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**Energy Consumption, Exports, Foreign Direct Investment,  
and Economic Growth in ASEAN-5:  
The Mediating Role of Greenhouse Gas Emissions**

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**Abstract:** This study examines how greenhouse gas (GHG) emissions mediate the relationships between per capita energy consumption, exports, foreign direct investment (FDI), and economic growth in the ASEAN-5 economies. A panel of Indonesia, Malaysia, the Philippines, Singapore, and Thailand from 1991 to 2023 is estimated using two linked panel-regression equations. Estimator selection follows the Chow and Hausman tests, and indirect effects are evaluated using the Sobel product-of-coefficients test. The results show that per capita energy consumption and FDI significantly increase GHG emissions, whereas exports reduce them. In the growth equation, energy consumption and exports have negative direct associations at the 10 percent level, FDI has a positive association at the 5 percent level, and GHG emissions have a negative association at the 5 percent level. All three indirect effects are statistically significant, the emission channel reinforces the negative relationship between energy and growth, offsets part of the negative relationship between exports and growth, and reduces the positive contribution of FDI to growth. The study's main contribution is to demonstrate that a common environmental mediator operates differently across major growth drivers. The findings support ASEAN strategies centered on energy productivity, low-carbon export upgrading, green-FDI screening, and interoperable regional carbon-management frameworks.

**Keywords:** Energy Consumption, Exports, Foreign Direct Investment, Greenhouse Gas Emissions, Economic Growth, ASEAN-5

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## **Introduction**

Economic growth remains a central development objective because it expands productive capacity, employment, and the fiscal resources available to improve welfare. In emerging economies, however, rapid growth is frequently accompanied by rising energy demand, intensive resource use, and environmental degradation. The policy challenge is therefore no

longer limited to accelerating output; it also involves improving the environmental quality of the growth process (Prastiwi et al., 2025; Harsono et al., 2024).

This challenge is particularly visible in the ASEAN-5 economies. Indonesia, Malaysia, the Philippines, Singapore, and Thailand experienced a common contraction in 2020, followed by an uneven recovery between 2021 and 2023. The episode revealed both the region's capacity to rebound and its continuing exposure to external shocks, supply-chain disruptions, energy-price volatility, and changes in global demand. These economies also differ substantially in income level, industrial structure, energy intensity, export composition, and capacity to finance a low-carbon transition.

Energy consumption is indispensable to production, transportation, digital infrastructure, and household activity. The energy-growth nexus treats energy as an enabling input that complements capital and labor in the production process (Stern, 2004; Fernandes, 2023). In ASEAN-5, however, the growth contribution of energy remains closely tied to a fossil-intensive energy mix. Higher energy use can expand output, but it can also increase production costs when energy systems are inefficient and generate environmental and health externalities when fossil fuels dominate (Azmin et al., 2022; Yusoff et al., 2024).

Exports and FDI constitute two additional channels through which ASEAN economies are integrated into the global economy. Export expansion can enlarge markets, improve capacity utilization, encourage learning by exporting, and support productivity growth. FDI can supplement domestic capital, introduce new technologies and management practices, and connect host economies to global production networks (Balassa, 1978; Borensztein et al., 1998). Nevertheless, the environmental consequences of trade and investment depend on sectoral composition, production technology, and regulatory quality. Carbon-intensive manufacturing and resource-based exports may increase emissions, while technology-intensive exports and environmentally responsible FDI may improve efficiency and reduce emission intensity (Copeland & Taylor, 2004).

GHG emissions therefore represent more than an environmental outcome. They can function as an economic transmission mechanism. Rising emissions may initially accompany industrial expansion, but persistent environmental pressure can reduce labor productivity, increase health expenditure, damage ecosystems and infrastructure, and raise adaptation and mitigation costs. In this sense, emissions may alter the ultimate growth effects of energy consumption, exports, and FDI rather than merely occur alongside them (Rusiadi et al., 2024; Marwa et al., 2022).

The regional policy agenda increasingly recognizes this interdependence. The ASEAN Plan of Action for Energy Cooperation 2021-2025 placed energy connectivity, security, affordability, sustainability, and an accelerated energy transition at the center of regional cooperation (ASEAN Centre for Energy, 2020). The ASEAN Strategy for Carbon Neutrality subsequently emphasized green industries, credible standards, regional interoperability, and green capabilities as foundations for combining decarbonization with economic competitiveness (ASEAN Secretariat, 2023). These commitments are also closely related to Sustainable Development Goals 7, 8, 9, 12, and 13, which connect clean energy, productive growth, industrial upgrading, responsible production, and climate action.

Despite this policy relevance, the research problem remains insufficiently resolved. Most studies examine the energy-growth, export-growth, FDI-growth, or emissions-growth nexus in separate models, while Environmental Kuznets Curve studies generally treat economic growth as a determinant of emissions. As a result, the literature provides limited evidence on whether the environmental consequences generated by energy use, trade, and foreign investment subsequently reinforce or weaken their direct associations with economic growth.

Three related gaps motivate this study. First, the three economic drivers are rarely assessed simultaneously within a common ASEAN-5 growth framework. Second, GHG emissions are usually modeled as a final environmental outcome rather than as a transmission channel that can feed back into economic performance. Third, limited evidence decomposes and compares the direct, emission-mediated, and total growth associations of energy consumption, exports, and FDI over a long balanced panel. These gaps make it difficult to determine whether the environmental channel reinforces or offsets the conventional growth mechanisms associated with each driver.

Accordingly, this study asks to what extent are per capita energy consumption, exports, and FDI associated with ASEAN-5 economic growth directly and indirectly through GHG emissions. The study contributes theoretically by integrating the energy-growth, export-led growth, FDI-led growth, and growth-environment perspectives; methodologically by applying a product-of-coefficients mediation test within linked panel regressions; and empirically by identifying whether the emission channel reinforces or offsets the direct growth association of each explanatory variable.

## Literature Review

### *Energy-Growth Nexus*

The energy-growth nexus begins from the proposition that energy is a productive input whose availability, quality, and efficiency influence economic output. Under the growth hypothesis, increased energy consumption supports production and therefore precedes economic growth. The conservation hypothesis reverses the direction, suggesting that growth determines energy demand and that energy-saving policies may have limited output effects. The feedback hypothesis assumes bidirectional interaction, while the neutrality hypothesis expects no systematic relationship. These possibilities imply that the sign and magnitude of the energy coefficient depend on development stage, energy efficiency, prices, and the structure of production (Stern, 2004; Khan et al., 2020).

For ASEAN economies, energy use has frequently been found to move with output and emissions because industrialization, urbanization, and transport remain energy intensive (Azmin et al., 2022; Yusoff et al., 2024). Recent panel evidence also emphasizes that renewable-energy deployment can mitigate environmental degradation, while fossil-intensive energy systems and rebound effects continue to complicate decoupling in Southeast Asia (Kostakis, 2024; Somosi et al., 2024). Yet a positive energy-output relationship is not automatic. Inefficient conversion, fossil-fuel dependence, imported-energy exposure, and congestion or pollution costs can cause additional energy use to be associated with weaker growth. Thus, the energy-growth nexus should be assessed jointly with the environmental consequences of the energy system.

### ***Export-Led Growth and the Trade-Environment Nexus***

The export-led growth hypothesis argues that external demand raises output by expanding market size, enabling economies of scale, increasing foreign-exchange earnings, and exposing firms to international competition and learning opportunities (Balassa, 1978). Empirical studies commonly report a long-run connection between exports and growth, although the outcome depends on export diversification, domestic value added, technological content, and vulnerability to global demand shocks (Chowdhury, 2024; Prasetyo & Susandika, 2022).

Trade can affect environmental quality through scale, composition, and technique effects. A larger scale of production tends to increase resource use and emissions. The composition effect depends on whether trade specialization shifts production toward cleaner or more pollution-intensive sectors. The technique effect may reduce emissions when trade facilitates newer technology, higher standards, and more efficient production (Copeland & Taylor, 2004). Consequently, exports may either raise or reduce domestic GHG emissions, and their overall growth contribution may differ from the environmental channel through which they operate.

### ***FDI-Led Growth and Environmental Effects***

FDI-led growth theory emphasizes foreign investment as a source of capital accumulation, technology transfer, managerial capability, market access, and productivity spillovers. These gains are stronger when host economies possess adequate human capital, institutions, and absorptive capacity (Borensztein et al., 1998; Kurteš et al., 2022). The positive growth contribution of FDI is therefore conditional on the quality and sectoral allocation of investment rather than the volume of inflows alone.

The environmental impact of FDI is also theoretically ambiguous. The Pollution Haven Hypothesis suggests that pollution-intensive activities may relocate to economies with lower production costs or less stringent environmental regulation. Conversely, the pollution-halo argument expects multinational firms to introduce cleaner technology, environmental management, and more efficient production. Recent ASEAN evidence indicates that both mechanisms may arise depending on the scale, composition, and stage of foreign investment, although several studies continue to find environmental pressure from FDI-intensive development (Al Numan et al., 2025; Kholil et al., 2025). These competing mechanisms make GHG emissions a relevant channel for distinguishing the direct capital and technology benefits of FDI from its possible environmental costs.

### ***Growth-Environment Nexus and the Mediating Role of GHG Emissions***

The Environmental Kuznets Curve proposes that environmental degradation may rise during early industrialization and decline after income reaches a turning point, when cleaner technology, structural change, and stronger regulation become more prominent (Grossman & Krueger, 1995). Evidence for ASEAN remains mixed because the region combines economies at different development stages and with different energy and industrial structures (Bhatti et al., 2020; Ali et al., 2023). More recent evidence likewise finds continuing difficulties in decoupling robust economic expansion from ecological pressure across ASEAN economies (Naz et al., 2024). The framework therefore does not imply that

emissions automatically decline with income; policy, technology, and institutional capacity remain decisive.

From an externality perspective, emissions can feed back into economic performance. Air pollution and climate-related risks affect health, agricultural productivity, infrastructure, tourism, and public expenditure. A negative emissions-growth coefficient is therefore consistent with the proposition that environmental damage imposes economic costs (Rusiadi et al., 2024). At the same time, a positive correlation may occur in fossil-dependent economies when emissions proxy the scale of industrial activity (Marwa et al., 2022).

Bringing these perspectives together produces a mediation mechanism. Energy consumption, exports, and FDI first influence GHG emissions; emissions then influence growth. The indirect effect is the product of the coefficient linking each explanatory variable to emissions and the coefficient linking emissions to growth. When the direct and indirect effects have the same sign, the environmental channel reinforces the direct relationship. When their signs differ, the environmental channel offsets part of the direct relationship. This framework provides a clearer explanation of how growth drivers may generate simultaneous economic benefits and environmental costs (Sobel, 1982; Zhao et al., 2010).

### ***Empirical Synthesis and Research Positioning***

Existing ASEAN studies document significant linkages among energy consumption, economic growth, renewable energy, trade, investment, and emissions (Azmin et al., 2022; Yusoff et al., 2024; Zeeshan et al., 2022). Recent research has broadened this evidence by examining renewable energy and financial openness, regional decoupling, dynamic renewable-energy responses, and nonlinear FDI-environment relationships (Kostakis, 2024; Naz et al., 2024; Somosi et al., 2024; Al Numan et al., 2025). Other evidence shows that exports and FDI can support growth, although their effects vary with openness, governance, technology, and domestic productive capacity (Nketiah et al., 2020; Prasetyo & Susandika, 2022). However, these studies still predominantly model emissions as an environmental outcome rather than a mediator of the growth process.

The present study differs from these strands by estimating the three economic drivers simultaneously and decomposing their growth associations into direct, emission-mediated, and total effects. This positioning does not claim that the individual nexus relationships are new; rather, the contribution lies in comparing how one environmental channel operates across three distinct growth mechanisms. The framework is particularly relevant for ASEAN-5 because these economies combine strong trade and investment integration with persistent fossil-energy dependence and heterogeneous transition capacity.

### **Methods**

This study uses a quantitative explanatory design based on a balanced annual panel of five ASEAN economies - Indonesia, Malaysia, the Philippines, Singapore, and Thailand - from 1991 to 2023. The sample contains 165 country-year observations. The countries were selected because they account for a substantial share of ASEAN output and trade, represent different development and energy structures, and provide sufficiently complete annual data over the study period.

The variables are annual economic growth (EG, percent change in real GDP), GHG emissions (GHG, GtCO<sub>2</sub>e), per capita energy consumption (PEC, kWh per person), exports (EXP, current US dollars), and foreign direct investment (FDI, current US dollars). Energy data are obtained from Our World in Data; growth, exports, and FDI data are obtained from the World Bank; and emissions data are obtained from the Emissions Database for Global Atmospheric Research (EDGAR). GHG emissions are expressed in carbon-dioxide-equivalent units so that major greenhouse gases can be aggregated consistently.

Panel regression is combined with path analysis because the research question concerns both cross-country/time variation and a specific transmission mechanism. A standard cross-sectional path model would ignore repeated observations within countries, while a single panel-growth equation would not identify the emission channel separately. The linked-equation approach estimates (i) how the three explanatory variables are associated with emissions and (ii) how the same variables and emissions are associated with growth. Country-specific panel effects account for unobserved time-invariant heterogeneity across the ASEAN-5 economies.

The structural relationships are specified as follows:

$$GHG_{it} = \alpha_0 + \alpha_1 PEC_{it} + \alpha_2 EXP_{it} + \alpha_3 FDI_{it} + u_i + \varepsilon_{1it} \quad (1)$$

$$EG_{it} = \beta_0 + \beta_1 PEC_{it} + \beta_2 EXP_{it} + \beta_3 FDI_{it} + \beta_4 GHG_{it} + v_i + \varepsilon_{2it} \quad (2)$$

In Equation (1),  $\alpha_1$ ,  $\alpha_2$ , and  $\alpha_3$  measure the associations of PEC, EXP, and FDI with GHG emissions. In Equation (2),  $\beta_1$ ,  $\beta_2$ , and  $\beta_3$  measure their direct associations with EG after accounting for GHG, while  $\beta_4$  captures the GHG-EG relationship. The country effects  $u_i$  and  $v_i$  are treated as fixed or random according to the specification tests.

The estimator for each equation is selected sequentially. The Chow test compares the Common Effect Model with the Fixed Effect Model. When the common model is rejected, the Hausman test compares Fixed and Random Effects. The reported test probabilities therefore determine the appropriate estimator separately for the emissions and growth equations rather than imposing one estimator on both equations (Gujarati, 2004; Widarjono, 2018).

Mediation is evaluated using the product-of-coefficients approach. For each explanatory variable  $Z_j \in \{PEC, EXP, FDI\}$ , the indirect effect is  $\alpha_j \beta_4$ , the direct effect is  $\beta_j$ , and the total effect is  $\beta_j + \alpha_j \beta_4$ . The significance of the indirect effect is assessed with the Sobel statistic (Sobel, 1982):

$$SE(\alpha_j \beta_4) = \sqrt{[\beta_4^2 SE(\alpha_j)^2 + \alpha_j^2 SE(\beta_4)^2]}$$

$$z = (\alpha_j \beta_4) / SE(\alpha_j \beta_4)$$

A statistically significant product indicates that GHG emissions transmit part of the association between the explanatory variable and growth. Following Zhao et al. (2010), mediation is described as complementary when direct and indirect effects have the same sign and competitive when the signs differ. Because the models are linear and do not include an exposure-mediator interaction, the product decomposition is applicable to the specified equations.

The model is intentionally parsimonious in order to focus on the proposed environmental transmission mechanism and to avoid over-parameterization in a panel with only five cross-sectional units. Country effects reduce bias from time-invariant omitted characteristics, but they cannot eliminate confounding from unobserved time-varying factors. The coefficients are therefore interpreted as conditional panel associations rather than definitive causal effects. Additional controls such as capital formation, labor, urbanization, renewable-energy share, and institutional quality are identified as priorities for future robustness analysis.

## Findings

The Chow and Hausman tests were used to select the estimator for each structural equation. The Chow results in Table 1 reject the Common Effect Model for both equations because the cross-section probabilities are below 0.01.

Table 1. **Chow Test Results**

| Effect Test                            | Statistic | d.f.    | Probability |
|----------------------------------------|-----------|---------|-------------|
| Equation (1): Cross-section F          | 110.32    | (4,157) | 0.000       |
| Equation (1): Cross-section Chi-square | 220.74    | 4       | 0.000       |
| Equation (2): Cross-section F          | 4.78      | (4,156) | 0.001       |
| Equation (2): Cross-section Chi-square | 19.07     | 4       | 0.001       |

Table 2. **Hausman Test Results**

| Test Summary                       | Chi-square Statistic | d.f. | Probability |
|------------------------------------|----------------------|------|-------------|
| Equation (1): Cross-section random | 4.6147               | 3    | 0.202       |
| Equation (2): Cross-section random | 19.1145              | 4    | 0.001       |

The Hausman probability for Equation (1) is 0.202, so the null hypothesis that the Random Effect estimator is consistent is not rejected; Equation (1) is therefore interpreted using the Random Effect Model. For Equation (2), the probability is 0.001, so the null is rejected and the Fixed Effect Model is selected. This equation-specific interpretation corrects the earlier statement that both probabilities exceeded 0.05.

Energy consumption has a positive and statistically significant association with GHG emissions. This result is consistent with the fossil-intensive structure of several ASEAN-5 energy systems: additional energy use increases production and mobility, but it also raises emissions when the marginal supply of energy continues to depend on coal, oil, and natural gas. The magnitude should not be compared directly with the export and FDI coefficients because the variables are expressed in different raw units.

Table 3. Equation (1) Regression Results

| Variable                            | Coefficient | Std. Error | t-statistic | Probability |
|-------------------------------------|-------------|------------|-------------|-------------|
| Constant                            | -4327.85    | 251.40     | -17.22      | 0.0000      |
| Per capita energy consumption (PEC) | 485.26      | 21.46      | 22.61       | 0.0000      |
| Exports (EXP)                       | -8.05E-10   | 6.89E-11   | -11.69      | 0.0000      |
| Foreign direct investment (FDI)     | 3.12E-09    | 3.78E-10   | 8.26        | 0.0000      |

Notes: Dependent variable = GHG. All coefficients are significant at the 1 percent level

$$\text{GHG} = -4327.85 + 485.26\text{PEC} - 8.05\text{E-}10\text{EXP} + 3.12\text{E-}09\text{FDI} + \varepsilon_1 \quad (3)$$

Exports have a negative association with GHG emissions after country-specific panel effects are considered. This result differs from a simple scale-effect expectation but is consistent with composition and technique effects. Within-country export expansion may coincide with efficiency improvements, movement toward higher-value activities, compliance with international production standards, or a larger role for services and electronics. The finding should nevertheless be interpreted cautiously because total export value does not reveal the carbon content or domestic value added of exports.

FDI has a positive association with emissions. The result is compatible with a pollution-haven or scale-effect mechanism when foreign investment is concentrated in manufacturing, extractive activities, infrastructure, or energy-intensive production. It does not imply that all FDI is environmentally harmful; rather, it shows that the average environmental outcome of observed inflows in the sample is emission increasing. The sectoral and technological composition of FDI is therefore central to its sustainability.

Table 4. Equation (2) Regression Results

| Variable                            | Coefficient | Std. Error | t-statistic | Probability |
|-------------------------------------|-------------|------------|-------------|-------------|
| Constant                            | 9.36        | 1.008      | 9.286       | 0.0000      |
| Per capita energy consumption (PEC) | -5.96E-05   | 3.47E-05   | -1.718      | 0.0877      |
| Exports (EXP)                       | -6.50E-12   | 3.66E-12   | -1.776      | 0.0780      |
| Foreign direct investment (FDI)     | 4.19E-11    | 1.66E-11   | 2.524       | 0.0126      |
| GHG emissions (GHG)                 | -0.0040     | 0.0016     | -2.404      | 0.0140      |

Notes: Dependent variable = EG. FDI and GHG are significant at 5 percent; PEC and EXP are significant at 10 percent.

$$\text{EG} = 9.36 - 5.96\text{E-}05\text{PEC} - 6.50\text{E-}12\text{EXP} + 4.19\text{E-}11\text{FDI} - 0.0040\text{GHG} + \varepsilon_2 \quad (4)$$

Energy consumption is negatively associated with growth at the 10 percent level after emissions and the other variables are included. This result does not support a simple growth hypothesis. In the ASEAN-5 context, it may reflect energy inefficiency, exposure to imported-fuel prices, congestion, or the high economic cost of fossil-intensive production. The result suggests that expanding energy quantity without improving energy productivity may not translate into stronger growth.

Exports also have a negative direct association with growth at the 10 percent level. The result may reflect the 1991-2023 sample's exposure to commodity cycles, global crises, imported intermediate inputs, and weak domestic value added in some export sectors. It also indicates that export expansion should not be equated automatically with broad-based growth. Export quality, diversification, technology content, and domestic linkages are likely to determine whether the export-led growth mechanism becomes positive.

FDI has a positive and statistically significant association with growth. This finding supports the FDI-led growth mechanism through capital formation, technology transfer, managerial knowledge, and participation in regional production networks. The positive coefficient is consistent with ASEAN's role as a major destination for export-oriented and manufacturing investment, although the environmental results show that the quality of FDI matters alongside its volume.

GHG emissions have a negative association with economic growth. This finding supports the externality channel: environmental degradation can reduce health and labor productivity, damage natural and physical assets, and increase public and private mitigation costs. In a climate-vulnerable region, these costs can offset part of the output generated by energy-intensive production and investment.

The indirect effects were recalculated using the product of the coefficients reported in Tables 3 and 4 and tested with the Sobel procedure. Table 5 presents the direct effect, the emission-mediated effect, the Sobel statistic, and the resulting total effect. Because the underlying coefficients and standard errors are rounded in the reported regression tables, the mediation statistics should be interpreted as approximate.

Table 5. **Mediation Effects through GHG Emissions**

| Path           | Direct Effect | Indirect Effect | Sobel z | p-value | Total Effect | Mediation Pattern |
|----------------|---------------|-----------------|---------|---------|--------------|-------------------|
| PEC → GHG → EG | -5.96E-05     | -1.9410         | -2.485  | 0.013   | -1.9411      | Complementary     |
| EXP → GHG → EG | -6.50E-12     | 3.220E-12       | 2.445   | 0.014   | -3.280E-12   | Competitive       |
| FDI → GHG → EG | 4.19E-11      | -1.248E-11      | -2.393  | 0.017   | 2.942E-11    | Competitive       |

*Notes: Indirect effect = coefficient of PEC, EXP, or FDI in the GHG equation multiplied by the coefficient of GHG in the EG equation. Sobel statistics are calculated from the rounded coefficients and standard errors in Tables 3 and 4.*

The indirect effect of energy consumption is negative and significant. Energy use raises emissions, and emissions reduce growth; consequently, the environmental channel reinforces

the negative direct association between energy use and growth. This complementary mediation result indicates that the weakness of energy-driven growth is not solely a direct efficiency problem but is also transmitted through environmental costs.

The indirect effect of exports is positive and significant because exports are associated with lower emissions, while lower emissions are associated with stronger growth. The environmental channel therefore offsets part of the negative direct export-growth relationship. This competitive mediation pattern helps reconcile the direct result with the possibility that cleaner export upgrading and compliance with environmental standards can generate economic benefits even when aggregate export expansion is not independently growth enhancing.

FDI displays a positive direct effect but a negative indirect effect. Foreign investment supports growth through capital and technology channels, yet its emission-increasing association reduces part of that benefit. The competitive mediation result is a central empirical contribution of the study: the growth value of FDI in ASEAN-5 depends not only on attracting larger inflows but also on directing them toward cleaner technology, renewable energy, and less carbon-intensive production.

Taken together, the mediation results show that GHG emissions are not a uniform intermediary. They intensify the adverse energy-growth relationship, partially counterbalance the direct export result, and erode part of FDI's positive growth contribution. This differentiated pattern extends earlier nexus studies by showing that the same environmental mediator can reinforce one economic channel while offsetting another.

## **Conclusion**

This study investigates the direct and emission-mediated associations of energy consumption, exports, and FDI with economic growth in ASEAN-5 from 1991 to 2023. The results show that energy consumption and FDI increase GHG emissions, while exports are associated with lower emissions. In the growth equation, energy consumption and exports have negative direct associations, FDI has a positive direct association, and GHG emissions have a negative association with growth.

The mediation analysis provides the study's main contribution. The emissions channel reinforces the negative energy-growth relationship, offsets part of the negative direct export-growth association, and reduces the positive growth benefit of FDI. The findings therefore demonstrate that the economic effects of energy, trade, and investment cannot be evaluated independently of the environmental mechanisms they generate.

Theoretically, the study integrates the energy-growth, export-led growth, FDI-led growth, and growth-environment perspectives in a single framework. Empirically, it provides ASEAN-5 evidence that the direction of mediation differs across growth drivers. Methodologically, it shows how linked panel equations and a product-of-coefficients test can distinguish direct, indirect, and total relationships rather than treating emissions only as an outcome of economic activity.

These contributions should be interpreted cautiously. The use of aggregate annual indicators, raw-unit monetary variables, a five-country panel, and a parsimonious specification limits

causal inference and masks differences between renewable and non-renewable energy and among export and FDI sectors. Future research should use disaggregated measures, additional time-varying controls, robust estimators that address cross-sectional dependence, and country- or sector-specific models to test whether the identified mediation patterns remain stable.

ASEAN energy policy should prioritize energy productivity rather than energy expansion alone. This requires faster renewable-energy deployment, stronger efficiency standards for industry and buildings, modernization of national grids, and deeper ASEAN Power Grid cooperation. Targeted support is also needed to prevent the transition costs from falling disproportionately on low-income households and workers in fossil-dependent sectors.

Trade policy should promote low-carbon value upgrading. ASEAN members can strengthen product-level carbon measurement, support cleaner production among exporting firms and small and medium enterprises, and encourage movement from raw or low-value commodities toward technology-intensive and environmentally certified products. Regional interoperability of carbon reporting and sustainability standards would reduce compliance costs and improve readiness for increasingly carbon-sensitive global markets.

Investment policy should distinguish between the quantity and quality of FDI. Incentives can be tied to clean-technology transfer, renewable-energy use, energy efficiency, local supplier development, and verifiable emission reductions. Environmental screening, ASEAN-aligned green taxonomies, and transparent monitoring can help prevent pollution-intensive investment while preserving FDI's positive contribution to capital formation and productivity.

Finally, ASEAN should strengthen regional measurement, reporting, and verification systems and improve the interoperability of carbon markets and green-finance frameworks. Coordinated policy would allow the region to reduce emissions without fragmenting trade and investment flows, thereby aligning the ASEAN energy-transition and carbon-neutrality agendas with sustained economic growth.

More specifically, future studies should test robustness by adding capital formation, labor, human capital, urbanization, renewable-energy share, institutional quality, and global-shock controls. They should also compare territorial with consumption-based emissions; distinguish renewable from non-renewable energy; separate resource-based, manufacturing, and service exports; identify green and pollution-intensive FDI; apply robust standard errors and cross-sectional-dependence tests; and examine heterogeneous effects across countries, sectors, and development levels.

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