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Dimensions of Sustainability: Assessing the Impact of Technology Intensity and Global Value Chains in East and Southeast Asia

Dimensiones de la sostenibilidad: evaluando el impacto de la intensidad tecnológica y las cadenas de valor globales en el este y sudeste asiático

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Abstract

This paper explores the Environmental Kuznets Curve hypothesis within East and Southeast Asia. The analysis, drawing on OECD and World Bank data, investigates how economic growth correlates with environmental indicators amid intense global trade and integration into global value chains. The findings indicate that while GDP growth and increased energy consumption initially raise emissions, higher integration in global value chains and high-tech sectors can mitigate these effects. The study emphasizes the role of technological innovation and energy efficiency, advocating for policies that foster economic growth alongside environmental sustainability. The results contribute to understanding how to align economic objectives with ecological sustainability in a highly interconnected global economy.

Keywords: Technology intensity; Emissions; Sustainability; Global value chains; East and Southeast Asia.

Resumen

Este trabajo explora la hipótesis de la curva medioambiental de Kuznets en el este y sudeste asiático. El análisis, basado en datos de la OCDE y el Banco Mundial, investiga cómo se correlaciona el crecimiento económico con los indicadores medioambientales en un contexto de intenso comercio mundial e integración en las cadenas de valor mundiales. Las conclusiones indican que, si bien el crecimiento del PIB y el aumento del consumo de energía elevan inicialmente las emisiones, una mayor integración en las cadenas de valor mundiales y en los sectores de alta tecnología puede mitigar estos efectos. El estudio destaca el papel de la innovación tecnológica y la eficiencia energética, abogando por políticas que fomenten el crecimiento económico junto con la sostenibilidad medioambiental. Los resultados contribuyen a entender cómo alinear los objetivos económicos con la sostenibilidad ecológica en una economía mundial altamente interconectada.

Palabras clave: Intensidad tecnológica; Emisiones; Sostenibilidad; Cadenas globales de valor; Este y sudeste asiático.

JEL Classification/ Clasificación JEL: N5, Q27, Q53.

1. Introduction

Some East and Southeast Asian countries, such as China or South Korea, have emerged as important contributors to the global economy. Initially due to their lower production costs and, in some cases, bolstered by their learning-by-doing and investment capacities, these Asian nations cover the entire spectrum of the production chain, from extraction and manufacturing tasks to high-value-added generation activities in both industry and services. This achievement stems from the developmental trajectories that have marked their integration into the global value chains (GVCs). However, several observations are pertinent. Firstly, not all economies in the region have adopted identical patterns of productive specialization. Secondly, the rate of economic growth and convergence towards the income and welfare standards of Western economies varies markedly across different cases. And thirdly, this rapid growth has resulted in a substantial reliance on fossil fuels, positioning the region as one of the leading carbon emitters globally (International Monetary Fund, 2023).

In this context, it is of great interest to analyze the role of these countries' productive specialization in high and medium-high technology sectors in the gradual reduction of their carbon emissions. This is particularly relevant when considering exports of domestic value-added (DVA) and through the lens of the Environmental Kuznets Curve (EKC) hypothesis. There is an important gap in the literature since it has primarily focused on the EKC in its traditional conception and, more recently, has begun to incorporate various institutional variables into the analysis. However, the influence of GVC participation and technology, especially from a foreign trade perspective, has received little attention. Regarding the role of technology, it is generally observed that there exists an inverse relationship between the value-added and the volume of emissions, a trend that is particularly true in extractive and industrial activities (Campos Romero & Rodil Marzábal, 2021).

Therefore, the objective of this paper is to examine the impact of participation in GVCs and exports of high and medium-high technology on emission reduction among East and Southeast Asian countries. This analysis is conducted through the lens of the EKC, incorporating a dual perspective on emissions from both the supply side (consumption-based emissions) and the demand side (demand-based emissions). Furthermore, this study distinguishes between countries based on their income levels to provide a nuanced understanding of the interplay between economic development, technological advancement, and environmental sustainability.

To achieve this objective, data have been collected for a total of 13 East and Southeast Asian countries: Brunei Darussalam, Cambodia, China, Hong Kong, Indonesia, Japan, Korea, Laos, Malaysia, Philippines, Singapore, Thailand, and Viet Nam. Information on trade and participation in GVCs was obtained from the OECD Trade in Value Added database (TiVA, 2023 edition). Emissions information from both perspectives has been collected from the Carbon Dioxide Emissions embodied in International Trade database (TECO$_2$, 2021 edition). Additional variables have been obtained from the World Development Indicators (The World Bank database).

The findings reveal that higher GDP levels correspond to changes in emission trends, but caution is advised due to the sensitivity of EKC models to variable, country, and timeframe changes. The research notes that while developed Asian countries may see increased emissions with greater GVC integration, there is a critical need for policy measures aimed at promoting less emission-intensive sectors within a globally agreed framework. Proposals include setting minimum standards for energy and water efficiency, emissions measurement, and environmental impact mitigation at the firm level.

The results point to the need of promoting high-value technological activities in developing Asian countries as a strategic approach to reduce emissions, suggesting that industrial upgrading could shift from emission-intensive to environmentally friendly practices. This requires policies supporting industrial promotion and robust R&D systems to build the necessary human capital. International cooperation is emphasized as crucial for facilitating these transitions. This cooperation can take a variety of forms, such as joint development of innovation projects, business partnerships that facilitate knowledge sharing, and training through supranational capacity programs.

The paper is structured into four main sections, beyond this Introduction. Section 2 reviews the most relevant literature, identifying the primary analytical methods, highlighting the research gap concerning the influence of GVCs and technological intensity, and identifying the main hypotheses. Section 3 details the data and methodology employed in this study. Section 4 discusses the study's main findings. Lastly, Section 5 presents the paper's key conclusions, offers policy recommendations, and outlines several avenues for future research.

2. Literature review

The relationship between economic growth and environmental impact has been studied extensively explored through the EKC hypothesis, which posits a non-linear relationship between GDP per capita and, typically, carbon emissions per capita (Grossman & Krueger, 1991, 1993, 1995). This relationship has often been examined in search of an inverted U-shaped curve between growth and emissions (Hussain et al., 2021; Polloni-Silva et al., 2021; Rodil-Marzábal

& Campos-Romero, 2021; Suki et al., 2020; Wang et al., 2023). However, this concept has faced criticism for assuming that, beyond a certain level of per capita income, countries would transition to a pathway of emissions reduction (Hasanov et al., 2021; Sinha et al., 2019). As a result, many studies, especially more recent ones, consider the possibility that this relationship could be wave-shaped (N-shaped or inverse N-shape), suggesting that a country on a decreasing emissions path at one time might see this trend reverse in the future (Balsalobre-Lorente et al., 2023; Mohammed et al., 2024; Wang et al., 2024).

Despite the extensive development of this literature, consensus on the validation of the EKC hypothesis has not been universally achieved. As highlighted by several scholars, the choice of data, time period, geographical area, and estimation method significantly impacts the outcomes (Özcan & Öztürk, 2019). An additional issue to consider is the error some studies make in affirming the EKC hypothesis without identifying specific turning points that indicate the per capita income levels at which a country shifts from an increasing to a decreasing emissions trajectory, and vice versa. In this context, an initial analysis involves examining the signs of the estimation coefficients, which provide insights into the curve's shape. Determining whether the minimum and maximum values of these curves are realistic and identifiable is crucial before confirming the existence of this curve.

Even though there are general inconsistencies when testing this relationship, most studies focusing on developing countries verify the EKC (Esmaeili et al., 2023; Gyamfi et al., 2021; Hussain et al., 2022; S. Li et al., 2020; Shahbaz et al., 2020, 2020). However, the foreign trade dimension is often overlooked, despite the fact that there are numerous studies using different hypotheses and methodologies that show a direct link between international trade and environmental impacts. (Das et al., 2023; Safi et al., 2023; Sorroche-del-Rey et al., 2023; Zhao et al., 2023). Table 1 provides a synthesis of the literature review, outlining the principal estimation variables, geographical scope, models, and results concerning the validation of the EKC and other analyses related to the environmental impacts that are relevant for this research. It is observed that, in broad terms, the referenced studies largely overlook the trade dimension. Accordingly, the examination of the impacts that participation in GVCs has on the environment, and its interplay with the EKC, represents an area minimally addressed in existing research, despite the increasing significance of these countries' involvement in both forward (via exports of DVA) and backward (through imports of foreign value-added) participation in GVCs. Similar to the broader interest in international trade within developing countries, the literature acknowledges the relevance of this perspective for discerning nations' environmental accountability, the influence of tariffs amidst significant production chain fragmentation, and, more broadly, the environmental ramifications of GVC participation GVCs (Ali et al., 2024; M. Li et al., 2023; Meng et al., 2023; Yang & Yan, 2023). Yet, the specific implications of GVCs concerning the EKC hypothesis remain underexplored.

Table 1. Literature review summary

Authorship	Variables	Sample Countries	Period	Method	Results
Ali et al. (2024)	GVA upstream and downstream participation, CO2 per capita, Internet users, mobile phone subscription, digitalization index, urban population, GDP per capita, FDI inflow, renewable energy consumption, and industry value-added	112 developing countries	1990-2018	Panel data estimation	GVC participation leads to higher emissions
Arshad Ansari et al. (2020)	Economic growth, urbanization, energy consumption, and globalization	Asian countries	1991-2017	Panel cointegration, pooled mean group, dynamic ordinary least square, and differenced panel generalized methods of moments	Mixed results
Assamoi et al. (2020)	CO2 emissions per capita, participation in GVCs, GDP per capita, energy use per capita, trade openness, and population density	Asian countries	1995-2014	Fully modified ordinary least square (FMOLS) and Dynamic ordinary least square (DOLS)	GVC participation leads to lower emissions
Balsalobre-Lorente et al. (2023)	Economic complexity, globalization, and renewable energy consumption	Central and East Europe	1993-2017	FMOLS, DOLS	Verify pollution haven hypothesis
Bhattacharjee and Chowdhury (2024)	CO2, Ch4, and N2O emissions per capita; GDP per capita, urban population, trade openness, and institutional quality	South Asia	1971-2018	OLS panel data	Verify EKC
Esmaeili et al. (2023)	CO2 emissions per capita, economic complexity index, FDI, renewable energy consumption	N-11 countries	1995-2019	Panel quantile regression	Verify EKC
Gyamfi et al. (2021)	GDP, CO2 emissions per capita, renewable, and non-renewable energy	Emerging 7	1995-2018	PMG-ARDL	Mixed results
Gyamfi et al. (2023)	CO2 emissions per capita, GDP, renewable energy consumption, information and communication technology imports and exports, and Human Development Index	Bangladesh, India, Nepal, Pakistan, and Sri Lanka	1990-2016	Pedroni cointegration test, Kao residual cointegration test, and Dumitrescu and Harlin causality test	Verify EKC
Hanif et al. (2020)	Renewable and non-renewable energy consumption, Human Capital Index, technology innovation, exchange rate, and oil prices	16 developed and 14 developing countries	1990-2018	Feasible Generalized Least Square panel estimation	Verify EKC
Hussain et al. (2022)	Ecological footprint, GDP, energy consumption, and population density	Pakistan	1981-2016	Autoregressive distributive lag model	Reject EKC
Li et al. (2020)	GDP, CO2 emissions per capita, population density, industrialization level, and urbanization rate	China	2000-2017	Spatial models	Verify EKC
Mao and He (2017)	SO2 emissions per industrial output, product upgrading, process upgrading, functional upgrading, and inter-sectorial upgrading	China (prefectural-level cities)	2003-2011	Panel data estimation	Environmental improvements depend on productive mix

Authorship	Variables	Sample Countries	Period	Method	Results
Polloni-Silva et al. (2021)	GDP per capita, CO2 emissions per capita, foreign direct investment, industrial sector, service sector, residential electricity, and population density	São Paulo (Brazil)	2010-2016	Fixed effect panel data	Mixed results
Ponce & Manlangit (2023)	CO2 emissions per capita, GDP per capita, energy consumption per capita	ASEAN countries	1960-2021	Panel root and cointegration tests	Verify EKC
Safi et al. (2023)	Consumption and production-based CO2 emissions, GDP per capita, exports and imports to GDP, energy productivity, renewable energy consumption, and eco-innovation	BRICS countries	1990-2020	Slope heterogeneity and cross-sectional dependency analysis	Economic growth and imports tend to increase emissions, innovation, exports, and energy productivity tend to reduce them
Shahbaz et al. (2020)	GDP, and energy consumption	China	1980-2018	Nonparametric panel test	Verify EKC
Shahzad et al. (2023)	GDP, coal consumption, FDI inflow, total population, and renewable energy	South and East Asian countries	1990-2020	Augmented mean group, and common correlated mean group panel data analysis. Slope heterogeneity and cross-sectional dependency analysis	Verify EKC for coal consumption
Shouwu et al. (2024)	GDP, urbanization, environmental technology, and clean energy use	North African countries	1990-2019	FM-OLS, D-OLS, and DSUR	Verify EKC
Suki et al. (2020)	GDP, ecological footprint, and economic, social, political, and overall globalization	Malaysia	1970-2018	Quantile autoregressive distributed lag	Verify EKC
Wang et al. (2024)	Merchandise trade openness, regional GDP per capita, regional CO2 emissions per capita, regional ecological footprint per capita, industrial value-added to GDP, net FDI inflow to GDP, and KOF globalization index	147 countries	1995-2018	Panel data analysis	Verify EKC
Wang et al. (2023)	GDP, CO2, human capital index, renewable energy consumption, total natural resources rents, and trade openness	208 countries	1990-2018	Generalized method of moments and fully modified ordinary least squares	Verify EKC
Yin & Chen (2015)	CO2 emissions per capita, GDP per capita, energy consumption per capita, environmental regulations, regional R&D expenditure to regional GDP, population, energy consumption to GDP, regional coal consumption to non-renewable energy consumption, trade openness, and FDI to GDP	China (regional level)	1999-2011	Generalized least squares	Verify EKC
Zhao et al. (2023)	Greenhouse gas emissions	World	1995-2015	Input-output	International trade increases emissions in agriculture exports

Source: Authors.

In the Asian context, a number of recent studies have examined this hypothesis from different perspectives. For example, Bhattacharjee and Chowdhury (2024) employ a balanced annual panel data for five South Asian countries revealing an EKC pattern depending on the greenhouse gas and estimation technique considered. Their study includes a foreign trade variable, but without further considerations regarding the type of trade or GVC participation. In addition, Shahzad and Aruga (2023) test the EKC in South and East Asian countries for coal consumption and support a non-linear relationship. Though this study finds interesting results, they also lack in considering foreign trade effects. Ponce and Manlangit (2023) also explore he relationship between CO_2 emissions, economic growth, and energy consumption in the ASEAN, supporting the EKC hypothesis but not considering foreign trade variables. In contrast, Arshad Ansari et al. (2020) incorporates a variable representing the globalization level of Asian countries, which has been found to improve ecological and material footprints. Regarding the EKC, the findings show mixed results when using ecological footprint, with the EKC being supported for Central and East Asian countries but not for West, South, and Southeast Asian countries. When using the material footprint indicator, results support the EKC hypothesis except for Central Asia. The study conducted by Gyamfi et al. (2023) is not only one of the few that incorporates foreign trade as an explanatory variable when analyzing the EKC in Asian countries, but it also considers high value-added exports and imports from the information and communication technologies (ICTs) sector. They found that ICT imports, renewable energy use, and human development significantly decrease CO_2 levels, while ICT exports and urbanization increase carbon emissions in the long run. Additionally, their results support the EKC hypothesis for South Asian countries. Thus, we can derive a first analysis hypothesis:

H1. There is a non-linear relationship between GDP and emissions in the East and Southeast Asian economies.

As noted, existing literature has not extensively explored the impact of GVCs in relation to the EKC, also in the case of Asian economies. However, analyzing this relationship within these countries is especially pertinent due to the potential positive environmental effects that participation in GVCs may offer Asian economies (Assamoi et al., 2020), and because of the intense level of engagement these countries have in global trade (Campos-Romero & Rodil-Marzábal, 2024), both as exporters of parts and components and as exporters of final goods. The increasing technological sophistication of exports from some East and Southeast Asian economies is also significant, though such profiles vary among them since different income levels coexist within the same region. Additionally, the lower environmental impact associated with higher value-added tasks has been recognized, whether these tasks are more service-oriented than manufacturing, or because they utilize more advanced and generally less polluting technologies (Campos Romero & Rodil Marzábal, 2021). In this context, integration into GVCs may entail patterns of economic and environmental upgrading, resulting in emission reductions via changes in the structure of production (Gereffi & Fernandez-Stark, 2016; Hofstetter et al., 2021; Khattak & Pinto, 2018; Mao & He, 2017). This observation leads us to propose the following hypothesis:

H2. Participation in GVCs leads to lower emissions in East and Southeast Asian countries.

The technological component emerges as a crucial element in interpreting the EKC. Technology has traditionally been integrated into the EKC literature through the analysis of environmental impacts divided into scale, composition, and technical or technology effects, as delineated by Copeland and Taylor (1994, 2001, 2004). The scale effect pertains to the volume of production and is generally suggested that this factor contributes to increased emissions, absent changes in the production structure. The composition effect precisely relates to the sectoral structure of an economy, with its impacts being ambiguous, contingent on shifts towards economic structures that are either more or less specialized in relatively polluting sectors. The technology effect concerns the adoption of new technologies which, being deemed more efficient in terms of energy and material use, typically result in lower emissions. It is vital to note that the technology effect does not exclusively refer to the adoption of clean technologies or a productive shift towards less polluting sectors but to the broader impacts of technological upgrading processes across any sector. However, there exists a notable gap in the literature regarding the analysis of the role played by changes in the production structure towards the development of more advanced technologies. Particularly in the context of Asian countries, known for their significant export activity, it is essential to also consider these shifts in industrial composition within their foreign trade structures.

Many studies incorporating the technology factor, beyond examining the influence of the three aforementioned effects, focus on the impact of adopting clean technologies on emissions. Research such as that by Smulders et al. (2011) or Shouwu et al. (2024) suggests that through innovation policies and the promotion of clean technologies, pollution can be mitigated, leading to cleaner production models. Similarly, other studies highlight the significant role of technological innovation in potentially advancing the tipping points posited by the EKC, thereby enabling earlier reductions in environmental impacts (Hanif et al., 2020; Yin et al., 2015). It is posited that, among Asian economies, the shift towards productive structures with higher technological and innovative content should manifest within their export structure. Based on these considerations, we propose the following hypothesis for analysis:

H3. High- and medium-high-tech exports have a moderating effect on emissions.

The subsequent section outlines the primary data sources and the methodological framework employed to examine the three hypotheses previously introduced.

3. Data and methodology

This paper aims to examine the impact of value-added exports in high and medium-high technology across a selection of 13 Asian countries[1], spanning from 1995 to 2018. It considers the countries' income levels and their emissions from both producer and consumer perspectives. Thus, it accounts for the environmental damage attributable to production activities, regardless of the location of the final consumption; as well as the environmental impacts stemming from domestic consumption, irrespective of the goods and services' geographical origin.

To attain this goal, data are compiled from various sources. For variables related to foreign trade and GVC participation, information is sourced from the database *Trade in Value Added* (*TiVA*, OECD, 2023 edition). Emissions data from both perspectives are obtained from *Carbon dioxide emissions embodied in international trade* (*TECO2*, OECD, 2021 edition). Additional variables of interest, such as renewable energy consumption, are gathered from The World Bank.

The use of export variables expressed in terms of value-added is considered particularly meaningful and relevant in this analysis, as opposed to traditional trade indicators expressed in gross terms. Traditional trade indicators introduce double counting of intermediate goods and services, which does not allow them to be calculated correctly and also does not represent the true contribution of value-added in each country. Due to the growing importance of trade in intermediate goods and the ability to correctly attribute the value generated to its origin, international trade indicators obtained by measuring trade in value-added are the most appropriate for this study. (Koopman et al., 2010, 2014). Furthermore, this approach facilitates the computation of the GVCs participation index, which is defined as the aggregate of forward and backward participations. The forward participation in GVCs pertains to DVA exports that are subsequently re-exported by third countries, whereas the backward share encompasses the value added by third countries that is exported by the reference economy. Collectively, these indicators, expressed as a percentage of a country's gross exports, serve as a gauge of its integration within GVCs.

Although the data are directly sourced from *TiVA* database, the methodological process enabling the extraction of trade variables in terms of value-added, utilizing the multiregional input-output methodology, is delineated next. For c countries and n sectors, the basic input-output entities

1 Brunei, Cambodia, China, Hong Kong, Indonesia, Japan, South Korea, Laos, Malaysia, Philippines, Singapore, Thailand, and Vietnam.

are as follows: $\mathbf{T}_{cn \times cn}$ is defined as the intermediate transactions matrix, $\mathbf{F}_{cn \times c}$ as the final demand matrix and $\mathbf{x}_{cn \times 1}$ is the total output vector, obtained as the sum of matrices T and F. From them, the matrices of technical production coefficients ($\mathbf{A=T\hat{x}^{-1}}$) and the inverse Leontief matrix ($\mathbf{L=(I-A)^{-1}}$) can be obtained.

$\mathbf{A}_{cn \times cn}$ is the matrix of technical coefficients of production, $\hat{\mathbf{x}}^{-1}_{cn \times cn}$ is a diagonal matrix containing the elements of the total output matrix on the main diagonal, the other elements being null; $\mathbf{L}_{cn \times cn}$ is the Leontief inverse matrix and $\mathbf{I}_{cn \times cn}$ is the identity matrix. The value-added coefficients, $v_{1 \times cn}$, which reflect the proportion of value created by sector i in country c is obtained as follows:

$$\mathbf{v=u-uA} \tag{1}$$

With $\mathbf{u}_{1 \times cn}$ being a vector of ones used to perform sums by columns. When performing sums by rows, we use a vector $\mathbf{u}_{cn \times 1}$ would be preferred. To define export flows in terms of value-added we shall consider any three countries, d, f and g; and any three sectors j, k and t; such that $d \neq f \neq g$ but intra-sector trade is possible, so $j = k = t$. Therefore, we define country d DVA exports for total of n columns as follows:

$$\mathrm{DVA}^d = \sum_{\substack{n,\\ d\neq f}} \hat{\mathbf{v}}_j^{\mathbf{d}} \mathbf{L}_{\mathbf{jk}}^{\mathbf{dd}} \mathbf{F}_{\mathbf{kj}}^{\mathbf{df}} + \sum_{\substack{n,\\ d\neq f}} \hat{\mathbf{v}}_j^{\mathbf{d}} \mathbf{L}_{\mathbf{jk}}^{\mathbf{df}} \mathbf{F}_{\mathbf{kj}}^{\mathbf{ff}} + \sum_{\substack{n,\\ d\neq f\neq g}} \hat{\mathbf{v}}_j^{\mathbf{d}} \mathbf{L}_{\mathbf{jk}}^{\mathbf{df}} \mathbf{F}_{\mathbf{kt}}^{\mathbf{fg}} \tag{2}$$

The first sum in equation (2) represents the so-called traditional trade, i.e. value generated totally by the country of origin exported and also exported by it as a final good. The second sum represents simple GVC trade, i.e., value generated by the country of origin, exported as an intermediate good and consumed as a final good by the direct importer. Finally, the third sum represent complex GVC i.e. value generated by the country of origin, exported as an intermediate good, re-exported by the direct importer and ultimately consumed in a third country. Value-added domestic exports are composed by the addition of these three elements.

Regarding the econometric study, we propose the following two panel data models incorporating fixed effects to analyze the EKC in East and Southeast Asian countries considering both consumptions and production-based emissions.

$$CO_{2ct} = \beta_0 + \beta_1 GDPPC_{ct} + \beta_2 GDPPC^2_{ct} + \beta_3 GDPPC^3_{ct} + \beta_4 GDPPCG_{ct} + \beta_5 TP_{ct} + \beta_6 DVAHMHT_{ct} + \beta_7 REC_{ct} + \varepsilon_{ct} \tag{3}$$

This model is replicated by treating emissions from both the production and consumption perspectives as dependent variables. These, along with the explanatory variables, are compiled along with the descriptive statistics in Table 2.

Table 2. Descriptive statistics. N. of observations: 312. Period: 1995-2018

	Mean	*Std. Deviation*	*Minimum*	*Maximum*	*Definition*	*Source*
CO2CPC	6.85	6.62	0.19	21.73	Consumption based emissions, tones per capita	$TECO_2$ (OECD, 2021 edition)
CO2PPC	7.03	7.41	0.04	31.28	Production based emissions, tones per capita	
GDPPC	13736.84	15982.66	243.99	66836.52	GDP per capita, US dollars	TiVA (OECD, 2023 edition
GDPPC2	4.43 × 10e8	7.55 × 10e8	59529.39	4.46 × 10e9	Square of GDPPC	
GDPPC3	1.75 × 10e13	3.86 × 10e13	1.45 × 10e7	2.98 × 10e14	Cube of GDPPC	
BP	25.68	11.31	5.40	48.00	Foreign value-added share in gross exports (%)	
FP	17.70	6.20	8.40	41.70	DVA embodied in foreign gross exports (%)	
TP	43.37	9.01	24.80	65.80	Total participation in GVCs (sum of BP and FP)	
DVAHMHT	41.65	28.41	0.00	89.10	High and medium-high technology DVA exported as a share of total DVA industry exports (%)	
GDPG	4.94	3.62	-13.13	14.52	Interannual GDP growth (%)	The World Bank
GDPPCG	3.61	3.56	-14.48	13.64	Interannual GDP per capita growth (%)	
REC	23.82	25.97	0.00	86.62	Renewable energy consumption as a share of total energy consumption (%)	

Source: Authors from $TECO_2$, TiVA, and The World Bank.

4. Results and discussion

In this section, we present the main findings of the paper, beginning with a series of descriptive statistics followed by the results of the proposed econometric models. Initially, we provide data on the contribution of industrial sectors to the GDP of the analyzed economies, categorized by their technological intensity (see Table 3). The results indicate markedly different patterns based on several factors: primarily, the level of regional development and, secondarily, the region's specialization in services.

In the first scenario, economies such as Brunei, Cambodia, Indonesia, and Laos exhibit a minimal presence of high-tech production within their economic structures, with a dominant share of medium-low or low-tech activities. Vietnam is an exception, which, from 1995 to 2018, increased its industrial participation across all levels of technological intensity, notably in high-tech sectors. In the second scenario, it is important to note that all countries demonstrate a higher proportion of service activities relative to GDP. In certain cases, the share of industrial sectors is less than 10%, as seen in Laos (8%) and Hong Kong (1%). Finally, it is worth noting the share of the high and medium-high technology sectors in Korea and Singapore, followed by Vietnam, China, Japan, Thailand, and Malaysia.

Table 3. Share of technological value-added to total GDP per technology intensity

	High technology		Medium-high technology		Medium-low technology		Low-technology	
	1995	2018	1995	2018	1995	2018	1995	2018
Brunei	0.08	0.03	0.26	0.49	7.80	10.23	0.74	0.54
Cambodia	0.10	0.14	0.35	0.51	2.42	2.36	15.64	19.45
China	3.51	3.56	8.66	8.35	9.72	9.50	9.14	7.02
Hong Kong	0.23	0.04	0.61	0.12	1.03	0.13	6.13	0.75
Indonesia	1.18	0.89	4.77	4.91	8.22	4.94	11.07	10.26
Japan	3.37	2.42	8.31	8.66	7.59	6.70	5.22	3.76
Korea	4.74	8.60	8.53	9.46	8.19	7.51	5.43	3.20
Laos	0.15	0.18	0.23	0.43	2.55	2.28	8.21	5.96
Malaysia	7.17	5.06	3.96	4.47	6.11	6.55	4.26	3.77
Philippines	3.74	3.53	3.39	3.36	4.73	3.33	11.86	11.56
Singapore	9.09	10.61	9.30	7.14	2.41	2.49	1.66	1.17
Thailand	3.99	4.09	5.83	6.66	7.84	6.68	9.76	8.46
Vietnam	1.63	7.76	4.66	5.36	7.62	9.79	12.04	13.95

Source: Authors from TiVA.

Turning to foreign trade and focusing on industrial sectors, Table 4 shows the content of exported DVA by technological intensity, along with the proportion of domestic carbon emissions in gross exports, relative to total industrial activity. From the perspective of exported DVA, all developed economies exhibit a greater share of medium-high and high technology-intensive exports. In the case of developing economies, the distribution is heterogeneous, with this situation occurring only in Brunei, China, Malaysia and the Philippines. However, from an emissions perspective, most of them are concentrated in medium-low and low technology-intensive exports. This is particularly remarkable considering the lower importance in USD of these exports in the case of countries such as Japan, Korea and Singapore. This trend may be attributed to the fact that activities in higher technological intensity sectors typically have lower emissions intensity, as they are less detrimental to the environment. In contrast, lower intensity activities often require more energy and material consumption, resulting in a higher volume of emissions.

Table 4. Share of exported DVA and domestic CO_2 emissions to total industry, 2018

	High and medium-high technology		Medium-low and low technology	
	DVA content of gross exports	Domestic CO_2 emissions embodied in gross exports	DVA content of gross exports	Domestic CO_2 emissions embodied in gross exports
Brunei	54.60	24.71	45.40	75.29
Cambodia	0.89	1.38	99.11	98.62
China	55.60	52.10	44.40	47.90
Hong Kong	29.35	8.66	70.65	91.34
Indonesia	27.27	26.32	72.73	73.68
Japan	81.09	57.72	18.91	42.28
Korea	80.72	55.08	19.28	44.92
Laos	9.67	3.87	90.33	96.13
Malaysia	52.83	43.89	47.17	56.11
Philippines	61.96	51.80	38.04	48.20
Singapore	84.88	51.75	15.12	48.25
Thailand	46.31	40.27	53.69	59.73
Vietnam	32.68	17.93	67.32	82.07

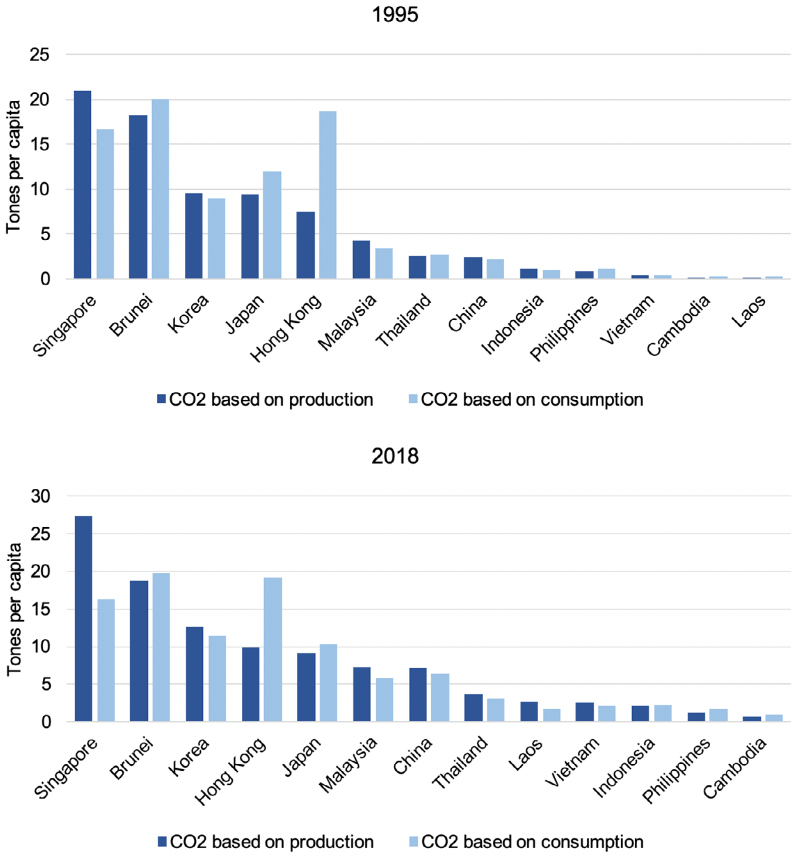
Source: Authors from TiVA and $TECO_{2.}$

Before presenting the results of the proposed models, it is important to highlight the value of incorporating both consumer and producer perspectives in the analysis of carbon emissions. Traditionally, the producer perspective has been used to assign environmental responsibilities, yet this approach is biased and disproportionately affects countries that have integrated more manufacturing-related tasks into the global economic structure, particularly for products of medium to low technological intensity. On the other hand, analyzing emissions solely from the consumer perspective also presents a skewed view, favoring countries with low consumption and high production levels. Thus, it is advantageous to consider both perspectives simultaneously.

Accordingly, Figure 1 illustrates the per capita tons of carbon emitted by the countries studied in 1995 and 2018 from both the consumer and producer viewpoints. Most of the countries display a balance between the two perspectives, with a variance of approximately 1 ton of CO_2 per capita. However, the cases of Singapore and Hong Kong are notable exceptions: Singapore exhibits a higher volume of emissions from the producer perspective, signifying its role as a significant supplier of inputs; Hong Kong, in contrast, shows a predominance of emissions from the consumption perspective.

Finally, Table 5 presents the results of the proposed models, categorizing the countries into three groups: the complete set, the developing economies (Brunei, Cambodia, China, Indonesia, Laos, Malaysia, Philippines, Thailand, and Vietnam), and the developed economies (Hong Kong, Japan, Korea, and Singapore). Additionally, within each group, emissions are distinguished between the consumer and producer perspectives.

Figure 1. CO_2 emissions based on consumption and production, 1995 and 2018



Source: Authors from $TECO_2$

Starting with an evaluation of the EKC, several observations emerge. First, across most models, there is a positive linear relationship between GDP per capita and emissions from both perspectives. The exception is observed in developed countries from the producer perspective, where an increase in GDP correlates with reduced emissions. The latter result can be explained by the progressive offshoring of various manufacturing activities and the growth of services in the economic structure of these countries. However, as the level of consumption per capita in the developed economies has not been reduced, an increase in disposable income implies higher emissions from the consumer's perspective.

Regarding the existence of Kuznets curves, the significance of the quadratic (parabolic shape) and cubic (N or inverse N shape) elements of GDP per capita is analyzed (GDPPC, GDPPC2, and GDPPC3). The production-based model among developing countries and the consumption-based model among developed countries do not exhibit this relationship. In contrast, for other models, these elements are significant, typically revealing an inverse U-shaped curve when considering the quadratic model, except for emissions from the perspective of the producer in developed economies, where a U-shaped relationship is found. The cubic models suggest the possibility of either an N-shaped or inverse N-shaped relationship. However, to confirm these relationships, it is essential to evaluate the inflection points in all cases. Table 6 provides a summary of the EKC analysis results for each model, which generally support *H1* and are in line with the findings obtained by Ponce and Manlangit (2023) and Shahzad and Aruga (2023), among others.

These results reinforce the interest in analyzing the existence of environmental Kuznets curves as a function of the level of economic development of countries, as important differences have been found. For developing countries, although no relationship was found from production-based emissions, the inverted U-shaped relationship and N-shape show that increases in per capita income can lead to a temporary reduction in emissions from a consumption perspective, probably due to changes in consumption habits. The results show that reaching a certain level of per capita income is not a sufficient condition to guarantee an emission reduction path in the long run. The same is true for production-based emissions in developed countries, where technical and technological progress seems to have reached a limit in terms of reducing emissions.

Table 5. Estimation results. Dependent variables: CO_2 from consumption and production perspectives (tones per capita)

	All countries		Developing countries		Developed countries	
	CO_2 consumption	CO_2 production	CO_2 consumption	CO_2 production	CO_2 consumption	CO_2 production
GDPPC	4.15E-4 (5.56E-5) ***	0.00035 (0.00006) ***	0.00063 (0.00006) ***	0.00043 (0.00006) ***	0.00047 (0.00018) ***	-0.00043 (0.00019) **
GDPPC2	-8.7E-9 (1.83E-9) ***	-4.8E-9 (1.87E-9) ***	-2.67E-8 (3.3E-9) ***	-4.3E-9 (3.04E-9)	-7.28E-9 (5.01E-9)	1.65E-8 (5.37E-9) ***
GDPPC3	6.28E-14 (1.91E-14) ***	3.8E-14 (1.95E-14) **	3.39E-13 (5. 05E-14) ***	-2.45E-15 (4.66E-14)	3.29E-14 (4.47E-14)	-1.41E-13 (4.79E-14) ***
GDPPCG	0.00178 (0.01879)	0.00804 (0.01921)	-0.0182 (0.0193)	-0.01501 (0.01779)	0.00816 (0.03657)	0.02394 (0.03922)
TP	-0.03078 (0.0137) **	0.02282 (0.014008) *	0.00568 (0.01459)	0.00081 (0.01345)	-0.0444 (0.02943)	0.09865 (0.03156) ***
DVAHMHT	-0.01584 (0.0068) **	-0.02726 (0.00695) ***	-0.01106 (0.00663) *	-0.02699 (0.00611) ***	-0.03096 (0.02925)	0.06476 (0.03136) **
REC	-0.03295 (0.0101) ***	-0.03308 (0.01033) ***	-0.0065 (0.00925)	-0.03063 (0.00852) ***	-0.38250 (0.20385) *	-0.3751 (0.21859) *
Constant	6.67574 (0.72965)	4.5745 (0.746)	2.4586 (0.8172)	4.12807 (0.75325)	10.3864 (1.83671)	6.3579 (1.96953)

	All countries		Developing countries		Developed countries	
	CO_2 consumption	CO_2 production	CO_2 consumption	CO_2 production	CO_2 consumption	CO_2 production
R^2 within	0.33	0.61	0.48	0.65	0.35	0.7
R^2 between	0.93	0.73	0.83	0.99	0.5	0.84
R^2 overall	0.9	0.71	0.74	0.96	0.47	0.75
rho	0.95	0.96	0.97	0.95	0.83	0.95

Note 1: The table shows the coefficients and the standard errors in brackets.
Note 2: ***, **, and * represent significance at 1%, 5%, and 10% respectively.
Source: Authors from TECO$_2$, TiVA, and The World Bank.

As for the other variables in the estimation, economic growth (GDPPCG), as measured through GDP per capita yearly change rate, is not significant; thus, increases in this variable do not have a relevant impact on carbon emissions in either direction. However, participation in GVCs (TP) shows significant effects in certain scenarios. When all countries are considered collectively, GVC participation positively impacts emissions from the producer perspective and negatively from the consumption perspective. This variable is also significant from the producer perspective for developed countries. These outcomes reflect the diverse integration patterns of the countries under consideration. From the consumption perspective, the reduction in emissions associated with GVC participation largely results from the importation of products that require less energy and material consumption. Conversely, from the producer perspective, increased emissions are linked to the manner of integration into GVCs, where increased forward participation (e.g., through value-added exports) necessitates higher levels of production, material, and energy consumption, thus leading to increased emissions. In this context, *H2* is partially confirmed, as participation in GVCs can lead to a reduction in emissions depending on the mode of integration and the emissions perspective adopted.

Table 6. EKC estimation results summary

Group	*Emissions perspective*	*Parabolic*	*Inflection point (USD per capita)*	*Cubic*	*Inflection points (USD per capita)*
All countries	*CO_2 consumption*	Inverted U-shape	23,856	No relation	-
	CO_2 production	Inverted U-shape	36,552	No relation	-
Developing countries	*CO_2 consumption*	Inverted U-shape	11,726	N-shape	17,679 and 34,828
	CO_2 production	No relation	-	No relation	-
Developed countries	*CO_2 consumption*	No relation	-	No relation	-
	CO_2 production	U-shape	13,027	Inverted N-shape	16,529 and 61,484

Source: Authors.

From the technological perspective, which considers the impact of foreign trade on emissions, exports of high and medium-high technology goods play a key role (DVAHMHT). These exports generally have a significant downward impact on emissions, except for emissions from the producer perspective among developed countries. In this case, the substantial role of high-tech activities within the industrial GDP means that any further increases could lead to a greater impact on emissions. However, in developing economies, an increased specialization in high-tech activities may lead to a reduction in less technology-intensive tasks, which, as previously discussed, tend to cause more environmental damage. In this context, *H3* is substantiated for developing economies in East and Southeast Asia, suggesting that an increase in their exports of high and medium-high technology goods would result in a reduction in emissions. Lastly, renewable energy consumption as a percentage of total energy consumed (REC), included as a control variable, yields the anticipated outcome. It shows a significant and negative effect on emissions across all scenarios, underscoring the positive environmental impact of integrating renewable energy sources into energy consumption patterns.

5. Conclusions

In the context of climate emergency, it is critical to examine the factors that can contribute to emission reductions and more efficient resource use. East and Southeast Asian countries have emerged as significant global suppliers to both neighbored economies and Western countries. Additionally, domestic consumption plays a crucial role in driving GDP in some of these countries. Accordingly, this paper aims to analyze the impact of high and medium-high technology exports on reducing emissions through the lens of the EKC. It also considers both consumer and producer perspectives on carbon emissions.

The findings indicate a non-linear relationship between emissions and GDP per capita, although year-on-year changes in GDP do not significantly affect this relationship. A parabolic or wave-like relationship has been established in instances where inflection points exist, thus identifying the levels of GDP per capita at which trend changes may occur. Caution is advised when interpreting these levels due to the EKC estimation models' high sensitivity to changes in dependent and independent variables, countries, and the time frames considered. On this basis, the results show that the share of GVCs and the DVA of high and medium-high technology goods in reducing emissions are particularly significant.

The effects of GVCs largely depend on the way that Asian countries are integrated and the development level. Notably, developed Asian countries tend to exhibit higher emissions from the production perspective when their participation in GVCs increases. In response, policy measures should be devised to guide productive specialization in foreign trade towards sectors that are less intensive in emissions. However, these policies must be crafted within a global consensus framework, considering their potential impact on the productive structures of developing economies. Specific proposals could include establishing minimum standards for efficient energy and water use, measuring emissions, and designing and implementing plans to mitigate environmental impact at the firm level.

Precisely, this study underscores the importance of incentivizing activities with higher technological content and value-added in developing countries as a key strategy for reducing emissions. Industrial upgrading in the developing economies of East and Southeast Asia could replace emission-intensive activities with more environmentally friendly alternatives. Consequently, there is a need for industrial promotion policies complemented by plans to develop robust R&D systems. Over the medium to long term, these initiatives are expected to produce a sufficient supply of human capital with the required knowledge to develop such activities. International cooperation, particularly from more developed countries, is essential to support and accelerate the economic transition in developing regions. From the consumer perspective, it is also of great importance to adopt consumer awareness policies, especially considering the gradual improvement in per capita income levels in some Asian economies and the effects this may have on personal consumption (Menezes & Rodil-Marzábal, 2012).

Future research lines should explore the potential barriers that the developing economies of East and Southeast Asia face in crafting proposals aimed at strengthening their productive structures and fostering activities that generate higher value. Additionally, it would be beneficial to examine the positive impacts these measures could have on social upgrading, particularly in addressing economic, gender, and labor inequalities.

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Appendix A

Table A1. Additional estimation results: Backward participation

	All countries				Developing countries				Developed countries			
	CO_2 consumption		CO_2 production		CO_2 consumption		CO_2 production		CO_2 consumption		CO_2 production	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
GDPPC	0.0004	0.0001***	0.0004	0.0001***	0.0006	0.0001***	0.0004	0.0001***	0.0005	0.0002**	-0.0005	0.0002**
GDPPC2	-8.86E-09	1.88E-09***	-5.25E-09	1.9E-09***	-2.63E-08	3.18E-09***	-4.72E-09	2.93E-09	-6.99E-09	5.06E-09	1.68E-08	5.24E-09***
GDPPC3	6.61E-14	1.94E-14***	4.1E-14	1.97E-14**	3.32E-13	4.83E-14***	1.98E-15	4.44E-14	3.09E-14	4.51E-14	-1.42E-13	4.68E-14***
GDPPCG	0.0009	0.0190	0.0097	0.0192	-0.0179	0.0193	-0.0142	0.0178	0.0066	0.0369	0.0254	0.0383
BP	-0.0073	0.0145	0.0272	0.0146*	-0.0004	0.0140	0.0116	0.0129	-0.0297	0.0365	0.1436	0.0378***
DVAHMHT	-0.0199	0.0066***	-0.0255	0.0067***	-0.0100	0.0063	-0.0280	0.0058***	-0.0360	0.0293	0.0744	0.0304**
REC	-0.0275	0.0102***	-0.0325	0.0103***	-0.0083	0.0089	-0.0280	0.0082***	-0.4513	0.1983**	-0.3061	0.2057
Constant	5.7059	0.6695	4.6302	0.6781	2.7413	0.6451	3.7703	0.5931	9.9070	1.8189	6.5560	1.8867
R2 within	0.32		0.61		0.65		0.65		0.34		0.71	
R2 between	0.94		0.73		0.99		0.99		0.56		0.93	
R2 overall	0.91		0.71		0.95		0.95		0.51		0.85	
rho	0.95		0.96		0.97		0.95		0.81		0.93	

Source: Authors from TECO$_2$, TiVA, and The World Bank.
Note 1: ***, **, and * represent significance at 1%, 5%, and 10% respectively.

TABLE A2. ADDITIONAL ESTIMATION RESULTS: FORWARD PARTICIPATION

	All countries				Developing countries				Developed countries			
	CO_2 consumption		CO_2 production		CO_2 consumption		CO_2 production		CO_2 consumption		CO_2 production	
	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error	Coefficient	Standard error
GDPPC	0.0005	0.0001***	3.58E-04	0.000060***	0.000617	0.000059***	0.000442	0.000055***	0.000449	0.000174**	-0.0003473	0.000199*
GDPPC2	0.0000	0.0000***	-4.62E-09	1.9E-09**	-2.67E-08	3.19E-09***	-3.51E-09	2.93E-09	-7.05E-09	4.93E-09	1.51E-08	5.65E-09***
GDPPC3	0.0000	0.0000***	3.46E-14	1.95E-14*	3.41E-13	4.98E-14***	-1.93E-14	4.57E-14	3.25E-14	4.41E-14	-1.33E-13	5.05E-14***
GDPPCG	0.0054	0.0187	0.0087	0.0193	-0.0194	0.0194	-0.0119	0.0179	0.0099	0.0361	0.0285	0.0414
FP	-0.0628	0.0220***	-0.0052	0.0227	0.0125	0.0208	-0.0242	0.0191	-0.1536	0.0725**	0.0210	0.0831
DVA-HMHT	-0.0148	0.0067**	-0.0234	0.0070***	-0.0110	0.0063*	-0.0250	0.0058***	-0.0202	0.0297	0.0750	0.0340**
REC	-0.0269	0.0096***	-0.0384	0.0099***	-0.0076	0.0082	-0.0319	0.0076***	-0.3003	0.2089	-0.1759	0.2394
Constant	6.0041	0.5301	5.5029	0.5472	2.5614	0.5163	4.4898	0.4742	10.6656	1.8092	8.0121	2.0734
R2 within	0.33		0.61		0.48		0.00		0.37		0.66	
R2 between	0.92		0.71		0.85		0.00		0.80		0.41	
R2 overall	0.89		0.70		0.75		0.00		0.71		0.41	
rho	0.95		0.96		0.97		0.95		0.75		0.96	

Source: Authors from $TECO_2$, TiVA, and The World Bank.
Note 1: ***, **, and * represent significance at 1%, 5%, and 10% respectively.