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INTERNATIONAL TRADE, TECHNOLOGICAL INNOVATION AND ENVIRONMENTAL PERFORMANCE: EVIDENCE FROM ASEAN AND GLOBAL ECONOMIES

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Abstract
This paper examines the relationships among international trade, technological innovation, foreign direct investment (FDI), carbon dioxide emissions, and environmental efficiency across ASEAN and global economies. A comparative analysis of reported panel quantile regressions, dynamic panel estimates, and environmental-efficiency frontier results provides evidence on the heterogeneity of these relationships. Export activity and trade openness show positive associations with emissions in several ASEAN specifications, whereas import coefficients vary across conditional quantiles. Technological innovation and renewable energy use generally exhibit favorable associations with environmental outcomes. Environmental efficiency differs across six world regions, and the association with FDI varies geographically. These findings demonstrate the importance of distinguishing exports from imports, accounting for energy composition, and recognizing differences in regional technologies and industrial structures. The study identifies measurement and inference limitations and discusses implications for coordinated trade, industrial, and environmental policy.

1. INTRODUCTION

International trade connects production systems across national borders and changes the economic geography of energy demand and emissions. Expanded export markets increase production opportunities, while international sourcing facilitates access to intermediate inputs, capital equipment, and new technologies. The environmental consequences of these processes are not uniform. Antweiler et al. (2001) distinguish scale, composition, and technique effects: larger production volumes can increase pollution, changes in industry composition alter average pollution intensity, and improved technology can reduce emissions per unit of output. Their combined effects depend on local economic and institutional conditions.

The issue is particularly relevant to member states of the Association of Southeast Asian Nations (ASEAN), whose integration into regional value chains has accompanied industrialization, urbanization, and changes in energy demand. The relationship between growth and environmental quality has also been considered through the environmental Kuznets curve (EKC), which allows a nonlinear association between income and some forms of pollution (Grossman & Krueger, 1995). Yet evidence for one pollutant or period should not be generalized to carbon dioxide, whose stock, global dispersion, and connection with fossil-fuel infrastructure differ from those of local air pollutants (Copeland & Taylor, 2004).

Existing studies offer multiple explanations for divergent findings. Investment may shift

pollution-intensive industries toward jurisdictions with less stringent regulation, a possibility associated with the pollution-haven hypothesis, or bring cleaner technologies and management systems to host economies, consistent with a pollution-halo mechanism (Copeland & Taylor, 2004). Trade can also move environmental burdens between producing and consuming countries, creating a distinction between territorial and consumption-based emissions responsibility (Peters, 2008). Accordingly, assessing trade using aggregate imports and exports alone does not reveal the carbon embodied in each traded product.

Three complementary empirical settings clarify these relationships. The first examines exports, imports, and technological innovation in seven ASEAN economies. The second evaluates trade openness, FDI, renewable and nonrenewable energy, and urbanization in four ASEAN economies. The third compares environmental efficiency across 100 countries grouped into six regions (Salman, 2020). Together these settings allow comparison of trade-related associations across different measures of environmental performance.

The objectives are to assess the reported links between international trade and emissions, compare the roles of technological innovation and energy composition, and evaluate regional differences in environmental efficiency. The paper also considers how the choice of econometric specification affects interpretation and what the evidence implies for environmental policy.

2. Literature review and analytical framework

2.1 International trade and environmental outcomes

The theoretical sign of the relationship between trade and pollution is indeterminate because trade liberalization changes output scale, industrial structure, and pollution-abatement techniques simultaneously. Antweiler et al. (2001) develop these distinct channels and find that their net effect may differ from a simple production-scale prediction. Copeland and Taylor (2004) explain why relative factor endowments, environmental regulation, and income conditions affect the specialization of countries. An aggregate measure of trade openness therefore risks pooling mechanisms that act in opposite directions.

An additional concern is the location of emissions. Territorial inventories attribute CO_2 to the country where fuel is burned, whereas consumption-based accounting allocates production emissions through international supply chains to final demand. Peters (2008) demonstrates that alternative accounting boundaries change interpretations of national responsibility. For ASEAN production networks, higher exports may coincide with emissions generated domestically for foreign consumption, while imported equipment may contribute to domestic output without corresponding emissions being produced in the importing country.

2.2 Economic development, technological change, and energy

The EKC framework proposes that pollution may rise during early development and decline after income reaches a threshold, although the empirical pattern is pollutant-specific and sensitive to measurement. Grossman and Krueger (1995) studied several environmental indicators rather than establishing a universal turning point for CO_2. In evaluating the analysis's EKC results, the signs of the income and squared-income coefficients are relevant, but a turning point should also be calculated, placed within the observed income range, and interpreted with model uncertainty.

Technological innovation potentially reduces energy intensity through improved machinery, process management, and knowledge spillovers. Patent applications provide one proxy for innovation in the seven-economy analysis (Salman, 2020). Patent counts nevertheless capture inventive activity imperfectly and do not directly measure adoption of cleaner technology.

2.3 Foreign direct investment and heterogeneous environmental efficiency

FDI can alter environmental quality through new productive capacity, technological transfers, and

the composition of industry. Pollution-haven and pollution-halo mechanisms offer competing interpretations; the observed direction of FDI–emissions associations can differ across destination economies (Copeland & Taylor, 2004). A positive coefficient for FDI is not, by itself, proof of regulatory relocation, just as a negative coefficient does not directly establish clean technology transfer. Mechanism testing would require further evidence on sector mix, environmental standards, and production technologies.

Environmental efficiency differs from aggregate pollution. Efficiency-frontier methods compare desirable production outputs and resource inputs while accommodating undesirable outputs under specified assumptions. Regional comparisons must recognize technological heterogeneity, because countries may not share access to identical productive opportunities. Salman (2020) applies a meta-frontier epsilon-based measure to compare regions, thereby addressing potential differences between group frontiers and a common benchmark. Such measures are sensitive to the selection and quality of input-output indicators.

Cross-country studies document heterogeneous trade–environment relationships and emphasize differences in industrial structure and economic development (Ahmed et al., 2017; Al-Mulali & Sheau-Ting, 2014; Aklin, 2016; Bosupeng, 2016; Ertugrul et al., 2016; Farhani & Ozturk, 2015). Theoretical models likewise suggest that environmental outcomes depend on comparative advantage and production location (Copeland & Taylor, 1994; Grossman & Krueger, 1991).

The emissions–growth literature stresses that results depend on regional income levels, energy prices, urbanization and production structure (Ahmad et al., 2016; Al Mamun et al., 2014; Acaravci & Ozturk, 2010; Acheampong, 2018; Bekhet & Othman, 2017; Destek & Sarkodie, 2019; Dinda, 2004; Grossman & Krueger, 1995). Renewable and nonrenewable energy have been examined separately because their emissions implications differ (Adewuyi & Awodumi, 2017; Al-Mulali & Ozturk, 2016; Al-Mulali et al., 2016). Research on innovation and environmental performance highlights the diffusion of knowledge, research investment, cleaner technology and rebound effects (Adenle et al., 2015; Ahmed et al., 2016; Ai et al., 2015; Dauda et al., 2019; Du et al., 2019; Fagerberg, 2018; Fernández Fernández et al., 2018; Greening et al., 2000; Grossman & Helpman, 1991). Firm and location responses to foreign investment are similarly ambiguous (Behera & Dash, 2017; Candau & Dienesch, 2017; Dou & Han, 2019).

Environmental-efficiency measurement introduces a separate methodological concern because frontier indices combine production outputs, undesirable outputs and assumptions about technology (Fan et al., 2017; Salman, 2020). The analysis's panel methods belong to a larger econometric tradition in which stochastic trends and cointegration require explicit testing (Dickey & Fuller, 1979; Engle & Granger, 1987). Human impacts, including population, affluence and technology, are commonly organized through the STIRPAT perspective (Dietz & Rosa, 1994).

2.4 Research contribution

Three themes emerge from the literature: trade-related carbon outcomes depend on multiple mechanisms, structural heterogeneity affects estimated relationships, and statistical association differs from causal impact. This paper compares evidence across emissions regressions and environmental-efficiency measures to identify agreements and tensions in these findings.

3. Materials and methods

3.1 Research design

This paper adopts a comparative secondary analysis of previously reported quantitative results. It evaluates three empirical settings using their published model specifications, coefficient tables, sample descriptions, and environmental-efficiency figures (Salman, 2020; Salman et al., 2019). The analysis is interpretive and comparative rather than a new estimation exercise.

The comparison groups findings under international trade, technological innovation, energy use, urbanization, FDI, and environmental

efficiency. Coefficient signs and reported significance are compared within each specification, while the measurement and assumptions of different models are considered when drawing cross-regional conclusions.

3.2 Study coverage and variables

The first empirical analysis examines seven ASEAN economies, with the detailed methods chapter identifying a 1990–2017 sample, although the source abstract describes an endpoint of 2018. It evaluates the separate roles of exports and imports, innovation, population, GDP per capita, and energy intensity using a STIRPAT-inspired specification and panel quantile regression. The second analysis studies Indonesia, Malaysia, the Philippines, and Thailand for 1970–2018, reporting a dynamic panel GMM model, country quantile regressions, and FMOLS/DOLS estimates. The third analysis covers 100 countries grouped into the Americas, Asia-Pacific, Eastern Europe, Western Europe, the Middle East and North Africa, and Sub-Saharan Africa during 1990–2018 (Salman, 2020).

Differences in sample-endpoint descriptions are acknowledged when comparing estimates. Because the empirical settings use different countries, periods, and dependent variables, coefficient sizes are not treated as directly comparable causal effects.

3.3 Scope of empirical evidence

Table 1. Coverage, variables, and estimation approaches across the three empirical settings.

Essay	Sample/period	Methods	Main variables
1: Trade disaggregation	7 ASEAN economies, 1990–2017 (methods)	Panel quantile regression; STIRPAT/EKC	CO_2, exports, imports, innovation, GDP, population, energy intensity
2: Trade, FDI and energy	4 ASEAN economies, 1970–2018	GMM; FMOLS/DOLS; country quantiles	CO_2, openness, FDI, renewable and nonrenewable energy, urbanization
3: Environmental efficiency	100 countries, 6 regions, 1990–2018	Meta-frontier epsilon-based measure; discontinuity analysis	Efficiency, FDI, policy period, technology gap

3.4 Analytical approach and quality checks

For the quantile analysis, the synthesis compares the sign and reported significance of exports, imports, innovation, and energy intensity across the conditional CO_2 distribution. For the dynamic models, it examines reported coefficient interpretations and cross-estimator agreement, without treating agreement alone as causal validation. For the efficiency assessment, it distinguishes frontier-based rankings from the estimated policy-period association. The review also checks whether a model's functional form supports the magnitude claimed in the narrative.

In a conventional log–log regression, an estimated coefficient of 0.674 corresponds to an approximately 0.674% difference in the outcome associated with a 1% change in the explanatory variable, other regressors held constant. Regression coefficients require interpretation in light of functional form, identification assumptions, and the variable definitions.

4. Results

4.1 Exports, Imports, and Technological Innovation in Seven ASEAN Economies

In the seven-economy quantile analysis, export coefficients are positive across the reported conditional emissions quantiles (Salman et al., 2019). The magnitude differs across the conditional distribution, suggesting that the export–emissions association is heterogeneous rather than fixed.

Import coefficients are more mixed in the full specification. Positive and negative estimates appear alongside statistically insignificant effects at different quantiles. Thus, the results do not support a uniformly emissions-increasing interpretation of imports (Salman et al., 2019).
Technological innovation is associated with negative coefficients at several quantiles, although statistical significance varies. Energy intensity displays positive associations across reported quantiles. The income and squared-income estimates are consistent with a conditional inverted-U specification, but the results do not establish a universal turning point (Salman et al., 2019).

4.2 Trade openness, energy sources, FDI, and urbanization in four ASEAN economies

The second analysis reports a positive association of trade openness with CO_2 emissions in the GMM specification, accompanied by a positive coefficient for nonrenewable energy and a negative coefficient for renewable energy. FDI is reported as positively associated with emissions in the pooled sample. The country-specific quantile analyses nevertheless indicate heterogeneous openness relationships: positive patterns for Indonesia, Malaysia, and Thailand contrast with negative reported coefficients in the Philippines (Salman, 2020, Chapter 5).
Urbanization patterns also differ among countries. The reported evidence identifies inverted-U relationships for Malaysia and the Philippines and U-shaped relationships for Indonesia and Thailand (Salman, 2020). These differences discourage the assumption of a common urbanization threshold across ASEAN economies.
The original GMM table includes a lagged dependent variable and reports specification diagnostics. These details matter when interpreting the estimated elasticity of trade openness and income. The coefficient on income in Table 5.2 is approximately 0.674. Under the conventional log–log reading, that estimate corresponds to a roughly 0.674% change in emissions for a 1% change in income, other things equal, not the 67.4% figure stated in an accompanying prose passage. This research paper retains the reported coefficient while flagging its interpretation as an issue requiring verification.

4.3 FDI and environmental efficiency across six world regions

Environmental-efficiency estimates for 100 countries show pronounced regional heterogeneity. Western Europe has the highest reported efficiency ranking, followed by Eastern Europe and the Americas in the aggregate comparison (Salman, 2020). Differences should be interpreted in relation to each region's technology set and the selected frontier assumptions.
FDI is positively associated with environmental efficiency in the Americas and Asia-Pacific and negatively associated in the Middle East and North Africa in the reported regional regressions (Salman, 2020). Such variation is consistent with region-specific investment composition and technology-transfer conditions, without independently identifying their causal influence.
Environmental-efficiency estimates also show a positive discontinuity near the Paris Agreement period (Salman, 2020). The observed timing is compatible with improvements during this period, but a causal attribution requires exclusion of other simultaneous changes in energy markets, economic activity, and environmental policy.

4.4 Regional environmental performance: Graphical evidence

Figures 1–4 present the previously reported regional environmental-efficiency patterns discussed above. Their values were not re-estimated for this paper. Each figure retains a source credit for academic attribution.

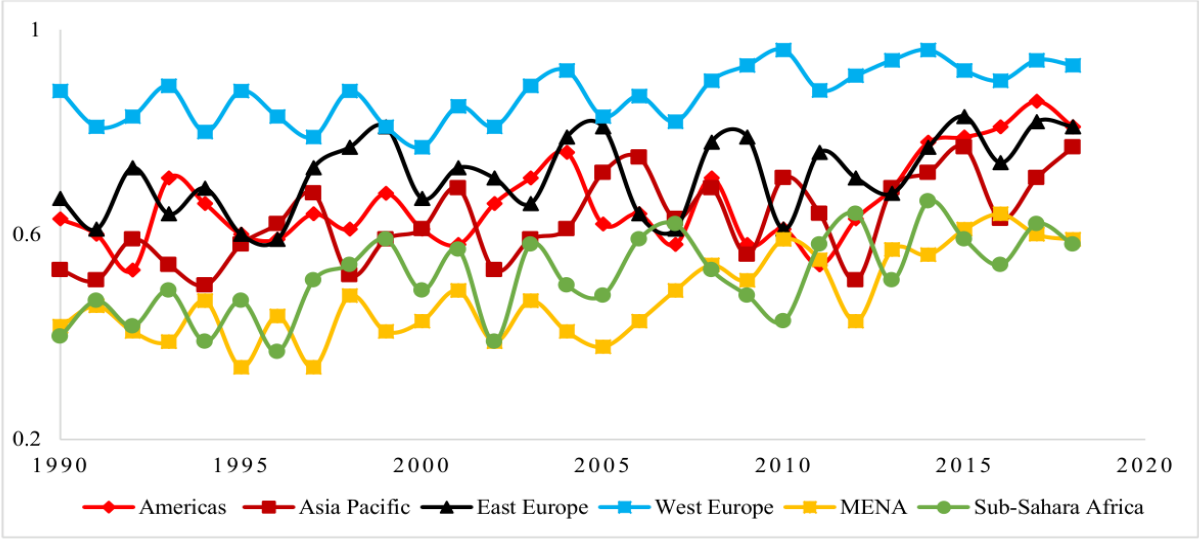


Figure 1. Environmental efficiency under the meta-frontier for six regions, 1990–2018.

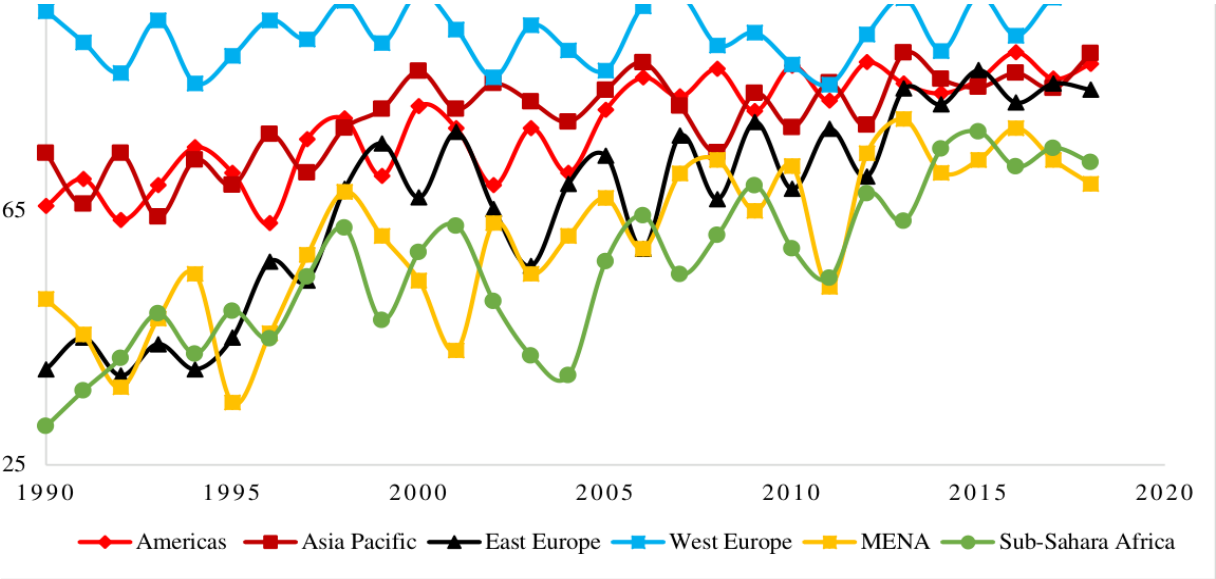


Figure 2. Regional technology-gap ratios.

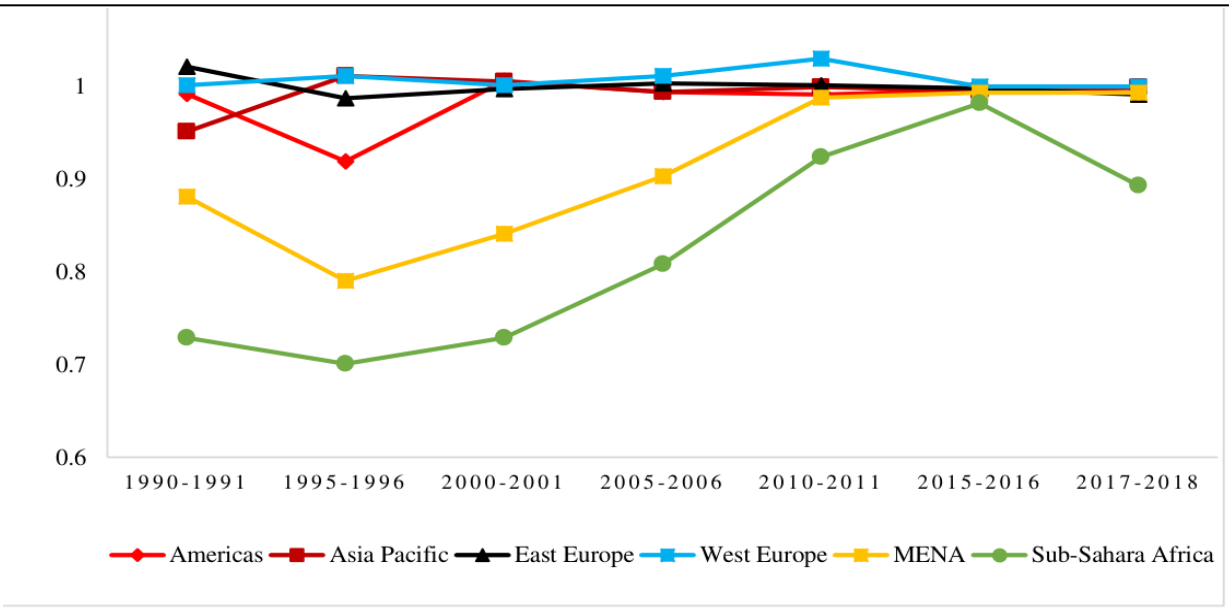


Figure 3. Regional Malmquist–Luenberger index.

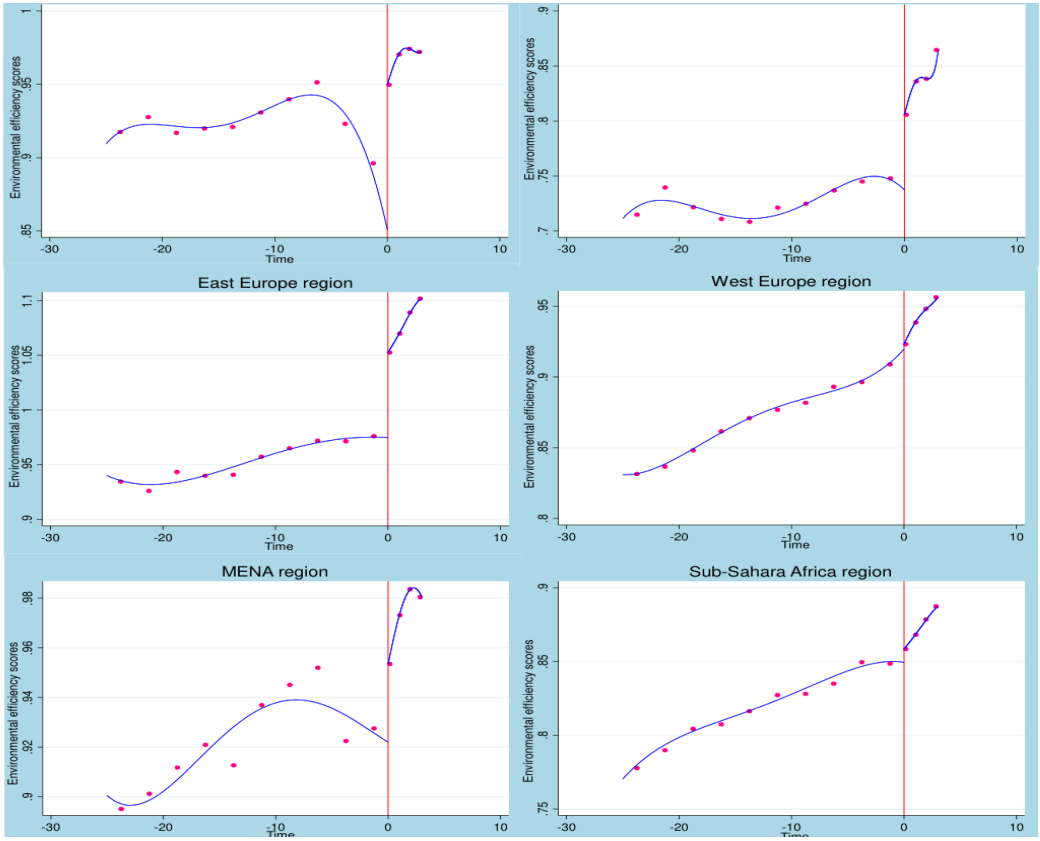


Figure 4. Environmental efficiency around the Paris Agreement policy year.

5. Discussion

5.1 Reconciling heterogeneous trade–emissions relationships

Across the three analyses, one consistent theme is that aggregate openness cannot stand in for the environmental characteristics of the traded goods. The scale–composition–technique framework of Antweiler et al. (2001) explains why greater trade may increase emissions when production expands, while cleaner machinery and productivity improvements may reduce emissions intensity. The analysis's positive export relationships are compatible with the production-scale channel, but the estimated associations do not independently measure that mechanism.

The import coefficients reveal why separating exports and imports is valuable. Imports comprise consumer products, intermediate inputs, and capital goods, each with different emissions implications. A technology import may lower domestic emissions intensity while increasing transport demand, and the carbon generated during its manufacture belongs to the producer's territorial inventory. Peters (2008) shows how consumption-based accounting changes the interpretation of responsibility. This limitation should shape subsequent studies rather than assuming a simple uniform effect of imports.

5.2 Technology, energy structure, and policy relevance

The generally negative innovation coefficients and renewable-energy relationships reinforce the relevance of the technique channel. Yet measures such as patent counts do not demonstrate that a technology was adopted or that emissions fell because of adoption. A more informative model would examine actual low-carbon capital formation, energy intensity, fuel shares, and the timing of industrial upgrading. Otherwise, rising output may offset improvements in emissions intensity.

Cross-country heterogeneity is also substantively important. The divergence between the Philippines and the other three ASEAN countries suggests that economic composition, power systems, and regulatory frameworks may interact with trade. A single pooled coefficient can mask these differences. Research drawing country-specific implications should present comparable confidence intervals and avoid extrapolation beyond observed samples (Salman, 2020).

5.3 Interpretation of foreign investment and frontier efficiency

Regionally different FDI associations invite investigation of technology transfer and sector composition, but do not settle the pollution-haven versus pollution-halo debate. The same investment flow may build emissions-intensive productive capacity and introduce more energy-efficient equipment. Without information on investment industries and adopted technologies, coefficients represent net associations. Copeland and Taylor (2004) emphasize how trade and investment relationships depend on the institutional and regulatory environment.

The frontier analysis adds a different perspective by measuring performance relative to feasible production combinations. Nevertheless, region rankings may change with selected inputs, undesirable outputs, and frontier assumptions. The ability to distinguish technological gaps from inefficiency is a strength of the meta-frontier approach; the need for robustness against variable definitions is its corresponding challenge.

5.4 Methodological limitations and directions for stronger evidence

The examined analysis spans countries and methods, but this breadth should not be mistaken for fully identified causal pathways. Exports, energy consumption, and output can affect one another contemporaneously. FDI is also responsive to growth prospects and institutions. Lag structures, internal instruments, or multiple estimators partially address particular statistical challenges but require careful validity tests. Transparent replication should report diagnostic results, sensitivity analyses, and model code.

The interpretation of a policy discontinuity around the Paris Agreement requires special care because treatment exposure is global and the cutoff may coincide with other developments.

Credible alternatives include sector-level variation in policy exposure, difference-in-differences with justified comparison groups, and event-study diagnostics where the assumptions are plausible. For trade-related carbon, linking harmonized commodity data to multiregional input-output inventories would also permit examination of embodied emissions and consumption-based responsibility (Peters, 2008).

The analysis relies on published coefficient tables and figures without access to the underlying observations or replication code. No fresh parameter estimates are reported. Differences across periods, regional groupings, environmental indicators, and model assumptions limit strict quantitative comparability. Stronger causal conclusions require independently assembled data and additional identification checks.

6. Policy implications

First, trade policy should be coordinated with industrial energy policy. The evidence examined here suggests that expanding market access without improvements in industrial electricity, process efficiency, and fuel choice may coincide with larger absolute emissions. Export promotion and industrial competitiveness programs therefore warrant emissions-intensity benchmarks and transparent monitoring rather than a simple target for trade growth.

Second, domestic innovation and technology diffusion merit attention. Public support for upgrading production equipment, technical skills, and adoption of cleaner processes is consistent with the analysis's innovation results, though the cost-effectiveness of particular incentives requires independent evaluation. Policymakers should distinguish research activity, measured by patents, from verified adoption and emissions savings.

Third, foreign investment screening and facilitation should account for both production-sector composition and technology quality. An indiscriminate restriction on FDI is unsupported by the mixed regional findings. More useful measures include transparent environmental standards, impact reporting, supplier upgrading, and independent monitoring of high-emission facilities.

Fourth, national climate strategies should consider imported and exported embodied emissions alongside territorial reporting where reliable data permit. Consumption-based accounts are useful complements rather than automatic substitutes for production-based inventories because system boundaries and uncertainty differ (Peters, 2008). Shared data infrastructure across customs, industry, energy, and statistics offices would improve policy targeting.

Finally, governments should evaluate outcomes using comparable country and sector baselines. Evidence of a positive association between policy timing and environmental efficiency should motivate careful policy evaluation, not a presumption of causality. Clear evaluation plans and public data access would make future environmental trade research more informative.

7. Conclusions

The comparison identifies positive associations between trade activity and carbon emissions in several ASEAN specifications, while showing that import effects are not uniform. Innovation and renewable energy generally align with improved environmental outcomes, and environmental efficiency varies substantially among regions. These patterns support a differentiated approach to international trade and sustainability (Salman, 2020; Salman et al., 2019).

The study contributes a structured comparison of emissions and environmental-efficiency evidence, clarifies differences between trade-flow measures, and identifies priorities for future evaluation of regional heterogeneity, model specification, and policy timing. Its principal implication is that trade expansion should be considered alongside industrial technology, energy structure, and environmental regulation.

Future research should use independently assembled country- and sector-level data, test the sensitivity of results to alternative specifications, and examine trade-related embodied emissions and investment-induced technology change.

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