_{it} - \bar{Y}_t / T)$ on the demeaned covariates $(X_{it} - \bar{X}_t / T)$.
- Step 2: Recover α_i as $\hat{\alpha}_i = \frac{1}{T} \sum_t (Y_{it} - X_{it}'\hat{\beta})$, and the residuals $\hat{R}_{it}$ are retrieved, $\hat{R}_{it} = Y_{it} - \hat{\alpha}_i - X_{it}'\hat{\beta}$.
- Step 3: Estimate γ by regressing demeaned $\hat{R}_{it}$, $(|\hat{R}_{it}| - \bar{|\hat{R}_{it}|} / T)$ on the demeaned Z_{it} covariates, $(Z_{it} - \bar{Z}_t / T)$ on demeaned Z_{it} to obtain $\hat{\gamma}$.
- Step 4: Recover $\hat{\delta}_i$ from the residuals and $\hat{\gamma}$.

$$\hat{\delta}_i = \frac{1}{T} \sum_t (|\hat{R}_{it}| - Z_{it}'\hat{\gamma}). \quad (4)$$
- Step 5: Estimate $q(\tau)$ by minimizing the check-function objective:

$$\min_q \sum_i \sum_t \rho_\tau(\hat{R}_{it} - (\hat{\delta}_i + Z_{it}'\hat{\gamma})q), \quad (5)$$

where $\rho_\tau(A) = (\tau - 1)AI(A \leq 0) + \tau AI\{A > 0\}$ is the check-function.

3. RESULTS

The empirical results presented in this section make three distinct contributions to the existing literature. First, it is the first to apply the Methods

of Moments Quantile Regression (MMQR) estimator of Machado and Santos Silva (2019) to the energy-emissions nexus in the ASEAN-5, enabling examination of how oil consumption, coal consumption, renewable energy, GDP, and trade openness jointly shape CO₂ emissions not merely at the conditional mean but across the entire emission distribution from low-emitting to high-emitting country-year observations. Such a distributional approach is not available in any of the previous ASEAN-based studies, which only use mean-based estimators such as panel ARDL or fixed-effects OLS, and it produces policy-desirable heterogeneity that averaged results are bound to mask. Second, instead of using aggregate energy consumption, the paper decomposes fossil fuel use into oil and coal to measure the separate impact of each type of fuel on emissions at each quantile, which allows more precise policy recommendations with regard to fuel-specific phase-out or substitution. Third, the paper covers a long-running and stable time series (1971–2020) to investigate short-run, long-run, and distributional effects within a single empirical framework, which has hitherto not been attempted for this regional area.

3.1. Panel time series findings

A panel time series model is estimated to determine the impact of GDP, oil consumption, coal consumption, renewable energy consumption, and trade on CO₂ emissions. First, the CD test developed by Pesaran (2004) is applied to the residuals of the estimated panel data model in Equation (1) to ensure the presence of cross-sectional dependence. The cross-sectional dependence tests conducted on the dataset are presented in Table 3. The CDLM test shows strong evidence of cross-sectional dependence, indicating that the observations are intercorrelated. However, neither the LM test nor the LM_{adj} test provides significant evidence of cross-sectional dependence, as the p-values for these two tests are greater than five percent. Hence, we conclude that the model does not exhibit significant cross-sectional dependence.

Table 3. Cross-sectional dependence test results

Test	Cross- sectional dependence
LM	17.4 (0.065)
CD _{LM}	5.135 (0.001)
LM _{adj}	-0.435 (0.663)

Note: Test probabilities are presented in parentheses.

Given this result, we implement the panel time series models allowing for cross-sectional independence by conducting panel IPS (Im et al., 2003) and LLC (Levin et al., 2002) unit root tests. The results are shown in Table 4. Based on the intercept and trend specifications, the two tests yield very similar results. Regarding CO_2 , both tests imply stationarity of the variable at the level. The results of $IGDP_{it}$ are ambiguous for both unit root tests, as the intercept specification indicates weak stationarity at the level, while the results show that $IGDP_{it}$ is stationary at the 1% significance level when the trend and intercept specifications are considered. Similarly, coal consumption is non-stationary, as evidenced by the test statistics, which are not significant when the intercept specification is considered. The unit root tests of renewable energy ($shrenr_{it}$) and trade ($trade_{it}$) provide mixed evidence, with significant values for both the intercept and trend and intercept models, suggesting that these variables can be treated as non-stationary, i.e., they are integrated of order one.

Given this mixed evidence regarding the integration level of the variables, panel cointegration tests allowing for cross-sectional dependence, such as Kao (1999) and Pedroni (2004), are no longer applicable. Therefore, we estimate a Panel ARDL model based on the vector error correc-

tion form of Equation (1) because this specification is appropriate irrespective of whether the variables are integrated of order zero, $I(0)$, or order one, $I(1)$, provided that none of the series is $I(2)$. Table 5 presents the long-run and short-run coefficients of the CO_2 equation of the Panel ARDL model. It is first worth noting that the sign of the error correction term is negative and statistically significant. This indicates the presence of a cointegration relationship between CO_2 and its determinants and suggests that the variables in the panel adjust towards their long-run equilibria following any deviation. In other words, any short-run shocks that cause the variables to diverge from their long-run relationship will be corrected over time.

The parameter estimates suggest that GDP, oil consumption, coal consumption and trade raise CO_2 emissions, whereas renewable energy consumption lowers them, although not all coefficients are significant in the short run (see Table 5). The short-run results show that all the estimated coefficients, except for renewable energy consumption and trade openness, are positive and statistically significant at different levels. The coefficient of renewable energy consumption is negative as expected, but statistically insignificant. The long-run results reveal that all the variables except for renewable energy consumption have positive and

Table 4. LLC and IPS panel unit root tests

Variable	Levin, Lin, and Chu			
	Intercept		Trend and Intercept	
	Level	First Difference	Level	First Difference
$ICO2_{it}$	-3.3096***	—	-2.89163***	—
$IGDP_{it}$	-1.83765*	-14.5233***	-2.99398***	—
$Icoal_{it}$	-0.93018	-23.3677***	-3.84965***	—
$loil_{it}$	-3.22628***	—	-3.21759***	—
$shrenr_{it}$	-2.10354**	-15.6590***	-0.56327	-12.3142***
$trade_{it}$	-3.56632***	—	-1.05944	-16.3989***
Variable	Im, Pesaran, and Shin			
	Intercept		Trend and Intercept	
	Level	First Difference	Level	First Difference
$ICO2_{it}$	-1.52170*	-12.3054***	-2.58954***	—
$IGDP_{it}$	-1.31584*	-11.8251***	-3.37331***	—
$Icoal_{it}$	-1.64558*	-18.7980***	-6.58419***	—
$loil_{it}$	-1.50153*	-11.2128***	-3.06573***	—
$shrenr_{it}$	-1.91835**	-14.4698***	-1.30081*	-11.5704***
$trade_{it}$	-3.52661***	—	-0.31783	-15.4193***

Note: The models were specified with individual effects. ***, **, and * indicate rejection of the null hypothesis at 1%, 5%, and 10% levels, respectively.

significant impacts on emissions.

More specifically, a one-percent increase in renewable energy consumption ($shrenr_{it}$) decreases environmental pollution by 0.33%. This finding is in line with Usman et al. (2020) for the US, Chien et al. (2021) for Pakistan, and Mehmood (2022) for selected South Asian countries. Conversely, one-percent increases in coal ($lcoal_{it}$) and oil ($loil_{it}$) consumption increase environmental pollution by 0.03% and 0.60%, respectively. This finding is in line with Alola and Donve (2021) for Turkey, Kanat et al. (2022) for Russia, and Wang et al. (2023) for 24 countries using nuclear power. Finally, a one-percent increase in trade openness ($trade_{it}$) increases CO₂ emissions by 0.21%, which is consistent with Udeagha and Ngepah (2022) for South Africa and Ibrahim and Ajide (2021) for G-7 countries.

Table 5. Long-run and short-run parameters

Variables	Long-run		
	Coefficient	Std. Error	P-Value
$IGDP_{it}$	0.505	(0.050)	0.001
$lcoal_{it}$	0.036	(0.013)	0.007
$loil_{it}$	0.604	(0.068)	0.001
$shrenr_{it}$	-0.338	(0.118)	0.004
$trade_{it}$	0.210	(0.066)	0.001
Variables	Short-run		
$IGDP_{it}$	0.314	(0.138)	0.023
$lcoal_{it}$	0.016	(0.005)	0.003
$loil_{it}$	0.288	(0.099)	0.004
$shrenr_{it}$	-0.111	(0.160)	0.486
$trade_{it}$	0.057	(0.055)	0.301
ecm_{it}	-0.220	(0.127)	0.084
Constant	0.503	(0.280)	0.074

Note: Standard errors of the coefficients are in parentheses.

3.2. MMQR findings

Given the non-normality of the variables used in this research, care must be taken in interpreting the CO₂ equation's parameters. Here, MMQR has significant advantages over methodologies based on OLS estimation, such as Panel ARDL, because it permits parameter estimates based on the conditional quantiles of the dependent variable, considering different points in the distribution, and

yields more robust results by dealing with non-normal or heavy-tailed distributions.²

Table 6 displays the results of the MMQR analysis for the CO₂ emissions equation across five quantiles, specifically 0.1, 0.25, 0.5, 0.75, and 0.9. These quantiles allow for an exploration of the impacts of diverse factors on CO₂ emissions while considering disparities in emission levels. Similar to the results for the long- and short-run estimates, the parameter estimates reveal that GDP, oil and coal consumption, and renewable energy consumption are statistically significant predictors of CO₂ emissions.

$IGDP_{it}$ has a positive impact on CO₂ emissions at all quantiles, which is statistically significant from the 0.25 quantile upwards. This key finding indicates that economic growth is associated with higher pollution. More specifically, the size of the coefficient becomes larger as the quantile increases, which implies that economic growth affects emissions more severely for countries with higher levels of CO₂ emissions. At the 0.1 quantile, the coefficient (0.137) is positive but statistically insignificant, suggesting that growth is not a significant driver of emissions in the lowest-emitting country-year observations.

Oil consumption ($loil_{it}$), a proxy for fossil fuel dependence, displays a strong positive association with CO₂ emissions at all quantiles. Notably, the size of the coefficient is fairly constant for different emission levels. Additionally, the oil consumption coefficient is significant at all quantiles, indicating a consistent effect on CO₂ emissions.

Coal consumption, an additional proxy for fossil fuel consumption, follows the same trend and is positively associated with CO₂ emissions across all quantiles, suggesting that coal consumption is a source of emissions at all levels of emissions. The coefficient for coal consumption is statistically significant for all quantiles, also reinforcing the robust positive relationship between coal consumption and higher levels of CO₂ emissions.

² See footnote 1.

Table 6. MMQR results

Variable	Location	Scale	Quantiles				
			0.1	0.25	0.5	0.75	0.9
$IGDP_{it}$	0.325*** (0.06)	0.087** (0.039)	0.137 (0.109)	0.238*** (0.075)	0.316*** (0.06)	0.390** (0.063)	0.465*** (0.082)
Z-statistics	5.417	2.231	1.257	3.173	5.267	6.19	5.671
$lcoal_{it}$	0.085*** (0.016)	-0.008 (0.01)	0.102*** (0.028)	0.093*** (0.019)	0.086*** (0.016)	0.079*** (0.017)	0.073*** (0.022)
Z-statistics	5.313	-0.8	3.643	4.895	5.375	4.647	3.318
$loil_{it}$	0.497*** (0.070)	-0.037 (0.046)	0.577*** (0.127)	0.534*** (0.087)	0.501*** (0.07)	0.470*** (0.075)	0.438*** (0.096)
Z-statistics	7.100	-0.804	4.543	6.138	7.157	6.267	4.563
$shrenr_{it}$	-0.993*** (0.150)	-0.112 (0.099)	-0.753*** (0.273)	-0.882*** (0.188)	-0.982*** (0.152)	-1.076*** (0.161)	-1.172*** (0.208)
Z-statistics	-6.62	-1.131	-2.758	-4.691	-6.461	-6.683	-5.635
$trade_{it}$	-0.001 (0.027)	0.059*** (0.018)	-0.128** (0.05)	-0.06* (0.035)	-0.007 (0.028)	0.043 (0.029)	0.094** (0.038)
Z-statistics	-0.037	3.278	-2.56	-1.714	-0.25	1.483	2.474
Constant	4.199*** (0.414)	-0.046 (0.274)	4.297*** (0.752)	4.245*** (0.518)	4.204*** (0.418)	4.166*** (0.442)	4.126*** (0.572)
Z-statistics	10.143	-0.168	5.714	8.195	10.057	9.425	7.213

Note: *, **, and *** denote statistical significance at 10%, 5%, and 1% levels, respectively. Standard errors of the coefficients are in parentheses.

A particularly intriguing pattern emerges when the focus shifts to the impact of renewable energy consumption. That is, as the quantile value increases, the negative coefficient becomes stronger. This indicates that renewable energy sources ($shrenr_{it}$) have a greater impact on reducing CO₂ emissions as they account for a greater proportion of energy consumption, especially for countries whose initial emission levels are higher. This variable remains statistically significant across all quantiles, demonstrating its consistent contribution to lowering CO₂ emissions.

In contrast, the association between trade openness ($trade_{it}$) and CO₂ emissions is more complex. As quantile values increase, the size of the coefficient changes over quantiles from negative to positive. This indicates that the impact of trade openness on greenhouse gas emissions is a function of the initial level of emissions. Interestingly, the effect of the variable is found to be statistically significant at the 0.1 and 0.25 quantiles (negative; at the 5% and 10% levels, respectively) and at the 0.9 quantile (positive; at the 5% level), implying that its impact on emissions is not uniform across emission levels.

3.3. Panel causality analysis

Besides regression, the Dumitrescu and Hurlin (2012) panel causality test is also applied to test the causality between CO₂ emissions and its variables for the ASEAN-5 nations. The Dumitrescu-Hurlin test is considerably superior to the standard pairwise Granger causality tests by allowing for cross-sectional heterogeneity. Therefore, it is assumed that ASEAN-5 countries might have different causal relationships due to different economic structures, energy policies, and levels of development, enabling the findings to be more robust and realistic in this multi-country regional framework of the energy-environment-economy complex.

The results of Dumitrescu and Hurlin (2012) causality test are reported in Table 7 and suggest a significant bidirectional causality between CO₂ emissions, economic activity, and energy consumption in ASEAN-5 (namely, Malaysia, Indonesia, Singapore, Thailand, and the Philippines). The results reveal strong bidirectional causality between GDP and CO₂ emissions, and both causality directions are significant at the 1% level. The same pattern is observed for oil consumption and CO₂ emissions, where the Granger causality test shows that oil use Granger-causes CO₂ emissions and that CO₂ emissions also Granger-cause oil use, with feed-

back between fossil fuel dependency and the environment.

Table 7. Dumitrescu-Hurlin causality test results

Null Hypothesis	W-Stat.	Zbar-Stat.	Prob.
LGDP $\rightarrow$ LCO ₂	3.165	3.089	0.002
LCO ₂ $\rightarrow$ LGDP	3.453	3.510	0.001
LOIL $\rightarrow$ LCO ₂	4.932	5.667	0.001
LCO ₂ $\rightarrow$ LOIL	2.694	2.403	0.016
LCOAL $\rightarrow$ LCO ₂	3.519	3.615	0.001
LCO ₂ $\rightarrow$ LCOAL	2.166	1.637	0.102
SHRENr $\rightarrow$ LCO ₂	0.376	-0.978	0.328
LCO ₂ $\rightarrow$ SHRENr	2.407	1.990	0.047
TRADE $\rightarrow$ LCO ₂	1.858	1.184	0.237
LCO ₂ $\rightarrow$ TRADE	2.157	1.620	0.105

The causality patterns for coal consumption and renewable energy sources have important policy implications. Coal consumption demonstrates a unidirectional causal relationship with CO₂ emissions, where coal significantly causes emissions, but the reverse causality is statistically insignificant, indicating that coal consumption drives environmental degradation without feedback effects from emission levels. Conversely, renewable energy consumption shows no significant causal impact on CO₂ emissions, while CO₂ emissions significantly influence renewable energy adoption, suggesting that environmental pressures may drive renewable energy policy responses rather than renewable energy directly reducing emissions. Trade openness exhibits no significant causal relationships with CO₂ emissions in either direction, indicating that trade liberalization operates independently of environmental outcomes in these countries. These findings underscore the complexity of energy-environment-economy interactions and highlight the need for targeted policy interventions that account for the varying causal mechanisms across different energy sources.

4. DISCUSSION

Although renewable energy consumption carries a strong and consistently negative coefficient on CO₂ emissions in both the Panel ARDL and MMQR estimates, the Dumitrescu-Hurlin test does not detect a causal effect running from renewable energy to CO₂ emissions; instead, causality runs from CO₂ emissions to renewable energy (Table 7). These two results are not contradictory: the quan-

tile regression coefficient captures a statistical association between higher renewable energy shares and lower emissions across the panel, whereas the causality test asks whether past changes in renewable energy consumption help predict future emissions. Because renewable energy still accounts for only a modest share of the ASEAN-5 electricity mix (about 14.2% in 2020; ACE, 2022) and capacity additions are gradual, year-to-year changes in the renewable energy share may simply be too small, relative to the much larger fossil fuel base, to generate a detectable predictive effect on emissions within the sample period. The significant reverse causality from CO₂ emissions to renewable energy instead suggests that rising emissions, and the environmental and regulatory pressure they generate, prompt governments and utilities to expand renewable energy capacity, consistent with a reactive rather than a proactive policy stance in the region (Delina, 2021).

The sign of the trade openness coefficient also changes across the emission distribution, from significantly negative at the 0.1 and 0.25 quantiles to significantly positive at the 0.9 quantile, while remaining insignificant around the median (Table 6). This pattern is consistent with two competing mechanisms identified in the trade-environment literature. At lower emission levels, trade openness may operate mainly through a composition or technology-transfer channel, whereby greater integration into global markets gives access to cleaner technologies and processes, in line with Shapiro (2016) and Shahbaz et al. (2013). At higher emission levels, by contrast, trade appears to operate mainly through a scale channel, in which export-oriented growth in energy-intensive manufacturing raises emissions, consistent with the pollution-haven-type effects reported by Shahbaz et al. (2017b) and Mahmood et al. (2019) for other developing-country samples. The coefficient's insignificance at the median quantile suggests that, for the typical ASEAN-5 country-year observation, these two channels roughly offset one another.

These results both extend and qualify earlier MMQR-based findings for the region. Zhu et al. (2016) reported that non-renewable energy consumption increases CO₂ emissions most strongly at higher quantiles in ASEAN-5; our results

likewise show the GDP elasticity of emissions rising with the quantile (from 0.137 at the 0.1 quantile to 0.465 at the 0.9 quantile), but the coal and oil coefficients instead decline slightly from the lowest to the highest quantile (from 0.102 to 0.073, and from 0.577 to 0.438, respectively), suggesting that, in our longer and more recent sample, economic growth matters somewhat more at the margin than fossil-fuel intensity does in the highest-emitting country-years. Our finding of a robust, monotonically strengthening negative renewable energy effect across all quantiles also contrasts with Pata et al. (2023), who found that renewable energy reduces CO₂ emissions only in the short run for a broader sample of ASEAN countries and has no significant long-run effect; our results instead point to a stable and significant long-run mitigating role for renewable energy in the ASEAN-5. The negative association between non-renewable energy use and environmental quality, and the positive role of renewable energy, are nonetheless broadly consistent with Hanif et al. (2022) for ASEAN-6 countries.

These distributional results carry distinct pol-

icy implications for low- and high-emission ASEAN-5 countries. In the lower quantiles of the emission distribution, trade openness is associated with lower emissions, and the marginal mitigating effect of renewable energy, while still significant, is smaller in absolute terms; policy in these economies may therefore benefit from continuing to use trade and investment liberalization as a channel for cleaner technology transfer, alongside early-stage renewable energy incentives. In the higher quantiles, where GDP growth has the largest emissions elasticity, trade openness is positively associated with emissions and renewable energy delivers its largest absolute reduction in emissions; for these economies, decoupling growth from emissions is likely to require a faster pace of renewable energy deployment together with tighter environmental standards on trade-exposed, energy-intensive industries. Because coal and oil consumption raise emissions significantly across the entire distribution, reducing fossil fuel dependence remains a policy priority for all ASEAN-5 countries, irrespective of their position in the emission distribution.

CONCLUSION

This paper examined the effects of oil consumption, coal consumption, renewable energy consumption, economic growth and trade openness on CO₂ emissions in the ASEAN-5 countries over 1971–2020 by combining the panel ARDL model, MMQR and the Dumitrescu–Hurlin panel causality test.

Three main results emerge. First, the panel ARDL estimates confirm a stable long-run relationship between emissions and their determinants: in the long run, 1% increases in GDP, oil consumption and coal consumption raise CO₂ emissions by about 0.51%, 0.60% and 0.04%, respectively, whereas a higher share of renewables in electricity generation significantly lowers them and trade openness raises them. Second, the MMQR results show that these effects are heterogeneous across emission levels. The effect of GDP rises from 0.24 at the 0.25 quantile to 0.47 at the 0.9 quantile, and the emission-reducing effect of renewable energy strengthens from –0.75 at the 0.1 quantile to –1.17 at the 0.9 quantile. Oil and coal consumption increase emissions at all quantiles, with effects that decline only slightly at higher quantiles, while trade openness reduces emissions at the lowest quantiles but increases them at the 0.9 quantile. Third, the causality tests reveal bidirectional causality between CO₂ emissions and both GDP and oil consumption, unidirectional causality from coal consumption to emissions and from emissions to renewable energy, and no causality between trade and emissions. Overall, H1, H2, H3, H4 and H5 are supported, whereas H6 is only partly supported.

These results imply that reducing coal and oil dependence should be a common priority for all ASEAN-5 countries, irrespective of their emission level. In high-emitting economies, where the growth elasticity of emissions and the mitigating effect of renewables are largest and trade openness raises emissions,

faster renewable energy deployment and stricter environmental standards for trade-exposed, energy-intensive industries are likely to be most effective. In lower-emitting economies, trade and investment openness can serve as a channel for cleaner technology transfer. Finally, the fact that emissions drive renewable energy adoption rather than the reverse suggests that renewable energy policy in the region has been reactive; binding renewable energy targets and carbon pricing could make it anticipatory.

The present study is subject to several limitations that point toward productive avenues for future research. Expanding the analysis developed in the paper as more recent data become available is a natural direction for future research. The exclusion of natural gas from the analysis, due to data unavailability, limits the completeness of the fossil fuel picture, and its incorporation in subsequent work would enrich the policy-relevant findings on fuel-specific abatement strategies. The significant heterogeneity in the quantile coefficients indicates the presence of structural breaks associated with major economic shocks and policy regime changes; future research employing structural-break-robust or regime-switching estimators would help assess the stability of the estimated relationships. Finally, extending the empirical framework to the broader ASEAN membership or to comparable developing-country panels would permit a more systematic assessment of the validity of the distributional findings reported in the paper.

AUTHOR CONTRIBUTIONS

Conceptualization: Ciler Sigeze, Esra Balli, M. Sedat Uğur, Bekhzod Kuziboev.

Data curation: Gulnoza Matyakubova, Jamshid Pardaev, O'g'iljon Artiqova.

Formal analysis: Ciler Sigeze, M. Sedat Uğur, O'g'iljon Artiqova.

Funding acquisition: O'g'iljon Artiqova.

Investigation: Jamshid Pardaev, O'g'iljon Artiqova.

Methodology: Esra Balli, M. Sedat Uğur, A. Nazif Çatik, Gulnoza Matyakubova.

Project administration: Bekhzod Kuziboev.

Resources: M. Sedat Uğur, Gulnoza Matyakubova, Jamshid Pardaev, O'g'iljon Artiqova.

Software: A. Nazif Çatik, Gulnoza Matyakubova, Jamshid Pardaev.

Supervision: Esra Balli, Gulnoza Matyakubova, Bekhzod Kuziboev.

Visualization: Ciler Sigeze, Bekhzod Kuziboev.

Writing – original draft: Ciler Sigeze, Esra Balli, A. Nazif Çatik, Gulnoza Matyakubova, Bekhzod Kuziboev.

Writing – review & editing: Esra Balli, M. Sedat Uğur, A. Nazif Çatik, Gulnoza Matyakubova, Bekhzod Kuziboev, Jamshid Pardaev, O'g'iljon Artiqova.

ACKNOWLEDGMENT

Esra Balli would like to acknowledge the financial support provided by the Council of Higher Education (YÖK) through the Academic Development Program (AKAP).

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APPENDIX A

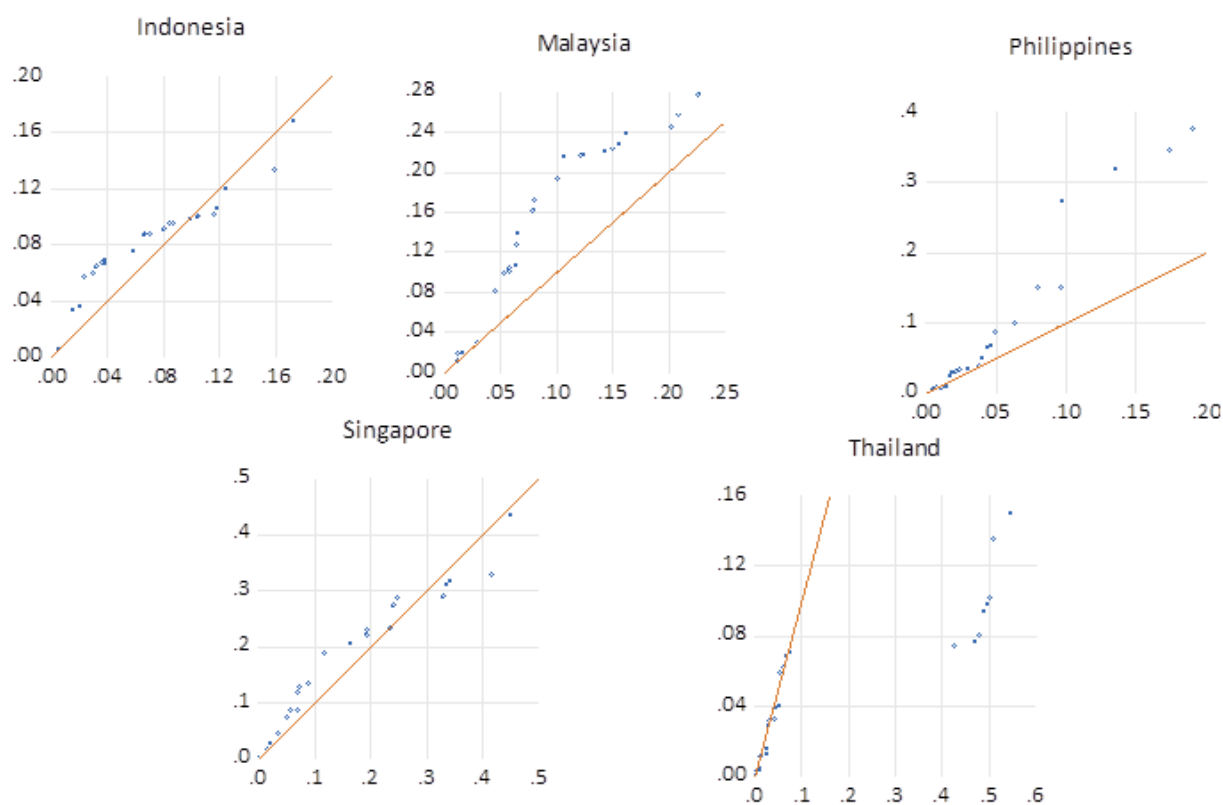


Figure A1. Q-Q plot of cross-sectional residuals