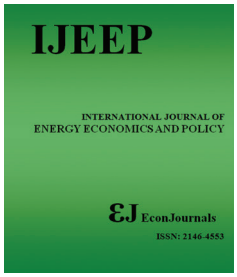

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# The Impact of Trade on Environmental Quality and Sustainable Development in ASEAN Region

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**ABSTRACT**

This study investigates the impact of trade on environmental quality and sustainable development in the ASEAN region, focusing on the long-term implications of trade liberalization under the ASEAN Free Trade Area (AFTA). While trade has played a central role in boosting economic growth and regional integration, concerns about its environmental consequences have intensified, particularly with rising carbon emissions, resource depletion, and ecological degradation. Using a dynamic Autoregressive Distributed Lag (ARDL) modeling approach, this study explores the relationship between trade openness, carbon dioxide ($CO_2$) emissions, and adjusted net savings as proxies for environmental sustainability and sustainable development. The empirical findings reveal a significant and negative long-run relationship between trade openness and both $CO_2$ emissions and adjusted net savings. This suggests that, without robust environmental and social safeguards, increased trade activities may exacerbate environmental degradation and compromise the region's long-term development goals. In contrast, the short-run effects appear weaker and mostly insignificant, implying that the detrimental impacts of trade develop progressively over time. These results challenge the conventional assumption that trade liberalization automatically promotes sustainable development. In the context of ASEAN, trade-driven growth may undermine environmental commitments outlined in the Sustainable Development Goals (SDGs), particularly those related to climate action and responsible consumption. The study underscores the urgent need for ASEAN policymakers to integrate trade policy with comprehensive environmental regulations to ensure that economic integration aligns with sustainability principles and intergenerational equity.

**Keywords:** Environmental Quality, Trade, Sustainable Development, ASEAN Region
**JEL Classifications:** F18, Q56, O44, Q01, C32

## 1. INTRODUCTION

In 1993, the member nations of the Association of Southeast Asian Nations (ASEAN) initiated the establishment of a free trade agreement (FTA) known as the ASEAN Free Trade Area (AFTA) (Okabe and Urata, 2014). Multiple motivations for the formation of AFTA can be identified. Initially, ASEAN policymakers believed that increasing intra-ASEAN trade would foster economic development among member countries, as the growth of exports would lead to output expansion and the rise in imports would enhance productive efficiency. The establishment of a comprehensive ASEAN market under AFTA would allow producers inside ASEAN to capitalize on the advantages of economies of scale. The increasing prevalence of regional trade agreements (RTAs), encompassing free trade agreements (FTAs) and customs unions, compels ASEAN members to establish an FTA, since they recognize that this trend may lead to discrimination against their products in export markets (Bun et al., 2009).

International trade has become one of the main pillars driving global economic growth, including in Southeast Asia, particularly since the implementation of various free trade agreements such as the ASEAN Free (Ainul Yaqin and Sulistyono, 2024). The liberalization of trade, especially through frameworks like AFTA

and RCEP, has led ASEAN countries to experience a significant increase in trade volume, foreign investment flows, and regional economic integration (Anwar and Kusairee, 2024).

Trade activities can stimulate economic growth, which in turn may indirectly lead to an increase in emissions (Idris and Rahman Razak, 2025). However, behind the economic growth supported by trade, through increased exports and investment, there is growing concern about its environmental impact, including pressures on the environment such as rising carbon emissions, deforestation, and the degradation of natural resources (Padhan and Bhat, 2023); (Bezrukova et al., 2024); (Harris, 2004). Intensive trade activities are often associated with higher carbon emissions, the exploitation of natural resources, and environmental degradation, particularly as trade volume and intensity increase across the ASEAN region (George et al., 2024); (Henley and Nordholt, 2015); (Dosch, 2010).

This condition raises an important question: Is economic growth driven by trade aligned with the principles of sustainable development? ASEAN countries have committed to the Sustainable Development Goals (SDGs), including environmental protection. Therefore, it is essential to examine whether trade liberalization in this region contributes positively to—or instead undermines, environmental sustainability and sustainable development. Amid ASEAN's commitment to the SDGs, particularly Goal 13 (Climate Action) and Goal 12 (Responsible Consumption and Production), this study is highly relevant in assessing how trade affects environmental outcomes and sustainable development in the region.

This study aims to investigate the impact of trade on environmental quality and sustainable development in the ASEAN region. Specifically, it seeks to analyze whether increased trade liberalization and economic integration, particularly under the ASEAN Free Trade Area (AFTA), have contributed to environmental degradation or supported sustainable development. By evaluating key environmental indicators such as carbon emissions, resource depletion, and ecological sustainability alongside trade metrics, the research will provide a comprehensive understanding of the trade-environment nexus in Southeast Asia.

While numerous studies have examined the economic implications of trade liberalization in ASEAN, relatively few have focused on its environmental consequences within the broader context of sustainable development. Most existing literature emphasizes trade's contribution to GDP growth or investment flows yet often overlooks the ecological costs and sustainability trade-offs involved. Moreover, studies that do address the environment typically focus on single countries or isolated indicators, lacking a regional perspective that reflects ASEAN's collective commitment to sustainability under frameworks like the SDGs.

The novelty of this research lies in its integrative approach that combines trade data, environmental quality indicators, and sustainable development goals to assess the multifaceted impact of trade in the ASEAN context. Unlike prior studies that analyze trade and environment separately, this research bridges both dimensions by evaluating how ASEAN's trade liberalization policies influence environmental outcomes and progress toward the SDGs. Furthermore, by employing recent datasets and regional panel analysis, this study provides updated insights that are highly relevant to current policy discussions on green growth and regional sustainability.

## 2. LITERATURE REVIEW

International trade is essential for stimulating economic growth and development. Countries engaging in open trade experience several advantages. Consumers can obtain a variety of goods and services, firms can leverage emerging technology globally, manufacturers can extend their market reach, and resources can be utilized more efficiently. The idea of comparative advantage in trade anticipates significant benefits from trade liberalization, highlighting the advantages of specialization rooted in comparative advantage (Jung, 2022). It is essential to acknowledge that trade liberalization can have substantial environmental consequences, especially in developing nations. A primary risk stems from potentially lenient environmental restrictions in these areas. This may result in practices detrimental to the environment. Concerns have been articulated over numerous environmental issues, including air and water pollution, habitat depletion, animal extinction, and the incorrect disposal of electronic and plastic garbage. Among these, global pollutants, particularly carbon dioxide emissions, emerge as significant focal areas; a key concept in this context is the pollution haven hypothesis (Kindo et al., 2024) This hypothesis posits that nations with less rigorous environmental rules may draw more pollution-intensive companies. They may take this action to reduce production expenses. This may result in a concentration of pollution-heavy activity in certain areas. Consequently, some contend that trade liberalization, especially without robust environmental protection, may result in increased environmental deterioration.

According to Antweiler et al., the consequences of trade liberalization on the environment are ultimately influenced by three primary factors: scale, technique, and composition effects. The scale effect refers to the impact of increased production, such as economic growth, on the environment (Antweiler et al., 2001). The technological effect pertains to the impact of income growth on the environment. This pertains to the impact of enforcing more rigorous environmental standards, which become viable as increased affluence heightens the demand for a superior environmental condition. The composition effect clarifies how the production structure impacts the environment, influenced by the level of trade openness and the comparative advantage of a certain country (Tsurumi and Managi, 2020). This effect may provide either favorable or unfavorable results, depending on a nation's resource availability and the effectiveness of its environmental regulations. Trade openness can increase production, elevate income levels, and transform output (Wu et al., 2022).

This study presents the subsequent contributions: This research innovatively examines the environmental Kuznets curve via the lens of trade protection, expanding the conventional Environmental Kuznets Curve hypothesis. By examining the three dimensions of trade, economy, and environment, it underscores the significance

of trade in sustainable development, offering policymakers insights into recognizing mechanisms of environmental effect (Sulaiman and Saboori, 2013); (Akca, 2021); (Destek and Sarkodie, 2019a).

This study conceptualizes nature, trade activities, and the economy as an integrated ecosystem, in contrast to traditional ecological studies that examine the interaction between species and their environment. It examines the influence of human activities and analyzes the effect of trade development on ecological restoration from a systemic viewpoint. This paper utilizes the threshold panel regression model, with trade as the threshold variable and industrial structure, foreign direct investment, and the globalization index as control variables, to examine the impact mechanism of trade on economic growth, carbon emissions, and ecological footprint. The research also encompasses the views of carbon emissions and ecological footprint, thoroughly assessing the outcomes for these two environmental factors. This article examines the economic-environmental correlation by integrating diverse variables into a cohesive assessment framework, thereby offering a thorough understanding of sustainability across several factors.

Numerous studies concentrate on international commerce and carbon emissions, with the majority asserting that worldwide trade can elevate carbon emissions (Kim and Tromp, 2021). Additionally, rising imports and exports contribute to a rise in consumption-based carbon emissions as well as carbon emissions from logistics and transportation (Shen et al., 2022); (Adebayo et al., 2021). Certain scholars propose that a positive correlation exists between imports and carbon emissions, while a negative correlation is observed between exports and carbon emissions (Jijian et al., 2021). Conversely, imports enhance $CO_2$ in low-income countries and detrimentally affect emissions in middle- and high-income groups (Muhammad et al., 2020). From a long-term viewpoint, imports elevate consumption-based carbon emissions, whereas exports substantially mitigate consumption-based $CO_2$, with sensitivity to policy alterations (Khan, 2020). Consumption-based carbon emissions, modified by international commerce, are more appropriate for assessing environmental impact, and an increase in exports can reduce the ratio of consumption-based carbon emissions (Jiang et al., 2022).

An increasing volume of research examining the correlation between ecological footprint and international trade is currently available (Okelele et al., 2021). The literature study indicated that several studies produced varied results regarding the association between trade openness and ecological impact (Al-Mulali and Ozturk, 2015); (Asici and Acar, 2016); (Charfeddine and Zouhair, 2017). Delineate the ecological footprint of consumption as the aggregate of the ecological footprint of production and the ecological footprint embedded in imports, excluding the ecological footprint of exports (Destek and Sarkodie, 2019b). The ecological footprints associated with imports increase the consumer ecological footprint, whereas those linked to exports decrease a country's ecological footprint. The impact of trade openness on ecological footprint is grounded in theoretical literature regarding the trade-environment nexus (Grossman and Krueger, 1991). Macroeconomic factors influencing the ecological footprint of consumption encompass international trade (Mrabet and Alsamara, 2017).

## 3. RESEARCH OBJECTIVE, METHODOLOGY AND DATA

This study employs panel data from ASEAN member states, concentrating on national-level information from 2000 to 2022 to examine the influence of trade activity on environmental quality and sustainable development. The data sources comprise World Development Indicators (WDI) provided by the World Bank. Panel data was selected due to its provision of enhanced information, increased variability, reduced collinearity across variables, augmented degrees of freedom, and superior efficiency in parameter estimation. The choice of study time and countries was dictated by the availability of data. Owing to the absence of data in Myanmar and Laos, which proved challenging to interpolate, the study concentrates on eight additional ASEAN nations.

Annual $CO_2$ emissions in tonnes were utilized as a proxy variable to indicate environmental quality, with data obtained from the Global Carbon Budget, and Adjusted Net Savings (ANS) serves as an indicator of sustainable development with statistics obtained from the World Bank (Kindo et al, 2024). $CO_2$ emission and ANS as the dependent variabelde and trade as independent variables. This study also introduces other variables that influence $CO_2$ emissions and ANS as control variables. This study identifies GDP Per capita, Energy, FDI and Natural resources rents as control factors based on previous research. The variables used and their sources are detailed in Table 1.

Considering that the number of time periods (T=23) surpasses the number of cross-sectional units (N=8), the variables are likely to exhibit non-stationarity and dynamism, This trait results in the variables exhibiting distinct orders of integration, such as I(0) and I(1) (Khan, 2020). Therefore, the suitable econometric technique to utilize is the ARDL panel model established (Pesaran and Smith, 1995). This model effectively captures both short- and long-term cointegration interactions among independent variables and offers an error correction technique to address short-term dynamics in panel data. In contrast to other dynamic panel methodologies like fixed effects, instrumental variables, or the Generalised Method of Moments (GMM), which may yield inconsistent parameter estimates unless coefficients are uniform across nations, the ARDL approach presents numerous advantages. The ARDL approach can produce more precise findings and mitigate autocorrelation difficulties by determining the ideal number of lags according to the variables' properties (Fajar et al., 2024).

The ARDL panel data estimation model is designed to integrate these dynamics, facilitating a thorough examination of both short-term adjustments and long-term equilibrium relationships. This method is especially advantageous for variables with mixed integration orders and offers a comprehensive framework for analyzing the interactions among economic variables throughout time. The estimating model derived from the ARDL Data Panel is

**Table 1: Variables used in model**

| Variable | Description | Source | Justification |
|---|---|---|---|
| Dependent variable | | | |
| $CO_2$ | Carbon dioxide ($CO_2$) emissions per capita as proxy for environmental quality (Tonnes) | Global Carbon Budget | (Song and Zhou, 2016); (Akbostanci et al., 2009); (Sharma, 2011); (Wang, 2012) |
| ANS | Adjusted Net Saving as proxy for Sustainable development (% of GNI) | World Bank | (Hamilton, 2000); (Twerefou et al., 2017) |
| Independent variable | | | |
| Trade | Trade: The net of exports and imports of goods and services (US Dollar) | World Bank | (Sharma, 2011); (Baek et al., 2009); (Jayanthakumaran and Liu, 2012); (Kirkpatrick et al., 2004) |
| Control variable | | | |
| GDP | Real GDP Per Capita (US Dollar) | World Bank | (Iwata et al., 2010); (He et al., 2010); (Franklin and Ruth, 2012); (Sharma, 2011) |
| Energy | Energy Consumption (Kg of oil equivalent per capita) | World Bank | (He et al., 2010); (Sharma, 2011); (Jayanthakumaran et al., 2012) |
| FDI | Foreign Direct Invesment (US Dollar) | World Bank | (Baek and Koo, 2009); (Jalil and Feridun, 2011); (Xing and Kolstad, 2002) |
| NRR | Natural Resources Rents (% of GDP) | World Bank | (Kirkpatrick et al., 2004); (Wenden, 2008) |

Source: own research, 2025

$$LnCO2_{it} = \varphi_i \left( LnCO2_{i,t-1} - \beta_1^{'} X_{it} \sum_{j=1}^{p-1} \right)$$
$$a_{ij}^{*} \Delta lnCO2_{i,t-j} + \sum_{j=0}^{q-1} \vartheta_{ij}^{*} \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \quad (1)$$

$$ANS_{it} = \varphi_i \left( ANS_{i,t-1} - \beta_1^{'} X_{it} \sum_{j=1}^{p-1} \right)$$
$$a_{ij}^{*} \Delta ANS_{i,t-j} + \sum_{j=0}^{q-1} \vartheta_{ij}^{*} \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \quad (2)$$

In this application, $\beta_i$ is a vector that measures the long-term impacts of independent variables, such as Trade, the principal variable of interest, in conjunction with other control variables, on the growth rate of carbon emissions and ANS. Simultaneously, $\varphi_i$ functions as an error correction method. The residual parameters encapsulate transient dynamics. The disturbances $\varepsilon_{it}$ are independently distributed over time and units, possessing a means of zero and a constant variance.

## 4. RESULTS AND DISCUSSION

### 4.1. Descriptive Statistics

Table 2 presents the summary statistics of the variables included in the investigation, offering insights into their distributional attributes. The data indicates substantial variation across all variables, especially GDP, Trade, and Government Expenditure, highlighting large discrepancies among ASEAN countries over the study period. The skewness and kurtosis values indicate that the majority of variables deviate from normal distribution, exhibiting large tails and a degree of positive skewness, particularly in variables such as GDP and government expenditure, which may signify the presence of outliers or rapidly growing economies.

The dependent variable, $CO_2$ emissions, has moderate variability and a slight right skew, indicating that while the majority of countries have comparatively low emissions, a minority possess substantially higher levels. The considerable variation in values across all categories underscores the heterogeneity in economic, environmental, and demographic conditions among ASEAN members. The discrepancies need the application of panel data analysis, enabling the examination to account for country-specific effects and temporal dynamics in evaluating the correlation between GDP and carbon emissions.

The analysis of $CO_2$ emissions trends for eight ASEAN countries from 2000 to 2022 reveals distinct patterns of emission growth and stability, seen in Figure 1. Carbon dioxide ($CO_2$) emissions across ASEAN countries have shown varying trajectories over the years, reflecting each nation's development path, industrial activity, and energy consumption patterns. Indonesia and Vietnam have experienced significant and consistent increases in emissions, indicating rapid economic growth accompanied by higher fossil fuel use. Malaysia and Thailand also showed steady rises, suggesting ongoing industrialization and energy demand. The Philippines exhibited moderate but continuous growth, while Singapore's emissions fluctuated, likely influenced by its status as a service-based economy with varying energy imports and exports. Cambodia, starting from very low emission levels, has seen sharp increases, signaling industrial emergence. In contrast, Brunei Darussalam's emissions remained relatively stable with minor fluctuations, consistent with its small population and oil-based economy. Overall, the data suggests a general upward trend in $CO_2$ emissions in the ASEAN region, highlighting the growing environmental challenges linked to economic expansion.

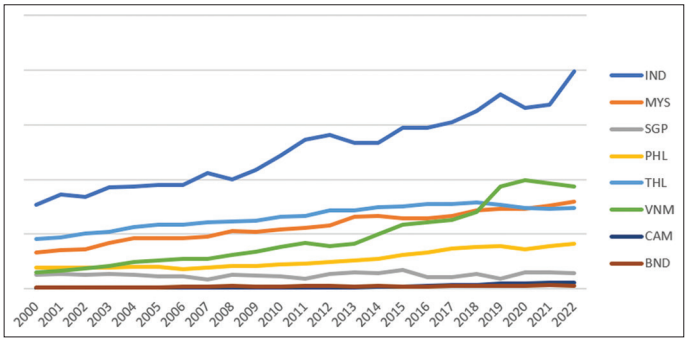
The analysis of ANS trends for eight ASEAN countries from 2000 to 20222 reveals diverse patterns across the region in Figure 2. The Adjusted Net Savings (ANS) trends across ASEAN countries reveal varied sustainability trajectories over the past two decades. Indonesia and the Philippines generally maintained positive ANS levels, indicating moderate but fluctuating sustainability efforts. Malaysia showed a significant decline in ANS after 2010, suggesting increased resource depletion or environmental degradation. Singapore displayed consistently high ANS levels, reflecting strong economic efficiency but with volatility in recent years. Thailand and Viet Nam demonstrated overall improvements, with some recent declines that may be linked to environmental or economic shifts. Cambodia showed a steady increase in ANS until a slight drop in the last years, while Brunei Darussalam recorded some of the highest ANS values in the region, though it

**Table 2: Summary statistic**

| Variable | Mean | Variance | Standard deviation | Skewness | Kurtosis | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 42.59895094 | 1822.288084 | 42.68826635 | 1.28352516 | 1.40921097 | 0.539 | 198.9310193 |
| ANS | 17.31514216 | 91.6078533 | 9.571199157 | 0.539658216 | −0.35004051 | 0.074555992 | 39.71457453 |
| Trade | 20659285866 | $7.85821e^{20}$ | 28032502174 | 3.094933001 | 13.18378349 | 91000000 | $2.02991e^{11}$ |
| GDP | 13251.36157 | 307344467.2 | 17531.2426 | 1.497658901 | 0.878478365 | 598.5619153 | 67948.89283 |
| Energy | 2502.820419 | 7279584.073 | 1698.070435 | 1.251112115 | 0.28454279 | 272.095279 | 9699.300252 |
| FDI | 6919438734 | $1.29827e^{20}$ | 11394146857 | 4.150475079 | 22.5751399 | 50992640 | 89386218569 |
| NRR | 9.21296708 | 112.5399889 | 10.60848664 | 1.148117389 | 0.035467079 | 0.000169266 | 37.40658778 |

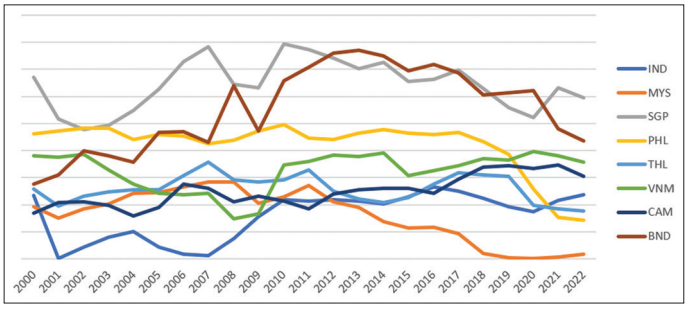
Source: Own research, 2025

**Figure 1:** Carbon emission trend in eight ASEAN countries, annual $CO_2$ (2000-2022)




Source: Own Research, 2025

**Figure 2:** ANS trend in eight ASEAN countries (2000-2022)

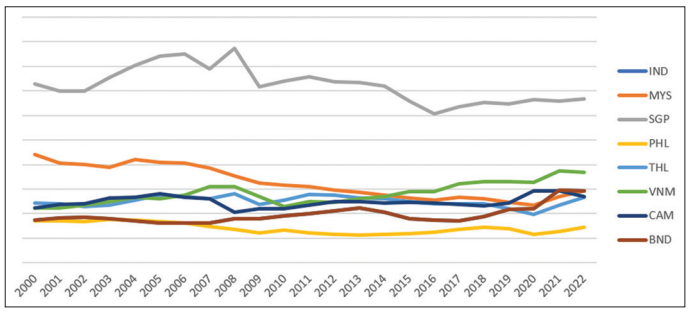



Source: Own research, 2025

too has seen recent reductions. These patterns highlight the diverse challenges and progress in sustainable development efforts across the ASEAN region.

The analysis of trade trends for eight ASEAN countries from 2000 to 20222 reveals diverse patterns across the region in Figure 3. Trade conditions in ASEAN countries have exhibited significant fluctuations over the years, reflecting diverse economic trajectories and external influences. Singapore consistently leads the region with the highest trade volumes, underlining its role as a global trade hub. Malaysia and Thailand also maintain relatively strong and stable trade activities, while Indonesia shows more variability but demonstrates a notable upward trend in recent years. The Philippines and Viet Nam display steady growth, especially after 2015, indicating strengthening trade engagement. Meanwhile, Cambodia and Brunei Darussalam experience smaller trade volumes, with occasional spikes and declines, suggesting more volatile or resource-dependent trade dynamics. Overall, ASEAN trade data reveals both shared growth momentum and individual country disparities shaped by economic structure, policy, and global market integration.

**Figure 3:** Trade activity trend in eight ASEAN countries (2000-2022)




Source: Own research, 2025

The scatter plots in Figure 4 illustrate the relationships between Trade activity and dependent variables, namely $CO_2$ Emission and ANS across ASEAN Countries.

The plot depicting the relationship between Trade (LnTR) and $CO_2$ emission (LnCO2) shows a strong positive correlation, indicating that as Trade increases, carbon dioxide emissions also increase. This relationship confirms the environmental trade-off in trade activity, where industrial activity and increased energy consumption contribute significantly to carbon emissions. ANS also shows a slight positive correlation with Trade, indicating that higher trade openness may increase sustainable development due to increased economic activity.

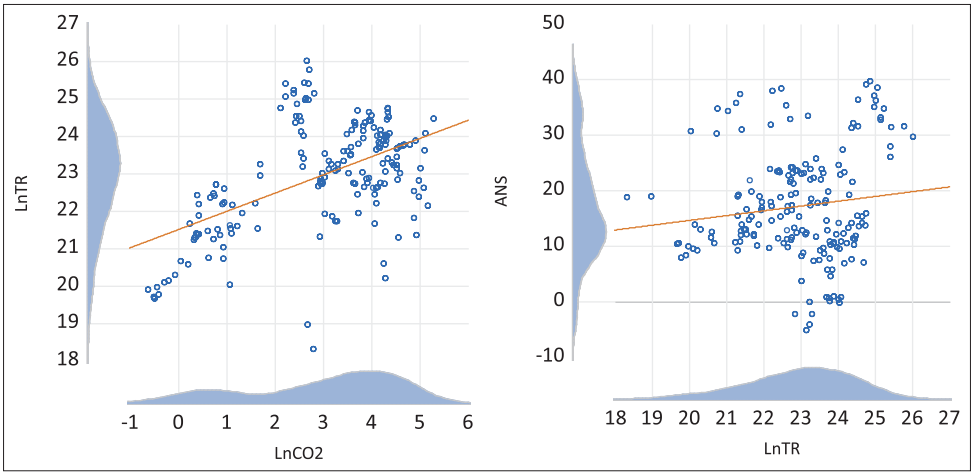
## 4.2. Stationarity and Co-Integration Analysis

We utilize the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests to evaluate the stationarity of the variables at their levels (I(0)) and first differences (I(1)). The existence of a long-term link is assessed by the ARDL bounds co-integration test.

Panels A and B of Table 3 demonstrate that the majority of variables display a high degree of stationarity when assessed in their first differences, as evidenced by the significance level. All variables such as $CO_2$, ANS, Trade, GDP, Energy, FDI and NRR exhibit significant stationarity in their first differences. This indicates that these variables are integrated of order one, I(1), signifying that they demonstrate steady behavior when examined in their period-to-period changes.

Based on the results presented in Table 4, the Pedroni Cointegration Test indicates evidence of long-run cointegration in both Model 1 and Model 2, although the strength of the evidence varies. In Model 1, all three test statistics, Modified Phillips-Perron t, Phillips-Perron t, and Augmented Dickey-Fuller t, show statistically significant results, confirming the presence of long-run

**Figure 4:** Scatter plots for independent and towards dependent variables




Source: Own research, 2025

**Table 3: Panel unit root test results**

| Variable | Level I (0) | | First Difference I (1) | |
|---|---|---|---|---|
| | Intercept | Intercept/Trend | Intercept | Intercept/Trend |
| Panel A: ADF test result | | | | |
| $LnCO_2$ | 1.10312 | −1.37955 | −5.81534*** | −4.48105*** |
| ANS | −0.49912 | 0.46048 | −5.53257*** | −4.77630*** |
| LnTR | −0.40311 | −1.48482 | −6.38891*** | −4.96195*** |
| LnGDP | 1.12979 | −1.12200 | −6.09726*** | −5.37458*** |
| LnEN | 0.89290 | −4.645512*** | −9.843458*** | −4.30292*** |
| FDI | −0.81915 | −1.65899 | −7.65085*** | −6.27241*** |
| NRR | 0.27017 | 0.12800 | −7.49284*** | −6.17604*** |
| Panel B: PP test results | | | | |
| $CO_2$ | −0.09827 | −0.91120 | −9.28511*** | −9.81360*** |
| ANS | 0.69641 | 1.11283 | −8.43074*** | −8.67508*** |
| LnTR | −0.60320 | −2.20936** | −10.4277*** | |
| LnGDP | 1.19401 | 0.91561 | −7.14686*** | −7.31075*** |
| LnEN | 1.02398 | −0.01948 | −8.07825*** | −7.62822** |
| FDI | −2.36969*** | −63.20478*** | | |
| NRR | −0.64272 | −2.02411** | −10.6915*** | −9.95425*** |

*P<0.10, **P<0.05, ***P<0.01
Source: Own research, 2025

**Table 4: Pedroni cointegration test**

| Test | Statistics | P-value | Conclusion |
|---|---|---|---|
| Model 1 | | | |
| Modified Phillips-Perron t | 2.862 | 0.003 | Long-Run Cointegration |
| Phillips-Perron t | 4.715 | 0.000 | Long-Run Cointegration |
| Augmented Dickey-Fuller t | 3.908 | 0.000 | Long-Run Cointegration |
| Model 2 | | | |
| Modified Phillips-Perron t | 1.402 | 0.601 | No Long-Run Cointegration |
| Phillips-Perron t | 3.118 | 0.001 | Long-Run Cointegration |
| Augmented Dickey-Fuller t | 4.543 | 0.000 | Long-Run Cointegration |

Source: Own research, 2025

cointegration among the variables. In contrast, Model 2 presents a mixed outcome: while the Modified Phillips-Perron t statistic does not support cointegration, both the Phillips-Perron t and Augmented Dickey-Fuller t statistics are significant, suggesting that long-run relationships still exist. These findings imply that despite some inconsistencies across individual test components, there is substantial evidence of long-run equilibrium in both models.

The results of the stationarity and co-integration analysis offer significant insights into the dynamics of the variables inside sustainable development and environmental quality models. The stationarity of variables in their first differences indicates that short-term dynamics and shocks can be accurately captured and studied. Moreover, co-integration denotes a solid and persistent relationship among the variables, providing a basis for examining both short- and long-term interactions.

### 4.3. Impact of Trade on Environmental Quality and Sustainable Development

The empirical findings in Tables 5 and 6 elucidate the short-term and long-term links among trade, environmental quality, and sustainable development in ASEAN. These findings offer essential insights. Insights into the intricate interplay of elements affecting ASEAN's pursuit of sustainable development goals.

**Table 5: Short-run ARDL model**

| Variables | EQ-Model | SD-Model |
|---|---|---|
| D (LnTR) | 0.029873 (0.1788) | 0.828416 (0.3342) |
| D (LnTR(−1)) | 0.034981 (0.0878)* | 0.097562 (0.9376) |
| D (LnGDP) | 0.387820 (0.2260) | 9.358375 (0.5205) |
| D (LnGDP(−1)) | 0.018216 (0.9517) | 9.681501 (0.4249) |
| D (LnEN) | 0.804201 (0.0230)** | 6.228797 (0.1204) |
| D (LnEN(−1)) | 0.550502 (0.0001)*** | −16.35161 (0.0251)** |
| D (FDI) | 0.022983 (0.3893) | −0.0730775 (0.7799) |
| D (FDI(−1)) | −0.001833 (0.3004) | −0.265693 (0.8044) |
| D (NRR) | 0.104534 (0.3004) | 0.135421 (0.8523) |
| D (NRR(−1)) | 0.435747 (0.3202) | −0.435956 (0.3252) |
| Constant | 1.471775 (0.02308)** | 6.67260 (0.0763)* |

*P<0.10, **P<0.05, ***P<0.01
Source: Own research, 2025

**Table 6: Long-run ARDL model**

| Variables | EQ-Model | SD-Model |
|---|---|---|
| LnTR | −0.306224 (0.0515)** | −2.093364 (0.0015)**** |
| LnGDP | 1.672329 (0.0030)*** | 8.140737 (0.0033)*** |
| LnEN | 0.440106 (0.0117)** | 12.96430 (0.0001)*** |
| FDI | −0.105998 (0.0310)** | −0.819466 (0.1202) |
| NRR | 0.056347 (0.1462) | 0.734527 (0.0000)*** |
| Error Correction Term (ECT) (−1) | −1.183068 (0.0000)*** | −0.988651 (0.0452)*** |

*P<0.10, **P<0.05, ***P<0.01
Source: Own research, 2025

In the short-run estimation for the Environmental Quality, the impact of trade on environmental quality, measured through $CO_2$ emissions, appears to be statistically weak in the current period but shows mild significance in the one-period lag. The coefficient of the first difference of trade is positive, indicating an insignificant immediate effect. However, the one-period lag of trade yields a positive and is marginally significant at the 10% level. This suggests that past increases in trade levels may lead to a short-run deterioration in environmental quality, implying that trade expansion could be associated with higher emissions, potentially due to increased industrial activity or relaxed environmental standards.

Regarding the control variables, energy consumption shows a highly significant and positive effect on $CO_2$ emissions in both the current and lagged periods, highlighting that increased energy use, likely from non-renewable sources, contributes to environmental degradation. This reinforces the need to manage energy intensity in economic activities, especially if trade-induced growth leads to higher energy demands. GDP per capita, foreign direct investment, and natural resource rents do not exhibit significant short-run effects in this model, suggesting that their influence on environmental quality may be more pronounced in the long run. Environmental quality implies that in the short run, trade may have a lagged, adverse effect on environmental quality, especially when accompanied by increased energy consumption. While trade liberalization can stimulate economic activity, the results highlight the environmental cost of such progress, emphasizing the necessity of complementary environmental regulations and clean energy adoption.

In contrast, the short-run results for Sustainable Development, where is proxied by Adjusted Net Savings (ANS), reveal that trade does not significantly influence sustainable development in the short run. Both the current and lagged first differences of trade are statistically insignificant. Although the positive signs of the coefficients suggest a potential association between trade and sustainability gains, the lack of statistical significance implies that trade alone may not generate immediate improvements in sustainability, possibly due to lagging structural adjustments or environmental externalities associated with trade expansion.

Among the control variables, energy consumption again plays a crucial role. The current period's energy use is positively related to sustainable development but not statistically. However, the one-period lag of energy has a significant and negative effect on Sustainable Development, suggesting that energy use may have delayed harmful consequences for sustainability. This result indicates a trade-off in the short run between energy-driven growth and the depletion of resources or environmental assets critical for sustainable development. GDP, FDI, and NRR are statistically insignificant, reflecting limited short-term influence on the sustainability indicator used in this model. Overall, the SD-model demonstrates that trade does not yield immediate benefits to sustainable development in the short run, and energy use may even undermine sustainability goals. The findings emphasize the importance of integrating long-term environmental planning and investment in green infrastructure to ensure that trade and economic growth are aligned with sustainability objectives.

In the long-run model for Environmental Quality, trade exerts a statistically significant and negative influence on environmental quality. This result implies that, over the long term, trade liberalization is associated with a reduction in environmental quality, proxied by higher $CO_2$ emissions. This finding aligns with the pollution haven hypothesis, suggesting that increased trade may lead to the relocation of pollution-intensive industries to countries with less stringent environmental regulations, thereby exacerbating environmental degradation in the long run.

Furthermore, GDP per capita demonstrates a significant positive effect on $CO_2$ emissions, indicating that economic growth, in the absence of environmental safeguards, tends to degrade environmental quality. Similarly, energy consumption also has a positive and significant impact, reaffirming that reliance on energy, potentially from fossil fuel sources, contributes to long-term environmental harm. Foreign direct investment negatively affects environmental quality, which may suggest that FDI in this context is not environmentally friendly or that it fuels emission-heavy industries. Natural resource rents, on the other hand, are not statistically significant in the long run.

The error correction term (ECT) is negative and highly significant, confirming the existence of a stable long-run equilibrium relationship. The relatively large magnitude of the ECT suggests a strong adjustment speed toward equilibrium after a shock, with over-adjustment possible. In summary, environmental quality indicates that trade has a detrimental long-run impact on environmental quality, and this effect is reinforced by economic growth, energy consumption, and certain forms of investment.

In Sustainable Development, trade has a substantial and statistically significant negative effect on sustainable development. This indicates that, in the long term, increased trade is associated with a deterioration in sustainability levels, as measured by Adjusted Net Savings (ANS). This adverse effect may be driven by trade patterns that emphasize short-term economic gain at the expense of natural capital and environmental conservation, undermining the capacity for intergenerational equity and long-term development.

In contrast to the environmental quality, natural resource rents show a significant and positive effect in sustainable development, suggesting that effective management and utilization of natural resources can support sustainable development. GDP per capita and energy consumption also significantly improve sustainable development, with large positive coefficients, which may reflect the role of economic prosperity and energy availability in enhancing investment in education, health, and infrastructure that contribute to sustainable development. Interestingly, FDI does not appear to have a significant long-run impact on sustainability in this model.

The error correction term is negative and significant, validating the model's long-run stability. The adjustment speed is slightly slower compared to the environmental quality but still strong, indicating convergence to the long-run path. Overall, sustainable development reveals that, despite economic and energy-driven progress, trade undermines sustainability in the long term, highlighting the need for policy interventions that align trade flows with sustainable practices.

A comparison between environmental quality and sustainable development reveals that trade has a significantly negative impact on both environmental quality and sustainable development in the long run. However, the magnitude of the impact is considerably greater in the Sustainable development, suggesting that trade-related activities may have broader and more profound effects on sustainability than on environmental degradation alone. While energy consumption and GDP positively affect both outcomes, their implications differ: in Environmental quality, they worsen emissions, whereas in sustainable development, they support broader development goals, possibly due to more efficient resource allocation or investments in sustainability.

When comparing short-run and long-run results, it becomes evident that the impact of trade on both environmental quality and sustainable development is more pronounced in the long run. In the short run, trade effects are mostly insignificant or only weakly significant, with slight or delayed consequences on $CO_2$ emissions and virtually no influence on sustainability. In contrast, the long-run findings show a clear, consistent, and significant negative relationship between trade and both outcome variables. This suggests that the harmful effects of trade may accumulate over time or manifest after structural adjustments take place. These differences underscore the importance of adopting long-term environmental and trade policies, as short-term data may underestimate the lasting consequences of trade liberalization on environmental and developmental outcomes.

### 4.4. Discussion

This study set out to investigate the impact of trade activities on environmental quality and sustainable development in the ASEAN region. The main objective was to examine whether increasing trade openness contributes to better or worse environmental and developmental outcomes. To capture these two dimensions, the study employed $CO_2$ emissions as a proxy for environmental quality and Adjusted Net Savings (ANS) as a proxy for sustainable development. The ARDL modeling approach was applied to assess both the short-run and long-run dynamics between trade and the outcome variables, while controlling for the effects of GDP per capita, energy consumption, foreign direct investment, and natural resource rents.

The empirical findings reveal a consistent and negative long-run relationship between trade and both environmental quality and sustainable development. In other words, greater trade openness in the ASEAN region appears to be associated with deteriorating environmental conditions and weaker sustainable development over time. This result suggests that the benefits of increased trade may come at the expense of environmental integrity and long-term development goals, particularly in the absence of adequate environmental safeguards and regulatory frameworks.

For environmental quality, the analysis indicates that trade expansion is linked with higher carbon emissions, reflecting a possible "pollution haven" effect. As ASEAN countries become more integrated into global markets, industries with high pollution intensities may relocate to regions with more lenient environmental regulations. This trend exacerbates environmental degradation, suggesting that trade policies in the region may prioritize economic gains over ecological sustainability.

In terms of sustainable development, the findings suggest that trade also has a detrimental long-term impact. This could be attributed to trade structures that emphasize short-term economic benefits rather than inclusive and sustainable growth. Export-driven growth strategies may exploit natural resources unsustainably, undermine social equity, and limit investments in human capital, all of which are essential components of sustainable development. Despite potential gains in income, these benefits may not translate into long-term prosperity if trade-related activities deplete natural capital and erode institutional capacity to support development.

Interestingly, the short-run analysis reveals weaker and often insignificant effects of trade on both environmental quality and sustainable development. This discrepancy between short- and long-run results highlights the cumulative nature of trade-related impacts, which may not manifest immediately but become significant over time. It underscores the need for ASEAN policymakers to adopt a forward-looking approach that considers the delayed consequences of trade liberalization on the environment and broader development goals.

The role of control variables further contextualizes the trade-development nexus. GDP per capita and energy consumption, for instance, were found to have dual effects, contributing positively

to economic growth and sustainable development, yet also associated with increased environmental degradation. This duality emphasizes the importance of transitioning to cleaner energy sources and promoting green growth strategies that decouple economic development from environmental harm. Moreover, the results show that natural resource management can positively influence sustainable development, but only when managed effectively and aligned with sustainability objectives.

These findings challenge the traditional notion that trade automatically leads to development and improved welfare. In the ASEAN context, trade appears to present both opportunities and risks. Without complementary policies that enforce environmental standards, promote green investment, and ensure equitable distribution of benefits, trade may exacerbate inequality and ecological decline. Thus, trade policy must be integrated with environmental and developmental planning to ensure that growth is inclusive, resilient, and sustainable.

Ultimately, this study contributes to a growing body of literature emphasizing the complexity of the trade-environment-development relationship. It calls for a rethinking of ASEAN's trade strategies to align more closely with the principles of sustainable development. Regional cooperation and policy harmonization may be key in addressing the transboundary nature of environmental degradation and in fostering collective action toward a more sustainable future for the ASEAN region.

## 5. CONCLUSION

This study examined the impact of trade on environmental quality and sustainable development in the ASEAN region by employing a dynamic ARDL modeling approach. The findings reveal a significant and negative long-run relationship between trade openness and both $CO_2$ emissions and adjusted net savings, indicating that increased trade activities, in the absence of environmental and social safeguards, may undermine environmental sustainability and long-term development in the region. The short-run results, however, show a weaker and mostly insignificant influence, suggesting that the adverse effects of trade manifest gradually over time.

The results challenge the optimistic assumption that trade liberalization inherently leads to development and improved environmental outcomes. Instead, trade in the ASEAN region appears to facilitate economic activities that contribute to environmental degradation and hinder sustainable development progress. These findings highlight the importance of integrating trade policy with comprehensive environmental and development strategies to ensure that economic integration does not come at the cost of ecological integrity and intergenerational equity.

In light of the findings, ASEAN policymakers should prioritize the implementation of green trade policies that align economic openness with environmental sustainability. This includes establishing stronger environmental regulations and standards across the region to prevent the relocation of polluting industries to countries with weaker enforcement, and promoting cleaner production practices through incentives, tax reforms, and technology transfers.

Furthermore, there is an urgent need to restructure trade and investment strategies to support sustainable sectors such as renewable energy, sustainable agriculture, and eco-tourism. Trade agreements should incorporate environmental and social clauses that encourage responsible resource use and ensure that the benefits of trade are equitably distributed across populations, particularly among vulnerable and marginalized groups.

ASEAN member states should enhance regional cooperation and institutional capacity to address the transboundary nature of environmental challenges. This can be achieved through coordinated monitoring systems, capacity-building programs, and shared innovation platforms aimed at integrating sustainability into trade governance. By fostering a shared vision of green development, ASEAN can transform trade into a catalyst for both economic resilience and environmental preservation.

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