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KEYWORDS	ABSTRACT
Industrialization; energy intensity; CO ₂ emissions; renewable energy; Asia; Driscoll-Kraay; panel data; moderation effect	With the growth of Asia's industry, concerns over carbon emissions and energy usage have grown. The aim of this study is to test whether the relationship between industrialization and CO ₂ emissions remains constant when energy intensity varies within the Asian economies analyzed for the period 2000–2021. Driscoll–Kraay standard errors to account for heteroskedasticity, serial correlation, and cross-sectional dependence. The results indicate that there is a positive relationship between industrialization and energy intensity and CO ₂ emissions, while there is a negative relationship between renewable energy consumption and emissions. The main result is that the relationship between industrialization and energy intensity is positive and very strong, meaning that the industrialization process becomes more intensive in energy consumption as energy intensity increases. This is confirmed by the marginal effects estimates: at low energy intensity levels, there is no statistically significant link between industrialization and emissions, while the link is positive and gradually more pronounced at average and high energy intensity levels. The results indicate that reduction in energy intensity is one of the key factors for cleaner industrial development in the selected Asian economies.
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Introduction

Asia has emerged as one of the biggest industrial production hubs in the world, but has also faced pressure on energy systems and the environment. Industrial expansion can lead to increased income,

employment, and productive power, but is frequently energy-intensive in the way industries are produced, built, and processed. The recent findings from Asia and Asia-Pacific consistently indicate that industrialization continues to have a positive correlation with CO₂ emissions, especially in countries where production still heavily relies on traditional energy sources (Ahmed et al., 2022; Yang et al., 2024). The environmental impacts of industrialization, however, are not likely to be equal in the various countries (Gillani et al., 2026). Energy intensity is a measure of the amount of energy consumed to produce a dollar of economic output and thus is a key measure of energy stress on production. A high energy intensity is a characteristic of economies that need more energy per unit of output; a low energy intensity of an economy is indicative of technological improvements, production efficiency, or structural change. But recent studies indicate that energy intensity is a key component of environmental performance and energy transition policy in emerging economies (Yang et al., 2025; Zaidi et al., 2024).

Previous research has largely focused on the separate or alternative impacts of industrialization, energy use, renewable energy, and carbon emissions. For instance, Claire and Widyawati (2023) demonstrate that the environmental impacts of industrialization can be offset by the use of renewable energy in the ASEAN economies, and Salahodjaev et al. (2023) reveal that industrialization leads to an increase in emissions while renewable energy leads to a decrease in emissions across the OIC countries. Recent Asian studies also show that industrialization and electricity consumption continue to be significant contributors to carbon emissions in Asia (Ali et al., 2026). Although much has been written on this subject, there has been limited research into the effect on the industrialization–CO₂ relationship when looking at energy intensity alone. It's a significant distinction. If expansion occurs in a relatively energy-efficient economy, the carbon cost may be lower than if it were happening in an economy that has to produce as much carbon. A conditional mechanism cannot thus be ignored if the study of energy intensity is done as if it were an independent factor.

This study aims to fill this void by analyzing whether energy intensity can moderate the relationship between industrialization and CO₂ emissions in 11 Asian economies in the period of 2000–2021. The analysis has three components. Firstly, it shifts from the impact of industrialization to the circumstances of its increased carbon intensity. Secondly, it explicitly captures the relationship between industrialization and energy intensity and assesses it using marginal effects. Third, the few multi-country Asian studies that explicitly examine a moderating effect of economy-wide energy intensity in the relationship between industrialization and CO₂ do not offer a direct test. Third, there are few Asian studies that explicitly test economy-wide energy intensity as a moderator using a direct interaction term and marginal-effects analysis.

The results reveal a positive relationship between industrialization and CO₂ emissions, which increases with the increase in energy intensity. The relationship between industrialization and emissions is statistically insignificant at low energy-intensity levels, and positive at average and high levels of energy intensity. The use of renewable energy is negatively correlated with emissions. The findings indicate that the environmental impact of industrial development can be reduced by

decreasing the energy intensity of its production in addition to increasing the supply of cleaner energy. This study thus offers a conditional perspective on the relationship between industrialization and emissions: the carbon impact of industrialization is not only the result of the extent of industrialization, but also of the intensity of energy use.

Literature Review

Industrialization and CO₂ Emissions

Industrialization has been the focal point of the economic transition, especially in Asia, where manufacturing, construction, and related activities have grown at a rapid pace. But industrial development typically involves significant energy inputs and can also lead to higher fossil fuel use, with a significant dependence on the production structure and energy system. The evidence for the Asian region is recent, and industrialization is generally recognized as a major contributor to carbon pressure. By analyzing ASEAN+3 economies, Elfaki et al. (2022) showed that there was a significant relationship between industrialization and carbon emissions and highlighted that the environmental impacts of industrial development vary between economies. In line with these findings, Ahmed et al. (2022) noted that in the Asia-Pacific region, industrialization, too, leads to environmental degradation, especially in countries where low-emission industrial production processes are not in widespread use.

More extensive samples of developing countries confirm these findings. Sikder et al. (2022) examined how the four factors affect CO₂ emissions for 23 developing economies using panel ARDL methods, revealing that industrialization and economic growth, together with energy use and urbanization, influence the overall level of environmental pressure, where industrial activity increases environmental pressures. Similarly, Jiang et al. (2026) also reported that growth in industrialization leads to environmental degradation, while renewable energy creates environmental benefits in the BRICS economies.

This is bolstered by more recent ASEAN studies; Claire and Widyawati (2023) highlighted the close relation between the process of industrialization and CO₂ emissions in the nine ASEAN countries and illustrated how the environmental impacts of industrialization can be transformed by the use of renewable energy. Similarly, Mu'min et al. (2023) analyzed industry value added, renewable energy, economic growth, and emissions in ASEAN and concluded that the industrial structure plays a major role in understanding carbon outcomes in the region.

Ekwueme et al. (2023) investigated eight Asian economies and concluded that while industrialization and non-renewable energy use boost CO₂ emissions in the long run, renewable energy enhances environmental sustainability. A similar finding by Salahodjaev et al. (2023) was found in the OIC countries, whereby industrialization was linked to higher emissions and renewable energy to lower environmental pressure.

The industrialization–emissions relationship is still relevant, as shown in recent work. Musa et al. (2025) specifically look at energy use, energy intensity, industrialization, and carbon–emission risk in Malaysia, whereas Ali et al. (2026) focus on industrialization, electricity consumption, and emissions in 35 Asian economies. The latter indicates that energy use is still a crucial factor in the economies of countries undergoing fast industrial growth. The evidence confirmed, thus, the idea that increases in industrial activity are accompanied by higher emissions, especially if industrial growth is still dependent on energy-intensive production.

H1: Industrialization is positively associated with CO₂ emissions.

Energy Intensity and CO₂ Emissions

Energy intensity is the quantity of energy used to produce a unit of economic output. It is thus a helpful indicator across the economy of the dependence of production on energy inputs. Energy intensity is not a pure indicator of technical efficiency, but a high energy intensity typically indicates a higher energy use to maintain the same level of output of economic activity. The present study offers relevant evidence from Rahman et al. (2022), with 25 big emerging economies, they discover that energy intensity and industrialization lead to an increase in carbon intensity over time and that renewable energy use decreases it. As they found, their environmental performance is related not only to the scale of production, but also to the amount of energy used for production. Energy intensity has been gaining in importance as a channel through which structural change and environmental results are connected in recent studies.

Somoye et al. (2024) investigate the relationship between energy intensity and renewable energy (RE), as well as between globalization and technological innovation and between technological innovation and CO₂ emissions, and demonstrate that the energy–emissions link could be different at different points of the emissions distribution. Similarly, in their analysis of 16 emerging economies, Zaidi et al. (2024) show that structural and economic factors such as globalization, growth, and financial development have an impact on energy intensity (Sui et al., 2026). The relationship between the energy structure and environmental performance is also revealed in Central Asia. In their study, He et al. (2024) conclude that the relationship between consumption of renewable energy and energy intensity, as well as carbon intensity, is not the same across the Central Asian economies and exhibits significant differences. This indicates that changes in the energy mix can have an indirect effect on emissions by impacting the need for energy in economic activity.

This connection has been confirmed by more recent studies. Musa et al. (2025) explicitly include energy intensity in the industrialization–emissions nexus in Malaysia. In addition to economic and structural changes, energy intensity is an important factor in regional emissions pathways, as mentioned by Kim et al. (2025) in their study on future emissions in Southeast Asia. On a higher level, Amadei et al. (2026) warn that decreasing domestic energy intensity does not necessarily mean that global decarbonization has occurred if energy-intensive production is shifted to other countries. Their results are also important for the interpretation of cross-country indicators of

energy intensity, which generally indicate that domestic energy demand is lower, but can be affected by structural changes and by relocating production abroad. The literature reviewed collectively indicates that energy intensity is an important issue for environmental performance and that higher energy consumption per unit of output is an indicator of higher carbon pressure exposure.

H2: *Higher energy intensity is positively associated with CO₂ emissions.*

Moderating Role of Energy Intensity

The main question of this study is not just if industrialization and energy intensity have an independent effect on emissions but whether energy intensity affects the magnitude of the correlation between industrialization and CO₂. This separation has been discussed in a number of places indirectly, and the nature of the relationship is not very well developed in Asian panel studies. There is some recent evidence indicating that the environmental impacts of industrialization are related to complementary technological or energy conditions. In major industrialized economies, Onwe et al. (2024) identify energy efficiency as a solution that helps to reduce the negative environmental impacts of industrialization. As the results of their study indicate, industrial growth can be environmentally less harmful when improvements in energy efficiency accompany growth (Sharif et al., 2026).

Similarly, Rasheed et al. (2024) demonstrate that carbon emissions are higher in emerging Asian countries because of industrialization, but renewable energy and artificial intelligence can help enhance environmental performance. This supports the overall perspective that environmental impacts of industry are contingent on the technology and energy environment in which industrialization takes place (Shafiq et al., 2021; Xie et al., 2026). More evidence from China is provided by Wang and Lei (2024). They discover that the development of renewable energy lowers the carbon-emission intensity and that energy-use efficiency, industrial restructuring, and green technological innovation affect the relationship. They find that the environmental outcome of the environment is determined by interaction mechanisms, and not by the energy variables alone.

Deng et al. (2024) also demonstrate that renewable energy and green technological innovation are also associated with a decrease in carbon-emission intensity. The comparative results reveal that there is significant variability in the relationship between structural and technological conditions and emissions. Recent studies illuminate the moderation literature that is now developing. Kakar et al. (2025) and Zhang et al. (2026) explored the issues of renewable energy, industrialization, financial technology, and carbon emissions, showing how technological and financial conditions can mitigate carbon emissions resulting from industrial processes. Similarly, based on the case of middle-income economies, Haloui et al. (2025) explore the interplay of renewable energy, financial development, industrialization, and CO₂ emissions, arguing that environmental outcomes are the result of interactions between structural and energy-related determinants, and not of isolated ones (Sun et al., 2025).

In addition, Nazir et al. (2026), show that energy technology and institutional conditions determine the emissions-reducing effect of renewable energy. This evidence supports the necessity to consider the environmental consequences of economic activity as contingent, not as a homogeneous phenomenon for all countries (Wang, Gillani, Balsalobre-Lorente, et al., 2025). The latest Asian research is along the same lines. In a study of 18 Asian economies and regions, Chiu et al. (2026) find significant variations in the efficiency of industrial production and conclude that energy intensity, the structure of renewable energy, and carbon constraints are significant factors in industrial performance. Similarly, Singh et al. (2026) conclude that the sustainability effects of industrialization vary across South and Southeast Asia, and highlight the importance of region-specific mixes of clean-energy and industrial policies.

At the country level, Endeer et al. (2026) show that the relationship among industrialization, renewable energy, ICT, and carbon emissions in China changes across time horizons and different parts of the distribution. This further challenges the assumption that industrialization has a constant environmental association under all technological and energy conditions. The implication for the present study is straightforward. If industrial expansion occurs where a large amount of energy is required for each unit of output, additional industrial production should be associated with a greater increase in emissions. Conversely, when economy-wide energy intensity is relatively low, the carbon burden associated with industrial expansion should be smaller.

H3: *Energy intensity positively moderates the relationship between industrialization and CO₂ emissions.*

Renewable Energy and Economic Development as Control Factors

Economic development and consumption of renewable energy are used as baseline controls, as both are closely associated with emissions and industrial transformation. Overall, recent evidence confirms that expansion of renewable energy is beneficial to the environment. Based on Chinese evidence, Li et al. (2021) conclude that energy consumption of renewable energy sources can help build a low-carbon economy. Rahman et al. (2022) also demonstrate that the proportion of renewable energy is negatively associated with carbon intensity in the large emerging economies. This trend is also evident in Asia. Ekwueme et al. (2023) conclude the existence of a long-run negative relationship between the use of renewable energy and emissions in Asia, while Claire and Widyawati (2023) demonstrate that the use of renewable energy can have a long-run effect on the environmental impact of industrialization in the ASEAN region. He et al. (2024) also shows that the use of renewable energy is strongly related to the energy intensity and carbon intensity in Central Asia.

Recent evidence is still relatively consistent. Generally, renewable technologies have a lower carbon intensity, but vary in reduction by technology and institutional contexts, according to Kongkuah and Alessa (2025). Yang et al. (2026) also note that clean and renewable energy are key factors of sustainable development in G20 economies. Economic development is not as strongly linearly associated with emissions (Wang et al., 2024). At first, when income rises, the demand for

energy, transportation, and infrastructure construction, and for industrial production, will also rise. This relationship can be reversed, however, at higher development levels as a result of cleaner technologies, regulatory capacity, and structural changes to less energy-consuming activities. It is therefore only as a control for the differences in economic development that GDP per capita is included, and for this reason only, and not as the main theoretical contribution of the study.

Research Gap and Contribution

From the literature 2021-2026 three general conclusions can be drawn. First, the emissions from industrial activities are strongly linked to the process of industrialization, particularly in developing and emerging economies. Second, energy intensity tends to have a negative impact on environmental performance, while the expansion of renewable energy and energy efficiency have a negative impact on carbon pressure. Third, there is growing evidence that the environmental consequences of industrialization are related to complementary aspects (renewable energy, technology, financial development, ICT, and energy efficiency).

Yet there is a particular problem that needs to be addressed. The majority of studies on Asian countries treat industrialization and energy as separate variables that influence emissions, and few of them directly examine the impact on the marginal relationship between industrialization and CO₂ emissions when energy intensity changes at the economy-wide level. At the same time, Claire and Widyawati (2023) look at renewable energy as a conditioning mechanism for ASEAN, Onwe et al. (2024) discuss energy efficiency as a mitigation mechanism in major industrialized economies, and Musa et al. (2025) examine the tradeoff between industrialization and energy intensity in Malaysia. However, none of these studies can be taken as a comprehensive cross-country Asian test of the centered industrialization $\times$ energy-intensity interaction, which is the interest of the present study.

This study thus makes an important contribution to the literature by studying the systematic variation of the emissions association of industrialization with energy intensity in 11 Asian economies over the period 2000-2021. There is no simple intention to use energy intensity as another variable to explain, but rather as a moderator. Using marginal effects, the effects of the industrialization-CO₂ association at low, average, and high energy-intensity levels are then shown. It gives a direct test of the hypothesis that the environmental impact of industrialization is related to the energy situation in which industrial growth takes place.

Data and Methodology

Data and Sample

This study focuses on the annual balanced panel of Asian economies of 11 countries (Bangladesh, Cambodia, China, India, Indonesia, Malaysia, the Philippines, South Korea, Thailand, Türkiye, and Vietnam) and spans the period from 2000 to 2021. The final dataset consists of 242 country-year observations, with all the variables of the baseline model available for all these observations. A

balanced structure is used to prevent changes in the composition of the samples over the years and to ensure that each economy's contribution is equal across the time dimension of the analysis. The data were collected annually from the World Bank's World Development Indicators (WDI).

CO₂ emissions per capita are estimated as total CO₂ emissions minus the emissions from land use, land use change, and forestry. Industrialization is represented by industry (construction, value added as a percentage of GDP). Based on the WDI definition, this indicator includes operations in the mining, manufacturing, construction, electricity, water, and gas sectors. Energy intensity is defined as primary energy supply per unit of GDP in MJ per 2021 PPP GDP. A higher number, therefore, means higher energy intensity to generate an economic output. Renewable-energy consumption is defined as renewables' share of total final energy consumption. The GDP per capita is log-transformed and, for ease of interpretation, the CO₂ emissions per capita are also log-transformed to minimize the scale difference. Industrialization and energy intensity are mean-centered before building the interaction term. This centering enables the coefficient of industrialization to be interpreted as its relationship with CO₂ emissions at the sample average value of energy intensity.

Measurement of Variables

There are 6 variables in the empirical model. CO₂ emissions per capita is considered the dependent variable and is log-transformed. Industrialization is calculated as industry value added as a percentage of GDP, including construction. The moderating variable is energy intensity, which represents the amount of primary energy needed to generate a unit of economic output. The higher the value, the more energy is used for each unit of output. To include a baseline control, GDP per capita is also included and is also transformed into natural logarithms. Renewable-energy consumption is the ratio of renewable energy to total final energy.

The robustness specification includes the measure of trade openness, defined as the sum of exports and imports as a share of GDP. Most of the variables are grand mean-centered to enhance the interpretation of the interaction model. Because of this, the coefficient for industrialization reflects the correlation between industrialization and CO₂ emissions if energy intensity were equal to the sample mean, and the interaction coefficient reflects the effect of a change in energy intensity on the relationship between industrialization and CO₂ emissions.

Table 1: Variable Definitions and Measurement

Variable	Symbol	Measurement
CO ₂ emissions	lnCO ₂	CO ₂ emissions excluding LULUCF, tonnes CO ₂ per capita
Industrialization	IND	Industry, including construction, value added (% of GDP)
Energy intensity	EI	Primary energy intensity, MJ per 2021 PPP GDP
GDP per capita	lnGDP	GDP per capita, constant 2015 US\$
Renewable energy	RNE	Renewable-energy consumption (% of total final energy)

		consumption)
Trade openness	TRD	Exports plus imports of goods and services (% of GDP)
Interaction term	IND × EI	Centered industrialization × centered energy intensity

Note. All variable data are drawn from the World Development Indicators. IND and EI are grand-mean centered before constructing the interaction term.

Model Specification

The empirical model analyzes the effect of energy intensity on the relationship between industrialization and CO₂ emissions. The baseline specification is:

$$\ln CO_{2,it} = \beta_0 + \beta_1 cIND_{it} + \beta_2 cEI_{it} + \beta_3 (cIND_{it} \times cEI_{it}) + \beta_4 \ln GDP_{it} + \beta_5 RNE_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$$

where *i* denotes a country, and *t* denotes the year. *cIND_{it}* and *cEI_{it}* are the mean-centered industrialization and energy-intensity variables, respectively. The interaction term *cIND_{it} × cEI_{it}* captures the moderating role of energy intensity. α_i represents country fixed effects, λ_t represents year fixed effects, and ε_{it} is the error term.

β_3 is the coefficient of primary interest. The positive and statistically significant β_3 suggests that the relationship between industrialization and CO₂ emissions gets stronger with higher energy intensity. Industrialization and energy intensity are mean-centered, so β_1 is the relationship between industrialization and CO₂ at the sample mean of energy intensity. Likewise, β_2 is the association between energy intensity and CO₂ emissions at the sample mean of industrialization. As baseline controls, GDP per capita and consumption of renewable energy are included. To explore the robustness of the moderation effect, the following robustness specification includes trade openness. The statistical analysis does not attempt to explain causality; instead, it is used to analyse the relationship between the variables. Thus, the estimated coefficients are considered conditional and not as causal relationships.

Econometric Strategy

The empirical analysis is based on a sequential model of panel data that is best suited to the statistical characteristics of the data. The data distribution of the variables and potential multicollinearity is assessed before examination of descriptive statistics, pairwise correlations, and variance inflation factors. The Hausman (1978) used for choosing among alternative estimators based on the preliminary estimated models: a fixed-effects model and a random-effects model. The heteroskedasticity of the groups is tested for by the modified Wald test, and the Wooldridge test is used to check for first-order serial correlation. The process of evaluating cross-sectional dependence is carried out by the CD test of Pesaran, and the process of evaluating slope homogeneity is carried out by the procedure of Pesaran and Yamagata (2008).

It is found that cross-sectional dependence exists, and therefore, second-generation panel unit root testing is used. The Pesaran CADF/CIPS approach is used to determine the order of integration of the variables, as it explicitly accommodates cross-sectional dependence. The results show a mixture of I(0) and I(1) variables, and no indication of I(2) processes. The Westerlund error correction test is then used to check if the variables have a long-run equilibrium relationship (Westerlund, 2007).

The main specification is estimated with fixed effects and Driscoll–Kraay standard errors because of the presence of heteroskedasticity, serial correlation, and cross-sectional dependence. This covariance estimator allows for inference that is robust to general types of cross-sectional and temporal dependence in panel data (Driscoll & Kraay, 1998). Fixed effects are used to control for time-invariant national characteristics (country fixed effects) and year-specific shocks common to all countries (year fixed effects). A second specification includes the robustness control of trade openness.

Lastly, the interaction term is estimated at low, mean, and high levels of energy intensity to be able to interpret the interaction term directly. This step demonstrates the variation of the association between industrialization and CO₂ emissions for each level of the moderator along economically meaningful ranges.

Empirical Results

Descriptive Statistics

The descriptive statistics of the variables used in the empirical analysis are summarized in Table 2. This is a 242-observation complete balanced panel. The average of the logged CO₂ emissions is 0.768, and the average of the industrialization ratio of GDP is 34.47%. The mean for energy intensity is 4.75, and the mean for renewable energy consumption is 27.93% of the total final energy consumption. The level of trade openness varies the most, with the extreme values of 25.99% to 220.41% of GDP.

Table 2: Descriptive Statistics

Variable	N	M	SD	Minimum	Maximum
lnCO ₂	242	0.768	1.129	-1.829	2.580
IND	242	34.466	6.773	21.646	48.530
EI	242	4.747	1.835	1.900	10.910
lnGDP	242	8.172	1.017	6.395	10.457
RNE	242	27.926	19.358	0.700	81.600
TRD	242	83.900	45.604	25.993	220.407

Note. lnCO₂ = natural logarithm of CO₂ emissions per capita; IND = industry (including construction), value added (% of GDP); EI = energy intensity; lnGDP = natural logarithm of GDP

per capita; RNE = renewable energy consumption (% of total final energy consumption); TRD = trade (% of GDP).

The pairwise correlation coefficients for all pairs of variables are shown in Table 3. The highest correlation between the regressors is between logged GDP per capita and the use of renewable energy, at -0.876 . There is a positive correlation between industrialization and energy intensity, with a value of 0.493 . These correlations indicate that there is a need to explore further the possible level of multicollinearity, but they do not, on their own, warrant the dropping of any variables from the model.

Table 3: Pairwise Correlations and Variance Inflation Factors

Variable	1	2	3	4	5	6	VIF
lnCO ₂	1.000						—
IND	.477***	1.000					—
EI	.362***	.493***	1.000				—
lnGDP	.923***	.290***	.184**	1.000			5.14
RNE	-.919***	-.358***	-.132*	-.876***	1.000		5.60
TRD	.149*	.350***	.098	.125	-.049	1.000	—
Centered EI (cEI)							156
Centered IND (cIND)							153
IND × EI interaction							131

*Note. Correlation significance is based on the Stata pairwise-correlation output. VIFs are reported for regressors in the baseline interaction model; mean VIF = 3.03. * $p < .05$. ** $p < .01$. *** $p < .001$.*

The VIF results reported in Table 3 indicate that multicollinearity remains manageable. The highest VIF values are 5.60 for renewable energy and 5.14 for logged GDP per capita, while all remaining variables have VIF values below 2. The mean VIF is 3.03. These results indicate moderate multicollinearity in some regressors, but no variable exceeds the conventional threshold of 10. Overall, the descriptive and diagnostic evidence supports proceeding with the panel estimations without excluding any of the baseline variables.

Panel Diagnostics

A group of panel diagnostic tests was performed to determine statistical characteristics of the data before estimating the main model. The modified Wald test strongly rejects the null hypothesis of homoskedasticity ($\chi^2(11) = 1649.03$) and ($p < 0.001$), suggesting that error variance is different across countries. The Wooldridge test also rejects the null hypothesis of no first-order serial correlation ($F(1, 10) = 33.069$, $p = 0.0002$), which confirms that there is a serial correlation in the panel errors. Cross-sectional dependence is also identified. The Pesaran CD statistic is (-2.423) , the p -value is 0.0154 , and the average absolute off-diagonal residual correlation is 0.411 . This indicates that shocks to one economy could be linked with movements in other economies, which may be possible in an area with trade, energy, and macroeconomic linkages. The Pesaran–Yamagata test

also suggests that the null hypothesis of slope homogeneity is rejected. The relationships between the regressors and CO₂ emissions are not the same across countries, as evidenced by the Delta statistic (8.801, $p < 0.001$) and the adjusted Delta statistic (10.659, $p < 0.001$). Overall, the diagnostics indicate the existence of heteroskedasticity, serial correlation, cross-sectional dependence, and slope heterogeneity in the panel. The results support the use of estimation methods that yield strong inference in this scenario, and not just the traditional fixed-effects or random-effects standard errors.

Table 4: Panel Diagnostic Tests

Test	Statistic	p
Modified Wald: groupwise heteroskedasticity	$\chi^2(11) = 1649.03$	< .001
Wooldridge: first-order serial correlation	$F(1, 10) = 33.069$	< .001
Pesaran CD: cross-sectional independence	$CD = -2.423$	.015
Pesaran–Yamagata slope homogeneity	$\Delta = 8.801$	< .001
Pesaran–Yamagata adjusted	$\Delta_{adj} = 10.659$	< .001

Note. The diagnostic results motivate inference robust to heteroskedasticity, serial correlation, and cross-sectional dependence.

Panel Unit-Root and Cointegration Results

To explore the stationarity properties of the variables, second-generation panel unit-root tests were employed, given the evidence of cross-sectional dependence. The Pesaran CADF/CIPS results presented in Table 5 reveal that the series of logged CO₂ emissions and the series of industrialization, energy intensity, and renewable-energy consumption are non-stationary at level but stationary after first differencing. These variables are therefore integrated of order 1 – I(1). In contrast, both logged GDP per capita and the interaction term are stationary at level (I(0)). The mixed order of integration means that not all the variables are integrated beyond the first order.

Table 5: CADF/CIPS Panel Unit-Root Tests

Variable	Level	p	First-difference	p	Order
lnCO ₂	-2.074	.149	-2.555	.004	I(1)
IND	-1.512	.811	-3.118	< .001	I(1)
EI	-2.115	.119	-2.700	.001	I(1)
lnGDP	-2.342	.025	—	—	I(0)
RNE	-1.569	.754	-2.731	.001	I(1)

Note. The null hypothesis is a unit root. Tests include a constant and one lag. First-difference tests are reported only for variables that were nonstationary at level.

The Westerlund error-correction test was then applied to test for the long-run equilibrium relationship between the variables. The results of this test are inconclusive but generally support

cointegration that presented in Table 6. At conventional significance levels, the Ga and Pa statistics reject the null of no cointegration, and the Gt statistic fails to reject the null. The Ga and Pa statistics reject the null of no cointegration at conventional significance levels, and the Gt statistic is only marginally significant. Thus, the evidence is taken with a grain of salt, suggesting that there is some support for a long-run relationship between variables. These results corroborate the continuation of the main panel specification but also acknowledge that not all of the Westerlund test statistics are available in the long run.

Table 6: Westerlund Error-Correction Panel Cointegration Test

Statistic	Value	Z	p	Robust p
Gt	-2.728	-0.283	.389	.098
Ga	-8.939	2.428	.992	< .001
Pt	-9.117	-1.154	.124	.058
Pa	-8.642	1.064	.856	.010

Note. H_0 = no cointegration. Robust p-values are based on 400 bootstrap replications. Evidence is mixed: Ga and Pa reject the null at 5%, while Pt and Gt do not at 5% (Pt is marginal at 10%).

Main Estimation Results

The Driscoll–Kraay fixed-effects results indicate that both industrialization and energy intensity have positive effects on CO₂ emissions. Other things remaining equal, a 1% increase in industrialization is related to an additional 0.77% CO₂ emissions at the mean energy intensity. The most important is that the interaction between industrialization and energy intensity is positive and statistically significant (0.0040, $p < 0.001$). This means that the positive correlation between industrialization and CO₂ emissions gets stronger as the energy intensity increases. GDP per capita is found to be positively correlated with CO₂ emissions, and renewable-energy consumption is found to be negatively correlated with emissions. These results are robust to country and year fixed effects. The result is stable across specifications, as the same moderation result is obtained with the robustness model (inclusion of trade openness), with a similar interaction coefficient (0.0047, $p < 0.001$).

Table 7: Driscoll Kraay Fixed Effects Estimates

Variable / Statistic	Main b	SE	p	Robustness b	SE	p
cIND	.0077	.0019	.001	.0090	.0014	< .001
cEI	.1163	.0101	< .001	.1309	.0120	< .001
IND × EI	.0040	.0007	< .001	.0047	.0008	< .001
lnGDP	1.3325	.0884	< .001	1.4480	.1148	< .001
RNE	-.0135	.0011	< .001	-.0133	.0011	< .001
TRD	—	—	—	-.0014	.0005	.006

Note. Dependent variable = $\ln CO_2$. The main model includes $cIND$, cEI , their interaction, $\ln GDP$, RNE , country fixed effects, and year fixed effects. The robustness model additionally controls for trade openness (TRD). Driscoll–Kraay standard errors use a maximum lag of 1.

Marginal Effects

The result of moderation is further illustrated in the marginal-effects analysis. The estimated marginal effect is 0.0003 at low energy intensity and insignificant ($p=.904$). At the mean level of energy intensity, it is 0.0077 ($p<.001$), and at high energy intensity, even higher, 0.0152 ($p<.001$). This trend reflects that carbon emissions tend to increase with industrialization primarily in economies with relatively high energy intensity. The findings substantiate the main moderation hypothesis of the study.

Table 8: Marginal Effect of Industrialization at Different Levels of Energy Intensity

Energy-intensity level	dy/dx	SE	z	p	95% CI
Low EI ($cEI = -1.84$)	.0003	.0024	.12	.904	[−.0044, .0049]
Mean EI ($cEI = 0$)	.0077	.0019	4.05	< .001	[.0040, .0115]
High EI ($cEI = 1.84$)	.0152	.0022	6.93	< .001	[.0109, .0195]

Note. Marginal effects are based on the Driscoll–Kraay fixed-effects interaction model. Low and high energy intensity correspond approximately to one standard deviation below and above the centered mean. The effect of industrialization is not statistically significant at low energy intensity but is positive and significant at mean and high energy intensity.

Discussion

The findings indicate that the impacts of emissions from industrialization are highly influenced by the energy intensity of the economy. Indeed, the findings indicate that the increase in CO_2 emissions is positively related to industrialization, with evidence suggesting that industrial growth can exacerbate environmental stress if energy- and carbon-intensive production processes are used in Asia-Pacific (Ahmed et al., 2022). Evidence from the nine ASEAN economies is also similar: industrialization is tightly associated with CO_2 emissions, but the relationship could be different under an alternative energy mix of renewables (Claire & Widjyawati, 2023).

The main contribution of this study is the positive and significant interaction between industrialization and energy intensity. The outcome suggests that the more energy must be expended to produce a unit of output, the more carbon-intensive industrial growth will be. The marginal-effects results support this interpretation: there is no significant link between industrialization and emissions at low levels of energy intensity, but the link is positive and strong at average and high levels of energy intensity. This indicates that the environmental price of industrialization is not solely defined by the process of industrialization, but also by the efficiency with which energy is used in the economy.

The discovery is significant for Asia, as several Asian economies are still expanding industrial production, while continuing to be persistently fossil-fuel dependent and with uneven progress in improving energy efficiency. In addition, previous evidence from ASEAN indicates a strong correlation between energy consumption and economic growth, and the lack of cross-country interdependence between them can lead to a misestimated relationship (Munir et al., 2020). The present results add to the literature that confirms that energy intensity is not just independently associated with emissions, but also influences the relationship between industrialization and emissions.

The results of both baseline and robustness models indicate that renewable-energy consumption is negatively related to CO₂ emissions (Wang, Gillani, Sharif, et al., 2025). It is in line with the findings of ASEAN by Claire and Widyawati (2023), which indicates that an increase in the use of renewable energy would be able to lower the environmental impact of industrialization. This indicates that the improvement of energy intensity can be supplemented by cleaner energy supply. Less carbon-intensive growth is therefore likely to occur in the sectors that have less reliance on energy, or have more renewables as their primary sources of energy. This means that growth in these sectors, which use energy more efficiently or rely less on fossil fuels, is likely to be less carbon intensive than growth in sectors that use energy less efficiently or rely more heavily on fossil fuels. However, GDP per capita, as an additional sample indicator, is still positive and associated with emissions, suggesting that increases in economic activity still drive-up carbon emissions within the sample. The robustness model shows that trade openness is negatively correlated with emissions, but such a negative correlation should be used with some caution, as trade can have multiple competing impacts on emissions through the scale, composition, technology transfer, and relocation of pollution-intensive activities.

For the whole, the results are coherent, so the knowledge to be taken from them is clear: industrialization is not homogeneous in countries. Where energy intensity is high, its carbon impacts are significantly higher. This puts energy productivity at the top of the agenda of the debate on decarbonizing industry and shows that the policies that aim to make the industrial sector more environmentally friendly must address energy-efficiency improvement, technological upgrading, and increased renewable energy use at the same time.

Conclusion and Policy Implications

Conclusion

This study explores the relationship between energy intensity and CO₂ emissions during industrialization in the 11 Asian economies between 2000 and 2021. The results indicate that industrialization and energy intensity both have a positive relationship with emissions, and that this relationship is positive and statistically significant as well when considering the interaction between the two. This means that the heavier the carbon footprint of industrialization, the more intensive it is. This result is confirmed by the analysis of the marginal effects. Emissions are not

significantly related to industrialization at low levels of energy intensity, but the relationship is positive and strong at average and high levels of energy intensity. Emissions are negatively associated with consumption of renewable energy, and GDP per capita is positively associated with emissions. In sum, the results indicate that the environmental impacts of industrial development are not just the result of the level of industrialization but of the energy environment that it is integrated within. Therefore, energy intensity reduction and increased usage of renewable energy sources can be significant drivers in curbing carbon impacts of ongoing industrial development in Asia.

Policy Implications

The results indicate that policies that seek to enhance production efficiency, minimize energy losses, and encourage the development of cleaner technologies can contribute to mitigating the carbon footprint of industrial growth. Reducing CO₂ emissions is also beneficial to increasing the share of renewables in the energy system, as is the negative correlation between consumption of renewable energy and CO₂ emissions. Increasing the consumption of renewable energy and improving energy efficiency can help reduce the reliance of industrial development on carbon emissions.

Policy should, therefore, promote energy-saving and energy-efficient technologies, as well as the reduced use of energy-intensive technologies, within the context of improving energy efficiency. A coordinated approach will likely be more effective than industrial development and environmental policy being taken as two separate goals.

Limitations and Future Research

There are some limitations of this study. Firstly, the analysis is based on aggregate country-level data and thus cannot address differences between individual industries and firms. Second, energy intensity is not a measure of industrial energy efficiency per se, but it is rather an economy-wide measure. Thirdly, the study identifies statistical associations and not causal effects. Using sector-level or firm-level data may allow for a comparison of whether energy intensity is a moderator for each of these different manufacturing activities and for construction. The sample of Asian economies is 11 and should not be viewed as representative of all Asian economies. Considering other indicators of industrialization, energy efficiency, and carbon intensity would also yield a more nuanced picture of the impact of industrial change on emissions in Asian economies.

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