

RESEARCH ARTICLE



WILEY

Environmental effects of growth and global value chains: The case of East and Southeast Asian economies

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Funding information

Xunta de Galicia, Grant/Award Number: ED431C 2022/15; MCIN/AEI, Grant/Award Number: 10.13039/501100011033

Abstract

The Environmental Kuznets Curve (EKC) hypothesis has become an important topic in the literature on the effects of growth on the environment, albeit surrounded by some controversy and nuance. Although this hypothesis has been analyzed in the literature in multiple ways and using different variables, there is still a gap in the consideration of global value chains (GVCs), which delve into the international division of production. This is particularly important in the intermediate stages of production, as they include tasks with a greater environmental impact. This research aims to analyze the environmental effects of economic growth and foreign trade linked to GVCs in a sample of 12 countries of East and Southeast Asia, given their strong insertion in GVCs. Based on the EKC, variables such as GDP per capita, environmental impact, and renewable energy consumption are incorporated. As a novelty, the research also includes GVCs participation and position indexes, and different measures of CO₂ emissions. Our results confirm the existence of a nonlinear relationship between economic activity and its environmental effects, although with important nuances depending on the mode of insertion of each country in GVCs. In this sense, although all the selected countries increased their total emissions, substantial disparities are observed depending on the perspective considered (producer, consumer, and exports). Ultimately, it is concluded that, for an effective reduction of the environmental impact in these countries, it is essential to design policy measures, targeting new technologies, consumption and production patterns, and attracting green foreign direct investment.

KEYWORDS

consumption and production-based emissions, East and Southeast Asian countries, economic growth, environmental Kuznets curve, global value chains

1 | INTRODUCTION

Asia, and especially its densely populated coastal regions, is particularly vulnerable to the effects of climate change. The less stringent economic environmental regulations and its economic structure

contribute to additional environmental issues, particularly concerning water and forest resource management, which, in turn, influence and contribute to climate change.

Despite major Asian economies, including China, signed the Paris Agreement and several countries committed emission reduction

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targets for the coming years, the reality is that Asian economies continue to witness annual increases in emissions. They rank among some of the leading emitters of greenhouse gases, either in absolute terms, as in the case of China, or in relative terms when considering emissions intensity. In fact, Singapore stands out as the only country included in this study that has managed to decrease its carbon emissions since 2000, achieving an average reduction rate of 1.45% in 2000–2020. Conversely, the remaining countries have maintained average growth rates spanning from 1% to 14% annual average, according to data from the World Bank.

This discrepancy is, in part, a result of the growth strategies pursued by developing Asian countries. Their economic structure would need to be altered significantly if they opted for radical changes that could result in a drastic reduction in emissions. Additionally, their integration into global value chains (GVCs) plays a pivotal role in this growth strategy, rendering Asian countries net exporters of emissions to Europe and North America. According to the (Asian Development Bank, 2023), emissions from exports have tripled in the last 20 years. Moreover, several Asian countries uphold less stringent environmental regulations compared to developed countries. This may be attributed to their integration into global markets, where an escalation in pollution penalties could potentially lead to a loss of competitiveness in attracting foreign investment.

However, as discussed in the following section, the academic literature is not unanimous on the environmental effects of economic growth, nor does it reach a consensus on the impacts of foreign trade, and even less so on the role of GVCs specifically. The GVC concept refers to the intensity with which production processes have been fragmented, allowing numerous countries to participate in the production of the same product. In general, it can be asserted that the most emission-intensive and energy-intensive tasks have shifted from developed to developing economies. This makes the analysis of emissions from a double perspective, as a producer and as a consumer, especially interesting.

Among the different approaches that can be adopted, this study is based on the environmental Kuznets curve (EKC). This hypothesis posits a potential correlation between economic growth and its influence on environmental quality. Specifically, the EKC suggests a theoretical curve resembling an inverted “U” shape. It assumes that during the initial stages of economic growth, the environmental quality deteriorates until a certain threshold of GDP per capita (often used as a growth proxy) is reached. Beyond this point, emissions levels are expected to decline.

In addition to the foregoing, it is important to point out that this process of economic globalization has entailed, from the perspective of environmental impacts, the relocation of production processes that are intensive in energy consumption and other materials from developed to developing countries. While certain theories, like the EKC, posit that greater economic growth will eventually result in improved environmental conditions, it remains uncertain whether this trend will be uniform across different regions or if the favorable environmental trajectory, once attained, will persist over the long term.

Therefore, the objective of this research is to examine the environmental consequences of economic growth, foreign trade, and, specifically, GVCs in 12 East and Southeast Asian countries (Brunei, Cambodia, China, Hong Kong, Indonesia, South Korea, Laos, Malaysia, the Philippines, Singapore, Thailand, and Vietnam). For this purpose, the theoretical model established by the EKC serves as the foundation, incorporating various environmental impact variables and considering the extent of involvement in GVCs (see Figure 1). The primary novelties of this study include, first, the inclusion of both consumer and producer perspectives in assessing environmental impacts and, second, the integration of GVCs into the examination of this complex relationship, encompassing a significant number of countries, some of which are notable for their high participation in the phenomenon of international fragmentation of production.

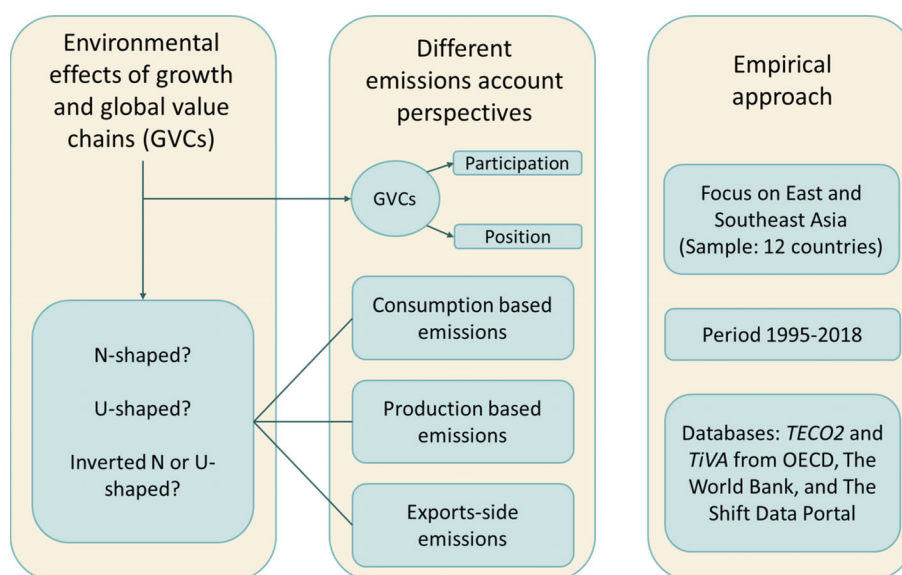


FIGURE 1 Research roadmap. Source: Authors.

The selected countries represent a diverse spectrum of economic development within the region, encompassing a range of income levels, industrialization stages, and environmental policies. In this sense, the research aims to capture a comprehensive understanding of the EKC dynamics across different contexts. Moreover, this group of countries is among the most vulnerable to the effects of climate change and is becoming some of the highest emitting countries, both in absolute terms (as in the case of China) and in relative terms, looking at the intensities of emissions and non-renewable energy use. The environmental policies implemented in these countries may face constraints as they rely on maintaining a competitive position in global markets. This entails minimizing limitations on foreign capital inflows while controlling costs, including those related to labor and taxes, including environmental taxes. This selection ensures a nuanced analysis, considering the unique socio-economic and environmental landscapes of each country. Furthermore, the inclusion of both developed and developing nations allows for the examination of potential correlations between economic growth and environmental quality at various stages of development.

The incorporation of both consumer (demand) and producer (supply) perspectives represents a significant contribution, as this distinction has not been previously addressed in EKC analysis. Furthermore, there is a critical ongoing discussion regarding which perspective should be employed when allocating environmental responsibilities, particularly from an environmental justice standpoint (Steininger et al., 2014). Developed Western economies have typically outsourced production processes to other countries, seeking various advantages. This practice, in addition to contributing to the formation of GVCs, has also resulted in the transfer of some of the most environmentally polluting tasks to developing countries. Consequently, it has allowed for the improvement of the environmental records of Western economies from the producer's perspective, as well as a reduction in their traditionally assigned environmental responsibilities. Notably, the research findings reveal varying effects of GVC participation and position, depending on whether emissions are analyzed from one perspective or the other, representing another significant contribution.

It should be noted that the decision-making centers within the GVCs are generally located within multinational companies based abroad. This condition significantly influences any potential changes affecting the type of activities and tasks carried out in these countries. Therefore, apart from designing a productive modernization strategy (structural upgrading) in the long term, it may be more practical and realistic in the medium term to adopt specific measures that contribute to the reduction of emissions, considering the specificities of the type of insertion of each country in the GVCs.

Accordingly, this work allows us to derive policy implications at two levels. On the one hand, at a general level, the results point to the need to adopt strategies of structural change in the long term, favoring environmental upgrading in the participation of countries in GVCs, compatible with their endogenous development potential. On the other hand, it is necessary to advance in the design of specific measures in accordance with the particular insertion of each country in

the GVCs. In this sense, specific measures must be applied to stimulate environmental upgrading in aspects such as the technologies used, modes of transport and logistics nodes, as well as in production and consumption patterns. This consideration should take into account the type of production linkages, activities, and tasks that define the insertion of each country in the GVCs.

The paper comprises four sections, in addition to this Introduction. Section 2 conducts a comprehensive review of the most pertinent literature on EKC analysis, with particular attention given to the case of East and Southeast Asian economies. Section 3 is dedicated to presenting the data and outlining the research methodology. Section 4 presents and deliberates upon the principal empirical findings, concluding the paper in Section 5 by presenting the primary conclusions.

2 | LITERATURE REVIEW

In recent years, there has been a growing focus in the literature on the relationship between economic growth and the environment. This shift has moved away from the traditional perspective of growth limitations associated with the concept of scarcity as a central element in the interplay between the economy and nature within the current model of accumulation. Consequently, alternative viewpoints that emphasize the impacts of economic activity on the environment and incorporate various hypotheses regarding the nature of this relationship have gained attention and interest.

As stated in the Introduction, the EKC stands out. This relationship between growth and emissions has been analyzed in the literature in various ways, with modifications and expansions of the number of variables influencing the formation of the curve, consequently affecting the deterioration or improvement of the environment. Explanatory models have evolved not only in terms of the possible forms this relationship can take but also in terms of the variables considered. In this context, environmental impact is now assessed using variables such as carbon footprint, ecological footprint, and other indicators related to the extent of soil or water pollution, not limited to air pollution alone. These various models have also incorporated other variables linked to the economic sphere, including foreign trade and the productive specialization of each country.

Related to international trade, the role of GVCs as the ultimate expression of the international division of labor is of particular significance (Aguar de Medeiros & Trebat, 2017; Coveri & Zanfei, 2022; Gereffi, 2014). While there are specificities depending on each industry and sector of activity, there is a consensus that the intermediate stages of the production chain (tasks more closely linked to manufacturing) generally entail more significant environmental impacts (Campos-Romero et al., 2023). In this context of globalized production, the emerging economies of East and Southeast Asia, whose economic growth and trade integration have been directly linked in recent decades to their participation in GVCs, have gained relevance. Consequently, these economies offer an excellent vantage point for studying the relationship between economic performance and environmental quality.

This process of economic globalization has entailed, from the perspective of environmental impacts, the relocation of production processes that are intensive in energy consumption and other materials to developing countries. While certain theories, like the EKC, posit that greater economic growth will eventually result in improved environmental conditions, it remains uncertain whether this trend will be uniform across different regions or if the favorable environmental trajectory, once attained, will persist over the long term.

Since the seminal contributions by Grossman and Krueger (1991, 1993, 1995), numerous studies have examined the relationship between economic growth and its environmental impact. Among the various theories employed in these studies, the EKC has gained prominence. The EKC posits an inverted U-shaped relationship between economic growth, typically measured by per capita GDP, and per capita emissions. Most of the research opt for using per capita carbon dioxide emissions (CO_2) or a set of greenhouse gases as the environmental impact variables (Özcan & Öztürk, 2019). However, some recent research also incorporates indicators such as the ecological footprint (Arshad Ansari et al., 2020; Balsalobre-Lorente, Nur, et al., 2023; Numan et al., 2022; Shahbaz et al., 2020; Wang et al., 2023).

This relationship suggests that as a country develops, emissions tend to increase until reaching a tipping point, after which they start to decline. Most of the research seeks to confirm the existence of this parabolic relationship (Carson, 2010; Jaunky, 2011; Martínez-Zarzoso et al., 2017; Polloni-Silva et al., 2021; Suki et al., 2020). However, several recent studies consider that this correspondence might exhibit an “N” or inverted “N” shape, following a cubic function and allowing for

the possibility of multiple inflection points and various phases of increasing and decreasing emissions, as illustrated in Figure 2 (Fakher et al., 2023; Gyamfi et al., 2021; Shehzad et al., 2022; Sinha et al., 2019).

Behind this evolution of emissions are the scale, composition, and technology effects, as defined by Copeland and Taylor (1994, 2001, 2004). The scale effect pertains to the change in emissions resulting from an increase in productive activity, which may stem from either greater consumption possibilities among the population or increased access to foreign markets, leading to a rise in emissions. The composition effect relates to the sectoral structure and the specific tasks in which each country specializes, making the effect on emissions not predetermined. In this context, GVCs are particularly relevant, as they largely determine the type of productive tasks performed by each region (Starosta, 2010). Lastly, the technology effect involves the adoption of new technologies and knowledge as countries' income levels increase. Given that newer technologies tend to be more energy-efficient and have lower emissions, this effect results in a reduction in environmental impacts.

The emergence of N-shaped and inverted N-shaped models gains particular significance when one considers that the technology effect is approaching its limits, particularly in the more developed economies (Balsalobre-Lorente, Shahbaz, et al., 2023; Ulucak & Yucel, 2021; Zhang, 2021). As the scope for technical progress to reduce energy consumption and emissions per product diminishes, the scale effect becomes increasingly relevant. In other words, a higher volume of economic activity will once again result in higher emissions, akin to the early stages of economic development. Emissions will increase

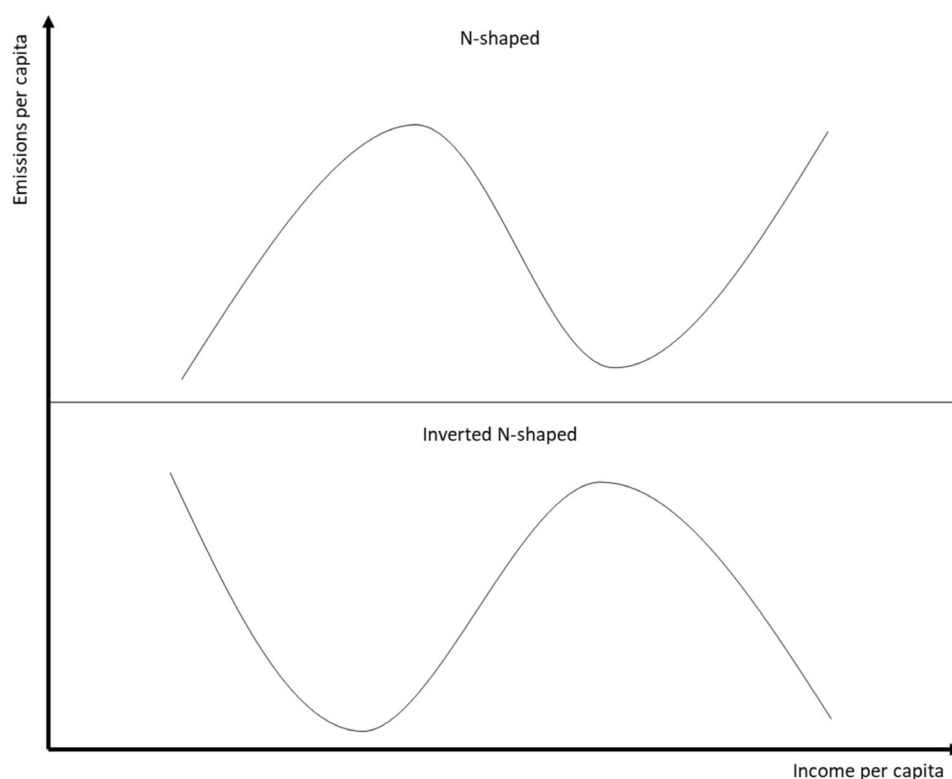


FIGURE 2 Cubic shapes of the environmental Kuznets curve.

Source: Authors.

both with rising income levels and with an expanding total population. Although in more advanced economies, especially in Europe and Japan, population growth has slowed or ceased, in Asian economies, both phenomena—rising living standards and total population growth—continue to manifest.

The analysis of the EKC in East and Southeast Asian countries holds particular significance due to their substantial accumulation of manufacturing tasks in recent decades, with some of them emerging as primary suppliers of a wide range of products (Eichengreen & Tong, 2006; Hamilton et al., 2006). This includes increasingly high-value-added goods, although with varying patterns of upgrading among different Asian countries (de Vries et al., 2019). From a producer's perspective, these countries have become significant carbon emitters, with China leading the way (Kurokawa & Ohara, 2020; Takahashi et al., 2014). Apergis and Ozturk (2015) conducted an analysis of the EKC scenario for a set of 14 Asian countries. In addition to emissions and GDP per capita, their study considers factors such as the scale of economic activity, the proportion of industry in total economic activity, as well as proxy variables for institutional quality and corruption. Their results confirm the existence of a nonlinear relationship between growth and emissions, positioning this group of countries within the declining section of the curve.

The study conducted by Arshad Ansari et al. (2020) investigates the presence of the EKC for the Association of Southeast Asian Nations (ASEAN) using both CO₂ emissions per capita and ecological footprint as independent variables. Their findings indicate the existence of this curve when the latter variable is employed. Notably, one of their key contributions lies in the disparity of results based on the dependent variable selected. However, it is worth mentioning that their model exclusively considers the possibility of an inverted U-shaped curve. This limitation hinders us from considering the possibility that future growth may lead to a resurgence of increasing emissions, a scenario that is plausible depending on changes in the industrial structure and available technologies, particularly in the field of energy production. In this study, it has been decided to incorporate models that consider both the inverse U-shaped curve and a wave-shaped curve to overcome this limitation.

It is common in contemporary research to include independent variables alongside GDP per capita. In addition to variables related to institutional quality, it has become customary to incorporate data on fossil and renewable energy consumption or production (Balsalobre-Lorente, dos Santos, et al., 2023; Esmaeili et al., 2023; Fakher et al., 2023; Murshed et al., 2022). The inclusion of these variables is justified both for their potential in mitigating carbon emissions and from a technical standpoint, as they serve as control variables. The expected outcome of fossil energy consumption is an increase in emissions. Notably, the two aforementioned studies, in addition to confirming the presence of the EKC, also identify energy-related variables as significant factors.

Population density is another variable often included as a control variable (Li et al., 2020; Luo et al., 2017; Nepal et al., 2019). However, there is a scarcity of studies that consider it as a central variable in explaining environmental degradation. In this regard, Hussain et al. (2022) center their study on the role of population density in the

ecological footprint in Pakistan, suggesting that an increase in population density can potentially contribute to reducing the ecological footprint. This somewhat counterintuitive result warrants further verification, as several papers point out that urbanization typically entails greater environmental pressure, particularly considering the limited progress of renewable energy sources (Hussain et al., 2023; Wang, Wang, & Li, 2022).

Despite the progress that EKC analysis has made in the literature, and despite the use of new techniques and more complete models in terms of the variables included, the fact is that the results of the literature are not unanimous regarding EKC compliance. One of the main problems is the acceptance of estimation results without effectively checking the existence of turning points in the curves. While it is true that different time frames and the choice of variables play an essential role in the results of these works, they are not always selected according to the underlying economic structure. The lack of clear and conclusive results creates problems for the implementation of effective policies in a heterogeneous territorial context. Moreover, studies that include samples from numerous countries, with a remarkable diversity of economic and political structures, may lead to uncertain results about the verification of the EKC hypothesis.

In this research, an approximation is made to the effects of growth on emissions considering the model of insertion in the global economic structure of the selected countries. As mentioned above, these countries stand out for a growth model based on input exports, having assumed an eminent manufacturing role in their external trade balance. Some of the consequences of this fact are, first, that their participation in the GVCs stands out for the assumption of relatively more polluting tasks; and second, although it is true that these countries are some of the most polluting, it should also be considered that a large part of their demand comes from Western countries.

To take these effects into account, two variables are included: one measures the degree of participation in GVCs, while the other measures the type of participation of each country (see Expression 1 in Section 3, and Figure 3 in Section 4). Furthermore, a distinction is made between emissions from three perspectives: production, consumption, and domestic value-added exports. This distinction is not common in the literature, even though it makes it possible to distinguish the emissions actually generated in a territory from those consumed. Among the few studies to make this distinction are the contributions by Frodyma et al. (2022) and Jiang et al. (2019). This differentiation can be particularly intriguing, as the volume and trends of emissions calculated under both systems can vary significantly. The inclusion of the consumer perspective in this analysis is notably significant and constitutes a noteworthy contribution for several reasons.

First, it allows for the recognition of substantial differences in the volume and trajectories of emissions depending on the chosen approach. Second, emissions from the consumer perspective are anticipated to increase as per capita income rises in these economies (Rahman et al., 2022). Third, Asian economies distinguish themselves by attracting a significant portion of Western economies' manufacturing output, making them not only major exporters but also some of the countries experiencing the highest growth rates in emissions from production.

Conversely, while it is usual to incorporate the degree of external integration as an explanatory variable in studies focused on the analysis of environmental impacts, including those examining the Kuznets curve (Jiang et al., 2019; Majeed, 2020; Wang et al., 2023), it is less common to consider the role of GVCs. This is despite the fact that GVCs, due to their characteristics related to the international division of labor and the increase in input transport flows, exert significant environmental effects. Furthermore, depending on the nature of external integration and the role played by each country in GVCs, their impacts on emissions may diverge based on the calculation method employed (Liddle, 2018). In this sense, this research contributes novelty to the study of the EKC among Southeast Asian countries by addressing this gap in the existing literature. Table 1 summarizes the main contributions of the literature analyzed.

Based on the literature and the gaps exposed throughout this review, the following hypotheses for analysis can be established.

- H1.** There exists a nonlinear relationship between economic growth and environmental emissions.
- H2.** Demand-based and production-based emissions have different effects on the Environmental Kuznets Curve.
- H3.** A greater participation in global value chains leads to a rise in emissions.
- H4.** A greater manufacturing versus extractive insertion in global value chains leads to higher emissions exported.

3 | DATA AND METHODOLOGY

This paper aims to analyze the presence of the EKC in a sample of 12 East and Southeast Asian countries for the period 1995–2018, employing carbon dioxide emissions per capita as the dependent variable. Emissions are examined from both the producer's perspective and the consumer's perspective, utilizing data from the *Carbon dioxide emissions embodied in international trade* (TECO2) provided in the OECD's 2021 edition. The explanatory variables include GDP per capita data from the World Bank, as well as variables related to renewable and non-renewable energy consumption from The Shift Portal. Additionally, the analysis incorporates the participation of these countries in GVCs, drawing on Trade in Value Added (TiVA) data from the OECD's 2021 edition. The selected countries for this study, Brunei Darussalam, Cambodia, China, Hong Kong, Indonesia, South Korea, Laos, Malaysia, the Philippines, Singapore, Thailand, and Vietnam, were selected based on the cross-availability of data from different sources.

Trade in value added analysis serves as the primary methodology for examining international trade flows within the GVC framework. Conceptually, participation in these chains is defined as the

combination of domestic value-added exports (VAD) exported by third countries and foreign value-added exports (FVA) exported by the economy under consideration. Traditionally, this index accounted for the complex relationships within GVCs, which involve the participation of more than two countries before reaching final consumption. However, recent developments consider any export of intermediate goods as a flow to be included in the GVC approach (Wang et al., 2017; Wang, Wei, et al., 2022). Consequently, this paper considers the following GVC participation and position indexes:

$$GVCpa = \frac{\text{Intermediate DVA exported} + \text{FVA exported}}{\text{Gross exports}}$$

$$GVCpo = \frac{\text{Intermediate DVA exported}}{\text{FVA exported}}. \quad (1)$$

While the participation index ($GVCpa$) represents the degree of integration into GVCs, the position index ($GVCpo$) indicates whether participation in these chains tends to occur more through value-added exports (forward participation), through imports (backward participation), or in a balanced manner if the index tends toward one. In general terms, and in particular in the context of the selected countries, a high forward participation accompanied by low backward participation tends to be associated with a more extractive integration (agriculture, fishing, forestry, and mining exports), while the opposite case tends to denote a strong external dependence. Industrialized countries typically maintain a certain balance between both types of participation.

Though the values needed to calculate the *participation and position indexes* have been directly sourced from the specified database, the process for obtaining the GVC-related variables and their transformation into emission flows will be outlined. To facilitate the explanation, we will consider a set of p countries and, for simplicity, a single sector. The following basic input–output entities are defined:

$$X = Tu + F,$$

$$A = \hat{X}^{-1}T,$$

$$L = (I - A)^{-1}, \quad (2)$$

where X is a column vector that encompasses the total output of the p countries under consideration, derived as the summation of rows from the matrix of intermediate transactions, T , and final demand, F . The element u is a vector composed of “ones” with the appropriate dimension, specifically a column vector of size $p \times 1$ in this instance, employed to manipulate the rank of the matrix T . $\hat{X}$ represents the diagonalized matrix derived from the vector X . Furthermore, A signifies the matrix of technical production coefficients, utilized to derive the inverted Leontief matrix, denoted as L . From the technical coefficients, it is feasible to compute the value-added coefficients for each country as follows:

TABLE 1 Literature review summary.

Authorship	Variables	Sample countries	Period	Method	Verify/ reject EKC ^a
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
Balsalobre-Lorente, dos Santos, et al. (2023)	CO ₂ , renewable energy, economic complexity, and foreign direct investment	BRICS	1995–2020	Panel data	Verify
Balsalobre-Lorente, Nur, et al. (2023)	Ecological footprint, economic complexity, human development index, high innovation processes, and renewable energy consumption	G7 countries	1991–2018	Cup-FMOLS, Konya panel bootstrap causality and panel VAR analyses	Verify (variation of original EKC)
Balsalobre-Lorente, Shahbaz, et al. (2023)	Economic complexity, globalization, and renewable energy consumption	Central and Eastern European countries	1993–2017	FMOLS, DMOLS	Verify
Doğan et al. (2022)	GDP, CO ₂ , energy consumption, natural resources rent, economic complexity, renewable energy consumption, and environmental tax	G7 countries	1994–2014	Panel data, FMOLS, and DOLS	Verify
Esmaeili et al. (2023)	CO ₂ , economic complexity index, foreign direct investment, and renewable energy consumption	N-11 countries	1995–2019	Panel quantile regression	Verify
Fakher et al. (2023)	GDP, renewable and non-renewable energy consumption, financial development, population density, composite trade share, ecological footprint, environmental performance, environmental sustainability, environmental vulnerability, adjusted net savings, and pressures on nature	OPEC ^b countries	1994–2019	Dynamic seemingly unrelated regression equations	Verify
Frodyma et al. (2022)	GDP, and CO ₂ (production and consumption based)	European Union	1970–2017	ARDL testing bound	Reject
Gyamfi et al. (2021)	GDP, CO ₂ , renewable, and non-renewable energy	Emerging 7	1995–2018	PMG-ARDL	Mixed results
Hussain et al. (2022)	Ecological footprint, GDP, energy consumption, and population density	Pakistan	1981–2016	Autoregressive distributive lag model	Reject
Jaunky (2011)	GDP, and CO ₂	36 high-income countries	1980–2005	Panel data, and generalized method of moments	Mixed results
Jiang et al. (2019)	GDP, and CO ₂ (production and consumption based)	39 countries	1995–2011	Panel data	Verify
Li et al. (2020)	GDP, CO ₂ , population density, industrialization level, and urbanization rate	China	2000–2017	Spatial models	Verify
Luo et al. (2017)	GDP, CO ₂ , trade openness, ratio of secondary industry value added to GDP, and population density	G20 countries	1960–2010	Panel data, and generalized method of moments	Verify

TABLE 1 (Continued)

Authorship	Variables	Sample countries	Period	Method	Verify/ reject EKC ^a
Majeed (2020)	Environmental footprint, GDP, human capital index, biocapacity, and trade openness	76 countries	1961–2018	Quantile fixed effects panel data	Mixed results
Nepal et al. (2019)	GDP, total forest area, rural population density, and size of labor force	116 countries	1990–2015	Ordinary least squares, fixed, and random panel data	Verify
Numan et al. (2022)	Ecological footprint, economic complexity index, renewable and non-renewable energy consumption, urban population, and trade openness	85 countries	2001–2021	Two-step generalized method of moments	Mixed results
Polloni-Silva et al. (2021)	GDP, CO ₂ , foreign direct investment, industrial sector, service sector, residential electricity, and population density	São Paulo (Brazil)	2010–2016	Fixed effect panel data	Mixed results
Wang, Wang, and Li (2022)	GDP, ecological footprint, CO ₂ , trade openness, population aging, renewable energy, and natural resource rent	134 countries	1996–2015	Panel data	Mixed results
Wang et al. (2023)	GDP, CO ₂ , 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
Shahbaz et al. (2020)	GDP, and energy consumption	China	1980–2018	Nonparametric panel test	Verify
Shehzad et al. (2022)	GDP, ecological footprint, economic globalization, and natural resource rent	Algeria	1970–2017	ARDL model	Verify
Suki et al. (2020)	GDP, ecological footprint, and economic, social, political and overall globalization	Malaysia	1970–2018	Quantiles autoregressive distributed lag	Verify

Source: Authors.

^a“Mixed results” denotes those cases in which different results are found depending on the models or variables used to estimate the EKC hypothesis.^bOrganization of the Petroleum Exporting Countries.

$$v = lu - Au. \quad (3)$$

Once these coefficients are obtained, it becomes possible to decompose a country's gross exports, denoted a *GEX*, into as many as nine value-added components, as per the methodology proposed by Koopman et al. (2014). To derive the indicator defined in Expression 1, it is needed to calculate the following three foreign trade flows:

$$DVA^{ef} = v^j \sum_{j \neq k}^P L^{jk} F^{kk},$$

$$DVA^{ei} = v^j \sum_{j \neq k}^P \sum_{t \neq j,k}^P L^{jk} F^{kt},$$

$$FVA^e = \sum_{t \neq j,k}^P \sum_{j \neq k}^P v^t L^{tj} F^{jk} + \sum_{t \neq j,k}^P \sum_{j \neq k}^P v^t L^{tj} A^{jk} L^{kk} F^{kk}, \quad (4)$$

where *j*, *k*, and *t* represent three distinct countries within the set *P*. The first element, DVA^{ef} encompasses the exports of intermediate goods consumed as final goods by the importing country (representing a simple GVC export flow). The second element, DVA^{ei} comprises exports of intermediate goods re-exported by the importing country (indicating a complex GVC export flow). The third element aggregates the exports of foreign value added by the reference economy, with the first sum considering them as final goods and the second as intermediate goods. Consequently, Expression 1 can be reformulated as follows:

$$GVCpa = \frac{DVA^{ef} + DVA^{ei} + FVA^e}{GEX}. \quad (5)$$

The variables available in the OECD's *TECO2* database essentially mirror the various trade flows found in *TiVA*, converted into flows of carbon dioxide emissions. This conversion involves the calculation of emissions intensity, which represents the ratio of total carbon emissions produced within an economy to its total output. Applying this intensity to the ratios specified in Expression 4 results in the corresponding carbon exports.

As mentioned earlier, this paper aims to analyze the EKC by considering emissions from both the producer and consumer perspectives. In the first scenario, emissions stemming from domestic industry are collected, irrespective of the location of final consumption. In the second scenario, these emissions undergo a recalculation process, reducing them by the amount of exported emissions and incorporating the imported emissions that are eventually consumed within the reference economy.

When it comes to studying the EKC, its analysis typically involves econometric modeling. To confirm this hypothesis, it is essential that both the signs of the coefficients of the GDP per capita variables are appropriate and that inflection points exist. Relying on the verification of the hypothesis based on just one of these two conditions would result in a false or incorrect statement of the hypothesis. For a standard specification, as demonstrated in Expression 6, and considering the possibility of a waveform curve, several situations can arise regarding the relationship between emissions levels and income. These possibilities are contingent on the combination of signs associated with the income variables and are detailed in Table 2.

$$CO_2 = \alpha_0 + \alpha_1 Y + \alpha_2 Y^2 + \alpha_3 Y^3. \quad (6)$$

The specifications of the three econometric models, the results of which are presented in the following section, are elaborated upon below. Model I employs per capita carbon emissions from the consumer approach as the dependent variable, Model II employs emissions from the producer approach, and Model III employs emissions from exports under the GVC approach as the dependent variable (sum of simple and complex GVC emissions).

$$\begin{aligned} \text{Model I: } CO_{2,it}^c &= 0 + 1GDP_{it} + 2GDP_{it}^2 + 3GDP_{it}^3 + 4GVC_{it} \\ &\quad + 5REC_{it} + it, \\ \text{Model II: } CO_{2,it}^p &= 0 + 1GDP_{it} + 2GDP_{it}^2 + 3GDP_{it}^3 + 4GVC_{it} \\ &\quad + 5REC_{it} + it, \\ \text{Model III: } CO_{2,it}^t &= 0 + 1GDP_{it} + 2GDP_{it}^2 + 3GDP_{it}^3 + 4GVC_{it} \\ &\quad + 5REC_{it} + it, \end{aligned} \quad (7)$$

The independent variables remain consistent across both models, with *GDP* representing GDP per capita in constant 2015 dollars. Additionally, the model incorporates GDP^2 and GDP^3 , representing the square and cube of the GDP variable, respectively. The variable

TABLE 2 Possible outcomes in emissions relative to income.

α_1	α_2	α_3	Relation emissions-income
0	0	0	No relation
>0	0	0	Positive linear relation
<0	0	0	Negative linear relation
>0	<0	0	Inverted U-shape
<0	>0	0	U-shape
>0	<0	>0	N-shape
<0	>0	<0	Inverted N-shape

Source: Adapted from Sinha et al., (2019, pp. 68–69).

denoted as *GVC* denotes the participation or the position index in GVCs, calculated by considering both simple and complex trade flows as a percentage of gross exports. On this point, it should be clarified that the models are calculated twice to incorporate, on the one hand, the effects of participation in GVCs, and on the other hand, the effects that may derive from the type of integration (forward or backward) of the countries under study. Both variables are considered separately in the empirical estimation of the model to avoid possible multicollinearity problems. Lastly, the variable *REC* represents per capita renewable energy consumption within each of the selected countries. Table 3 provides an overview of the descriptive statistics pertaining to the variables included in the models.

4 | RESULTS AND DISCUSSION

This section presents the primary findings of the research. Initially, a series of descriptive statistics for the key analysis variables is presented to provide a characterization of the countries in the sample. Given the substantial influence of the Chinese economy within the selected set, certain tools are employed to isolate the data specific to this country. This setting aids in facilitating a clear visualization of the other economies in the sample.

To begin with, the profile of the East and Southeast Asian economies, including China, Hong Kong, Kazakhstan, and South Korea, exhibits diversity concerning GDP per capita (see Table 4). In general, the selection comprises upper-middle and lower-middle-income economies, with Singapore, Hong Kong, South Korea, and Brunei Darussalam being notable exceptions, as per the World Bank's classification for the year 2022. China, in particular, stands out as the economy with the highest average growth rates, reaching nearly 8% on average.

These disparities in per capita income are not necessarily reflected in their export performance. In general terms, these countries maintain a high share of exports. However, it is worth noting that this indicator can be calculated in two different ways. Firstly, by using the ratio of gross exports to GDP, and secondly, by employing exported domestic value added (DVAE) as the numerator. The second approach eliminates the value added generated in third countries but included in domestic gross exports, providing a

TABLE 3 Descriptive statistics. Number of observations: 288.

	Mean	Standard deviation	Min.	Max.	Units
CO ₂ ^c	6.461004	6.742722	0.18811	21.72629	Thousand kg per capita
CO ₂ ^p	6.834514	7.680585	0.043	30.961	Thousand kg per capita
CO ₂ ^t	2.242931	3.35803	0.005544	14.83475	Thousand kg per capita
GDP	11638.33	14758.61	244	66,859	2015 USD per capita
GDP ²	3.53E+08	7.07E+08	59,536	4.47E+09	Square of GDP per capita
GDP ³	1.39E+13	3.75E+13	1.45E+07	2.99E+14	Cube of GDP per capita
GVCpa	70.57788	9.857903	48.94	95.57	Percentage
GVCpo	2.51292	3.747375	0.4967045	26.28783	Dimensionless ratio
REC	2.76E−06	1.15E−05	0	8.91E−05	TWh per capita

Source: Authors.

TABLE 4 GDP per capita (2015 USD) and foreign trade indicators (year 2018 and cumulative variation since 1995).

	GDPpc	ΔGDPpc %	GEXP %	ΔGEXP %	DVAE %	ΔDVAE %	FVA %	ΔFVA %
Brunei Darussalam	29438.10	−0.78	50.00	4.26	45.09	4.03	4.91	7.20
Cambodia	1384.97	5.55	63.81	11.62	45.29	11.50	18.52	11.93
China	9619.19	7.99	18.01	13.09	14.91	13.01	3.10	13.50
Hong Kong	45280.21	2.40	49.60	4.51	36.72	4.77	12.88	3.87
Indonesia	3741.31	2.81	21.59	5.40	18.48	5.32	3.11	5.95
Korea	31053.64	3.56	43.18	6.96	29.37	6.59	13.81	7.89
Lao PDR	2467.96	5.09	34.31	11.07	27.85	11.24	6.46	10.40
Malaysia	10777.75	2.60	61.29	4.57	39.97	5.42	21.32	3.33
Philippines	3439.10	2.92	32.07	6.03	24.46	5.98	7.61	6.17
Singapore	61373.65	2.97	119.44	7.13	62.96	6.54	56.48	7.90
Thailand	6336.24	2.39	67.32	6.61	44.04	6.02	23.28	8.00
Vietnam	3090.77	5.25	104.44	16.17	51.08	13.99	53.36	20.11

Note: Symbol “Δ” indicates the cumulative rate for the period 1995–2018. GDP per capita has been obtained in constant 2015 dollars (World Bank). Trade indicators have been obtained as a ratio of real GDP, obtained in TiVA.

Abbreviations: DVAE, domestic value-added exported; FVA, foreign value-added; GEXP, gross exports.

Source: Authors from TiVA (OCDE, 2021) and World Bank.

measure of the value generated specifically by the economy under consideration. Table 4 also presents various indicators of trade performance as a percentage of GDP and their variations over the analyzed period.

As observed, all the economies under consideration have witnessed an increase in their exports, whether measured as gross exports or in terms of value added. Notably, Vietnam, China, Cambodia, and Laos have exhibited remarkable export growth rates, surpassing 10% per year. Six out of the thirteen economies maintained a share of gross exports exceeding 50% of their GDP in 2018. Singapore and Vietnam stood out with ratios exceeding 100%. These values stem from the significant inclusion of value added from third countries, subsequently incorporated into their gross exports. In fact, both countries accounted for more than 50% of FVA. Nonetheless, they also possess the highest proportions of exported DVA. China, on the other hand, distinguishes itself with a relatively low share of domestic value added, despite experiencing substantial growth in

DVAE. This reflects China's strategic shift aimed at fostering higher value-added activities and sectors (Liu & González García, 2021; Wen & Zhao, 2021).

Figure 3 illustrates the overall participation in GVCs as defined in Expressions 1 and 5. Notably, all the selected countries exhibit a significant level of participation, exceeding 50% of gross exports. Furthermore, it is worth highlighting that, with only four exceptions, exports of intermediate DVA surpass exports of FVA, placing these countries predominantly in the initial and intermediate stages of the production chain. In essence, they specialize in tasks related to extraction, transformation, and manufacturing, serving as suppliers of inputs for other countries, as well as finished products. However, they typically do not market these products as final consumer goods. In specific instances, such as Brunei, Indonesia, and Laos, their substantial forward participation corresponds to their well-known specialization in providing fuels and raw materials, resulting in a very high position index (ratio well above 1) compared to the rest.

Table 5 concludes the description of the 12 countries in the sample by incorporating descriptive statistics related to their carbon emissions under both the producer and consumer approaches. It also includes data on emissions generated per dollar of GDP and the cumulative rate of change, also under both approaches, during the period from 1995 to 2018. In terms of emissions volume, China emerges as the largest exporter of emissions among the selected economies, followed by South Korea and Indonesia. However, the distinction between the producer and consumer approaches yields differing results across these economies. In the case of Brunei, Cambodia, and Laos, both computations are relatively balanced. Conversely, Hong Kong, Indonesia, and the Philippines are notable for exhibiting a higher volume of emissions computed from the consumer perspective. In contrast, emissions

from the production side dominate in other cases, particularly in China.

Distinct income levels correspond to varying levels of emissions intensity. In general, higher-income countries tend to calculate lower emissions intensity, exemplified by Hong Kong, Singapore, and South Korea. Conversely, middle, and low-income economies tend to compute higher emissions per dollar of production. Regarding the evolution of emissions volume over the analyzed period, it is apparent that all the countries in the sample have increased their total emissions under both approaches, albeit at varying rates. Malaysia stands out for its substantial growth in emissions, particularly under the producer approach, with an average annual rate of nearly 20%. Following Malaysia, countries such as Cambodia, Singapore, and China also exhibit notable increases in emissions.

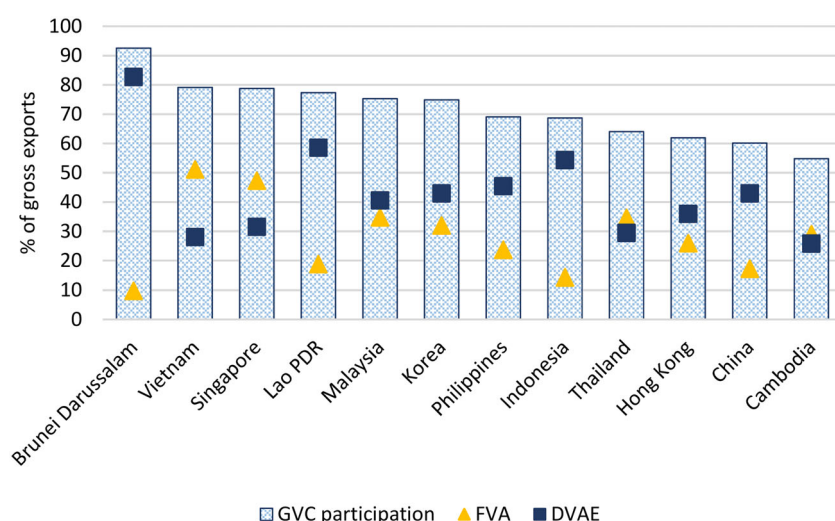


FIGURE 3 Total participation in GVCs and its components, 2018. Source: Authors from TiVA (OCDE, 2021 edition).

TABLE 5 Emission indicators under the producer and consumer approach.

	CO ₂ from production	CO ₂ from consumption	Difference production–consumption	CO ₂ produced/GDP	CO ₂ consumed/GDP	ΔCO ₂ production %	ΔCO ₂ consumption %
Brunei	8.15	8.57	−0.43	0.64	0.67	1.70	1.51
Cambodia	11.65	14.88	−3.23	0.52	0.67	8.95	7.36
China	9915.8	9020.35	895.45	0.73	0.67	5.20	5.30
Hong Kong	72.96	143.1	−70.14	0.22	0.42	2.32	1.03
Indonesia	560.78	584.37	−23.59	0.56	0.58	1.92	0.90
Korea	648.07	593.72	54.35	0.40	0.37	0.85	0.79
Lao PDR	18.51	11.89	6.62	1.06	0.68	1.69	1.63
Malaysia	236.93	190.41	46.52	0.68	0.55	19.43	9.24
Philippines	135.89	176.38	−40.49	0.36	0.47	4.32	4.38
Singapore	154.1	91.91	62.19	0.45	0.27	6.73	6.14
Thailand	265.46	223.67	41.79	0.59	0.50	3.41	3.49
Vietnam	246.55	194.24	52.31	0.84	0.66	3.12	1.90

Note: “Δ” indicates the cumulative rate for the period 1995–2018. Emissions under the producer and consumer approaches are in millions of tons of CO₂. Emission intensities are in thousands of tons of CO₂ per dollar of GDP (2015 USD, from the World Bank).

Source: Authors from TECO2 (OCDE, 2021 edition) and World Bank.

To complete this analysis, the results of Models I, II, and III, as presented in Expression 7, are shown below. In this regard, Tables 6 and 7 encompasses the cubic specifications of the models, while Tables 8 and 9 incorporates the quadratic specifications. Regarding the cubic models, they initially appear to suggest an N-shaped relationship in Models I and II, and an inverted N-shaped relationship in Model III when including GVC participation index (Table 6). However, it is worth noting that positive inflection points are only evident in the case of Model I with GVC participation. Nevertheless, these points are at exceedingly low levels of GDP per capita, placing any of the countries within the group on an upward emissions trajectory. When the position index is used (Table 7), the presence of an N-shaped or inverse N-shaped curve cannot be confirmed. The result derived from Model I regarding the EKC is consistent, as it focuses on per capita

carbon emissions calculated under the consumer approach. Given that most of the countries in the study are classified as middle- or low-income, an increase in income levels, and consequently consumption levels, is likely to lead to an associated rise in emissions.

In addition to the aforementioned findings, models presented in Tables 6 and 8 consistently reveal that participation in GVC produces significant results. In Model I, an increase in GVC participation leads to a reduction in emissions from consumption. A higher level of GVC involvement may promote emissions reduction through the importation of products that require less energy or materials in their production processes. However, it is important to emphasize that the ultimate impact of GVC participation on emissions is contingent upon the sectoral composition of trade flows, regardless of the approach taken to compute emissions (Wang et al., 2019; Zhang et al., 2021).

TABLE 6 Results of cubic estimates with GVC participation (GVCpa).

	Consumption based			Production based			GVC emissions exported		
	Model I: CO ₂ ^c			Model II: CO ₂ ^p			Model III: CO ₂ ^t		
	Coef.	SE	t	Coef.	SE	t	Coef.	SE	t
GDP	.0004702	5.37E-05	8.75***	.00035	5.41E-05	6.48***	−5.7E-05	0.00003	1.9*
GDP2	−1.15E-08	1.79E-09	−6.4***	−4.99E-09	1.80E-09	−2.8***	5.96E-09	9.97E-10	6***
GDP3	9.35E-14	1.87E-14	4.99***	3.95E-14	1.89E-14	2.09**	−5.85E-14	1.05E-14	5.6***
GVCpa	−0.03339	0.019279	−1.7*	.051143	0.019402	2.64***	.056674	0.010759	5.3***
RECpc	−2202.976	6296.852	−0.4	7530.001	6337.021	1.19	5740.667	3514.024	1.6
constant	6.099929	1.304063	4.68	.336359	1.312382	0.26	−2.39847	0.727746	3.3
R ² within	.30			.60			.70		
R ² between	.93			.86			.80		
R ² overall	.88			.82			.74		
rho	.96			.96			.94		

Note: Significance at 1%, 5%, and 10% are indicated by ***, **, and * respectively.

Source: Authors from TiVA, TECO2 (OCDE, 2021 edition), The Shift Data Portal, and World Bank.

TABLE 7 Results of cubic estimates with GVC position index (GVCpo).

	Consumption based			Production based			GVC emissions exported		
	Model I: CO ₂ ^c			Model II: CO ₂ ^p			Model III: CO ₂ ^t		
	Coef.	SE	t	Coef.	SE	t	Coef.	SE	t
GDP	.000435	0.0000516	8.44***	.000382	0.000053	7.26***	−7.97E-06	0.00003	−0.27
GDP2	−9.69E-09	1.80E-09	−5.38***	−5.13E-09	1.84E-09	−2.79***	4.15E-09	1.05E-09	3.96***
GDP3	7.33E-14	1.93E-14	3.79***	3.70E-14	1.97E-14	1.88*	−4.00E-14	1.12E-14	−3.56***
GVCpo	.111198	0.043975	2.53**	.076208	0.044857	1.7*	−.072467	0.025549	−2.84***
RECpc	−2172.437	6255.186	−0.35	6572.478	6380.761	1.03	5259.283	3634.21	1.45
Constant	3.520061	0.2978355	11.82	3.473639	0.303815	11.43	1.596391	0.17304	9.23
R ² within	.30			.60			.68		
R ² between	.98			.84			.72		
R ² overall	.94			.80			.65		
rho	.95			.96			.95		

Note: Significance at 1%, 5%, and 10% are indicated by ***, **, and * respectively.

Source: Authors from TiVA, TECO2 (OCDE, 2021 edition), The Shift Data Portal, and World Bank.

TABLE 8 Results of quadratic estimates with GVC participation (GVCpa).

	Consumption based			Production based			GVC emissions exported		
	Model I: CO ₂ ^c			Model II: CO ₂ ^p			Model III: CO ₂ ^t		
	Coef.	SE	t	Coef.	SE	t	Coef.	SE	t
GDP	.0002525	3.27E−05	7.73***	.000258	3.17E−05	8.14***	7.93E−05	1.84E−05	4.3***
GDP2	−2.83E−09	4.56E−10	−6.2***	−1.33E−09	4.43E−10	−3***	5.49E−10	2.57E−10	2.14**
GVCpa	−.018267	0.019857	−0.9	.057536	0.01928	2.98***	.04721	0.011201	4.21***
RECpc	3144.748	6471.362	0.49	9790.53	6283.202	1.56	2394.096	3650.278	0.66
Constant	5.801979	1.358645	4.27	.210413	1.319142	0.16	−2.212016	0.766366	−2.9
R within	.23			.59			.67		
R between	.95			.86			.81		
R overall	.89			.82			.77		
rho	.96			.96			.92		

Note: Significance at 1%, 5%, and 10% are indicated by ***, **, and * respectively.

Source: Authors from TiVA, TECO2 (OCDE, 2021 edition), The Shift Data Portal, and World Bank.

Taking a broader perspective, it is worth noting that the potential environmental benefits derived from imports may be counterbalanced by pollution generated in the logistics process, the effects of which are not accurately captured in the carbon calculations from the consumption side (Salman et al., 2019; Stojanović et al., 2021).

Similarly, the models presented in Tables 7 and 9 reveal significant results regarding the GVC position index. In Models I and II, the index tends to imply an increase in emissions, while in Model III, it implies a reduction in emissions. This result is logical, given the greater focus of the latter perspective (GVC emissions exported) on flows strictly linked to GVCs. In any case, the interpretation of the results derived from this variable is complex as its evolution depends on the simultaneous evolution of forward and backward participations. The evolution of these variables may imply changes in the productive structure of the countries. For example, as pointed out in Section 3, a high position index derived from high forward and low backward participation tends to imply a greater extractive integration, while the opposite cases are typical of a manufacturing insertion, with dependence on inputs of foreign origin and oriented toward final transformation and/or assembly tasks. In this sense, these results should be interpreted in conjunction with Figure 3. For example, due to the extractive nature of many of the countries in the sample, they need imports of capital goods and other inputs in order to develop their productive capacities, which in turn places them on a path of increasing emissions from both the consumer and producer perspective.

Although an increase in GVC participation may lead to reduced emissions from the consumer's perspective, the results obtained from Models II and III in Table 6 indicate that emissions would increase from the producer's standpoint. Moreover, exported emissions would also rise due to the heightened intensity and participation in these supply chains. In this sense, the results allow us to verify H3 from the perspective of the producer and DVA exports. Greater involvement in GVCs can manifest in an increased forward position (i.e., a higher volume of exports), a greater backward position (i.e., a higher volume of

imports), or both. A higher forward position in the GVCs implies a greater volume of exports and depending on the sectors affected (composition effect), this could result in a higher volume of emissions associated with domestic production due to the scale effect. It is important to note that a detailed analysis distinguishing the effects of each specific form of GVC insertion is beyond the scope of this research.

In addition to the cubic specification, the three models have been also estimated to explore a quadratic U-shaped or inverted U-shaped relationship (Table 8), which involves omitting the cubic element of GDP per capita (GDP3). The results unveil the presence of a nonlinear inverted U-shaped relationship in Models I and II, with inflection points at USD 44,611 and USD 97,105 per capita in the case of the Models I and II in Table 8 respectively, and at USD 45,833 and USD 85,365 per capita in the case of Models I and II in Table 9 respectively. Based on these findings, none of the countries in the sample would have achieved a declining emissions trajectory from the producer perspective, except for Singapore when considering the consumer perspective. These results align with the cubic estimation of Model I, which indicates that a higher level of GDP per capita would likely lead to increased emissions when computed from the consumption perspective. Regarding the variable of GVC participation (GVCpa), it is not significant in Model I, but the results are akin to the cubic specifications in Models II and III. These results imply that an increase in GVC participation would result in a higher volume of emissions from the producer perspective, as well as exported emissions. These outcomes are in line with those obtained by Fong et al. (2020) and Tan et al. (2022), among others.

In the quadratic models, it is worth noting the significant difference in the level of GDP per capita from which higher growth levels would lead to lower emissions per capita. As noted, from the producer's perspective, no country would have passed this turning point in the period under analysis, and most of the countries analyzed are

TABLE 9 Results of quadratic estimates with GVC position index (GVCpo).

	Consumption based				Production based				GVC emissions exported			
	Model I: CO ₂				Model II: CO ₂				Model III: CO ₂			
	Coef.	SE.	t		Coef.	SE.	t		Coef.	SE.	t	
GDP	.000281	0.0000323	8.69***		.000304	0.0000323	9.4***		.0000765	0.000019	4.09***	
GDP2	−3.06E−09	4.44E−10	−6.89***		−1.78E−09	4.44E−10	−4.01***		5.30E−10	2.57E−10	2.06**	
GVCpo	.162589	0.04285	3.79***		.102152	0.042868	2.38**		−.1005157	0.024819	−4.05***	
RECpc	1382.393	6334.465	0.22		8367.098	6337.703	1.32		3319.071	3669.377	0.9	
Constant	3.862541	0.290674	13.29		3.646537	0.290823	12.54		1.409466	0.168379	8.37	
R within	.27				.59				.66			
R between	.98				.84				.71			
R overall	.94				.80				.65			
rho	.95				.96				.95			

Note: Significance at 1%, 5%, and 10% are indicated by ***, **, and * respectively.

Source: Authors from TIVA, TECO2 (OCDE, 2021 edition), The Shift Data Portal, and World Bank.

far from it. Thus, it can be established that, indeed, the adoption of emissions under the consumer or producer perspective yields significantly different results in relation to the EKC, verifying H2. Furthermore, these results allow us to partially verify H1, insofar as the quadratic models show a nonlinear relationship between economic growth and emissions based on supply and demand, and in one of the cubic models taking emissions from demand as the dependent variable. Regarding, per capita consumption of renewable energy does not yield statistically significant results. This observation may be attributed to the fact that in most of the countries within the sample, the adoption of these technologies remains at a relatively low level, and their influence on carbon emissions, whether produced or consumed, has yet to reach a significant magnitude (Bakhtyar et al., 2013; Malahayati, 2020).

Finally, when considering the overall R^2 , it becomes evident that all three models account for a substantial portion of the variability in the respective dependent variables, signifying a robust goodness of fit. In the case of Model I, both in the cubic and quadratic specifications, a noteworthy distinction arises between the R^2 within and between values. Notably, the R^2 value between the models surpasses that within the models, suggesting the existence of significant differences in consumption patterns among East and Southeast Asian countries. These differences, however, may not be fully captured by the variables integrated into the model.

Indeed, the group of countries under investigation exhibits diverse development profiles, as evident from Tables 3 and 4. This diversity extends beyond disparities in GDP per capita and encompasses variations in consumption emissions intensity (emissions from the consumer perspective over GDP), among other factors. In Models II and III, distinctions in the R^2 values within and between the models persist, though to a lesser degree. Lastly, the notably high values of the rho coefficient (representing the fraction of variance attributed to the individual term) align with the earlier findings, underscoring the significance of individual differences, or differences among countries, in interpreting the results.

The current state of environmental policies in East and Southeast Asia reveals a significant gap in addressing the urgent challenges posed by the climate crisis. The findings suggest that the existing strategies are insufficient to achieve meaningful reductions in emissions within a reasonable timeframe. To comprehend this situation more thoroughly, it becomes crucial to examine the specific policies implemented and their alignment with the broader economic and environmental frameworks. Furthermore, the way in which these countries integrate into global markets appears to hinder the implementation of strategies aimed at mitigating the environmental impacts arising from their economic activities. While the adoption of strict environmental policies, in this context, could be perceived as a potential compromise for global competitiveness in the eyes of international investors, they can also be perceived as a new obstacle to the logic by which global production chains operate.

One key aspect is the apparent lag in transitioning toward renewable energy sources. The limited embrace of sustainable alternatives raises questions about the prioritization of economic development

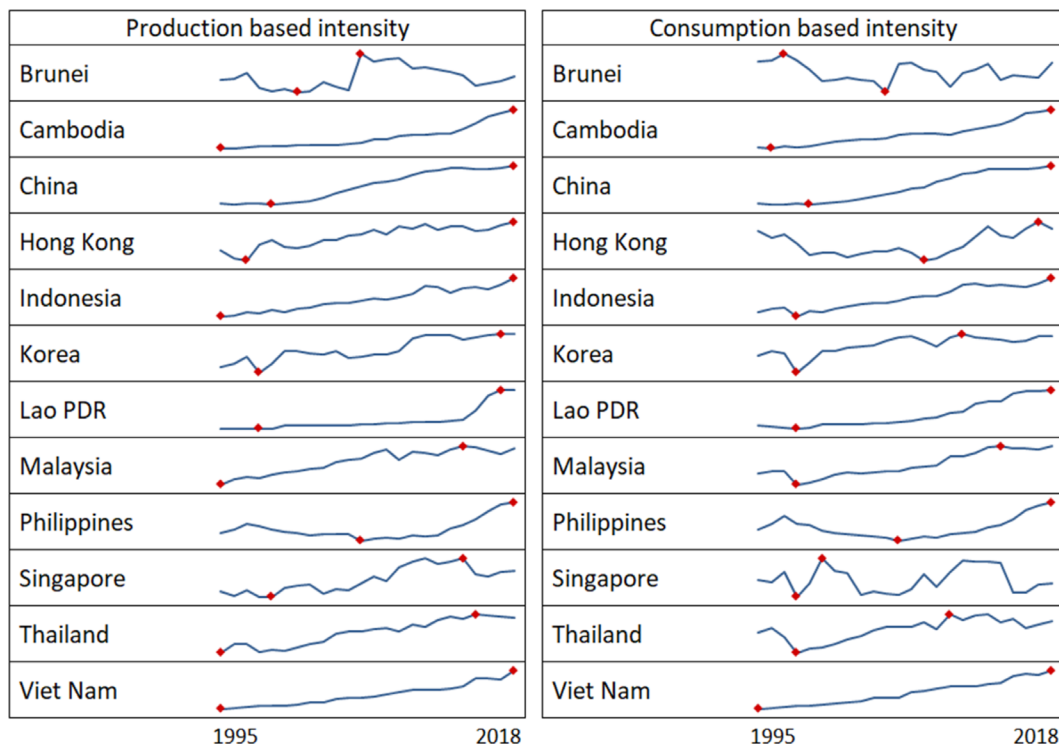


FIGURE 4 Emissions intensity. Thousands of tons of CO₂ per USD (constant 2015) (see Tables A1 and A2 in Appendix A for annual emission intensity value). Note: See Appendix A for annual emissions intensity value. Source: Authors based on TECO2 (OECD, 2021 edition) and World Bank

over ecological considerations. In this sense, a deeper exploration of the economic policies in place and their alignment with environmental objectives is essential. Furthermore, the results point out a development strategy that prioritizes growth at the expense of environmental considerations. Therefore, a reevaluation of the overarching economic strategy may be necessary. Assessing the balance between economic prosperity and ecological responsibility becomes imperative for crafting effective policies that reconcile both objectives. Another crucial aspect to consider is the potential margin available for implementing measures to mitigate environmental impacts without necessarily compromising the competitive position of East and Southeast Asian countries.

Lastly, while this work does not aim to provide an in-depth analysis of the effects of scale, technique, and composition, certain considerations can still be derived from an examination of the evolution of emission intensities (see Figure 4). On the one hand, it is crucial to highlight that most of the countries under consideration exhibit an upward trend in their emission intensities during the period spanning from 1995 to 2018. This contrasts with the trends observed in other countries. On the other hand, it is noteworthy that this upward trend is observable from both the producer's and the consumer's perspectives.

From a production standpoint, many of the selected nations have emerged as leading export-oriented producers. This, coupled with the growth of their domestic markets, exacerbates the scale effect in emissions generation. Similarly, the surge in domestic demand serves

as a catalyst for increased emissions from the consumer's viewpoint, whether for domestically produced or imported goods. While this research does not delve into a detailed analysis of the technological and compositional effects, it does present intriguing prospects for future investigations suggesting that the scale effect outweighs the emissions reduction that can be derived from the technical effect Ali et al. (2021).

5 | CONCLUSIONS

Climate change and the escalating scarcity of resources stand as prominent challenges confronting contemporary society. Economic globalization, in its pursuit of cost reduction, has often shifted production processes to developing regions. However, this phenomenon carries a range of adverse externalities, notably including environmental harm linked to economic activities. Theoretical frameworks and hypotheses posit that heightened economic growth could ultimately yield improved environmental conditions. Yet, two critical uncertainties persist: the likelihood of the occurrence of such tipping points and the sustainability of environmentally favorable trends over time. These uncertainties are further complicated by the variability in emissions allocation methodologies among different territories.

The primary aim of this study was to examine the environmental consequences of economic growth and GVC-linked foreign trade within a group of 12 East and Southeast Asian countries. A distinctive

feature of this research is the inclusion of the GVC perspective in the investigation of this nexus, extending the empirical analysis to encompass a substantial number of countries distinguished by their substantial participation and position (i.e., type of linkages) in GVCs. Another novelty lies in the consideration of emissions calculated from the producer, consumer, and exports standpoints.

The results of the present research reveal that the current path of growth and insertion in global markets is not yielding environmentally desirable outcomes. The industrial specialization of these countries through GVCs has resulted in a focus on cost reduction to increase export volume. This, coupled with the extractive profile of some countries, leads to environmentally damaging consequences. Even among countries with higher per capita income, as Singapore, the results suggest that emissions will continue to increase in the long term, at least from the producer's perspective.

As discussed in earlier sections, a primary challenge lies in the reluctance to implement more stringent environmental policies due to the perceived risk of losing competitiveness in the global markets. The uneven implementation of environmental policies might result in the relocation of certain activities, particularly the most polluting ones. Therefore, coordinated efforts among different countries become imperative to prevent the emergence of the so-called pollution havens.

Several measures can be proposed by Asian countries. Some of the classic proposals that have proven to be efficient in other countries include environmental taxes and emission quotas (Doğan et al., 2022), with a specific focus on the most environmentally damaging sectors. Beyond tax policies, East and Southeast Asian countries can implement various measures to propel sustainable development. Initiatives such as the development of green infrastructure, subsidies for acquiring green technologies, and the cultivation of new capabilities (both human capital and technologies) can play pivotal roles. By promoting or attracting green foreign investments related to activities with higher technological content and added value, these countries can foster an environment that is inherently more environmentally friendly. Such comprehensive strategies contribute not only to ecological sustainability but also to the advancement of technological prowess and economic growth. Additionally, considering the role and influence of developed countries as major importers of East and Southeast Asian countries, some measures could be implemented from their end, such as the uniform establishment of specific environmental requirements for imported products.

More recent approaches involve green public procurement and transitioning to a circular economy. Green public procurement can be particularly interesting for countries with public spending capacity. This approach enables authorities to tender for goods or services with a low environmental footprint or that contribute to technologies reducing energy and material consumption, ultimately decreasing pollution. Additionally, this mechanism incentivizes innovation by mitigating the business uncertainty associated with introducing a new and innovative product to the market.

The circular economy, as a comprehensive and innovative concept in industrial and environmental policy, is gaining prominence.

Some areas, the European Union, have taken significant steps in developing circular measures, with the overarching goal of maximizing resource utilization, decreasing the consumption of new raw materials, promoting renewable energies, and addressing critical environmental challenges. While the transition to a circular economy is a complex process requiring a medium- to long-term perspective, it offers various benefits, extending beyond environmental considerations. First, it helps reduce external dependence on key raw materials by enhancing the utilization of resources already circulating in the economic system. Additionally, circular activities, mostly labor-intensive, have the potential to create new, high-quality jobs. On this note, some authors suggest easing the tax burden on labor to foster the growth of circular sectors, replacing it with higher taxes on polluting activities (Vence & de López Pérez, 2021, 2022).

It is also important to promote measures that influence consumption patterns toward more environmentally friendly behavior. In particular, greater awareness of environmental issues should be promoted, as well as a culture of reuse. In order to effectively achieve these objectives, these countries can take advantage of the experiences carried out in other areas. In this regard, it is worth highlighting the efforts being made, for example, in the European Union, against planned obsolescence, the defense of the right to repair and the promotion of second-hand markets.

Furthermore, the results of this research give crucial importance to the degree of participation and the country's position in GVCs, which explains the international disparities in emissions and thus influences the environmental effects of economic growth. This must be considered when designing effective policies for further progress in reducing emissions, in line with the objective of environmental sustainability. Therefore, these policy measures, which may affect technologies, transportation modes, consumption, and production patterns, should take into account not only the level of participation of each economy in GVCs but also its insertion pattern (backward/forward linkages), specific activities and tasks.

This work paves the way for further research in several directions. First, it underscores the importance of distinguishing between scale, technical, and composition effects in developing countries. Second, it highlights the necessity of a more comprehensive examination of the various impacts that GVCs can exert on environmental consequences arising from international trade, contingent on each region's predominant mode of insertion. Third, it reveals the need for more specific studies focused on individual countries and sectors for two primary reasons. On the one hand, it allows for the identification of the most detrimental activities, providing a targeted approach to environmental policy. On the other hand, it enables the formulation of more pertinent, concrete, and effective policy proposals. Fourth, it is crucial to examine whether structural challenges within East and Southeast Asian countries impede the adoption of renewable energies. Such analyses can offer insights into overcoming obstacles and tailoring strategies for sustainable energy transitions.

ACKNOWLEDGMENTS

This research has been supported by the ICEDE research group, to which the authors belong, Galician Competitive Research Group

ED431C 2022/15 financed by Xunta de Galicia and project “REVAL-LEC” REFERENCE PID2022-141162NB-I00 financed by MCIN/AEI/10.13039/501100011033/EFRD, EU.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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How to cite this article: Campos-Romero, H., & Rodil-Marzábal, Ó. (2024). Environmental effects of growth and global value chains: The case of East and Southeast Asian economies. *Sustainable Development*, 32(4), 4114–4134. <https://doi.org/10.1002/sd.2877>

APPENDIX A

TABLE A1 Emissions intensity from producer side, thousand Kg of CO₂ by USD produced.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Brunei	18.18	18.32	19.47	16.37	15.79	16.28	15.64	15.72	17.65	16.63	16.08	23.33	21.82	22.28	22.43	20.40	20.60	20.03	19.65	18.93	16.92	17.39	17.91	18.76
Cambodia	0.14	0.14	0.15	0.16	0.16	0.16	0.18	0.18	0.19	0.19	0.20	0.22	0.27	0.27	0.32	0.34	0.34	0.36	0.35	0.43	0.51	0.63	0.67	0.73
China	2.44	2.39	2.41	2.48	2.38	2.49	2.59	2.78	3.20	3.71	4.20	4.59	4.96	5.08	5.41	5.91	6.43	6.57	6.82	6.78	6.70	6.68	6.81	7.07
Hong Kong	7.50	6.85	6.66	7.90	8.33	7.73	7.66	7.82	8.31	8.33	8.66	8.75	9.14	8.79	9.40	9.23	9.59	9.11	9.41	9.37	9.08	9.15	9.50	9.79
Indonesia	1.09	1.12	1.20	1.18	1.25	1.21	1.28	1.31	1.42	1.45	1.44	1.51	1.57	1.53	1.58	1.68	1.90	1.87	1.72	1.83	1.85	1.81	1.91	2.10
Korea	9.61	9.97	10.55	9.14	9.91	11.07	11.03	10.81	10.77	11.05	10.45	10.50	10.72	10.79	11.09	12.22	12.52	12.49	12.47	12.12	12.31	12.50	12.60	12.56
Lao PDR	0.05	0.05	0.04	0.04	0.04	0.21	0.23	0.24	0.24	0.25	0.25	0.30	0.32	0.37	0.42	0.45	0.45	0.47	0.56	0.59	1.24	2.21	2.61	2.60
Malaysia	4.27	4.72	4.91	4.83	5.09	5.29	5.43	5.57	5.68	6.12	6.34	6.44	6.91	7.19	6.37	6.97	6.88	6.78	7.22	7.50	7.38	7.12	6.87	7.31
Philippines	0.88	0.93	1.00	0.97	0.91	0.90	0.88	0.85	0.86	0.87	0.86	0.79	0.81	0.82	0.81	0.85	0.84	0.85	0.93	0.98	1.05	1.14	1.23	1.25
Singapore	20.94	19.78	21.57	19.48	19.45	22.14	22.93	23.06	20.42	21.95	21.41	23.64	25.52	24.09	28.41	30.36	31.21	29.59	30.12	31.28	26.43	25.79	27.00	27.33
Thailand	2.57	2.85	2.88	2.59	2.67	2.62	2.74	2.88	2.96	3.21	3.29	3.30	3.38	3.40	3.28	3.50	3.43	3.65	3.78	3.70	3.85	3.80	3.79	3.73
Viet Nam	0.39	0.44	0.50	0.55	0.54	0.58	0.65	0.75	0.78	0.94	1.00	1.03	1.12	1.24	1.36	1.51	1.49	1.46	1.52	1.67	2.11	2.12	2.10	2.60

Source: Authors from TECO2 (OECD, 2021 edition).

TABLE A2 Emissions intensity from consumption side, thousand Kg of CO₂ by USD consumed.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Brunei	20.01	20.25	21.73	20.34	18.32	16.02	16.36	16.63	16.23	15.99	13.71	19.49	19.83	18.29	17.92	14.83	17.66	18.34	19.51	16.20	17.26	17.08	16.66	19.74
Cambodia	0.25	0.23	0.26	0.23	0.26	0.31	0.34	0.37	0.39	0.39	0.42	0.48	0.49	0.49	0.50	0.47	0.53	0.59	0.61	0.66	0.73	0.86	0.89	0.93
China	2.17	2.12	2.12	2.16	2.11	2.17	2.30	2.45	2.70	2.99	3.25	3.51	3.84	4.02	4.60	4.96	5.52	5.67	5.98	6.00	6.03	6.06	6.13	6.43
Hong Kong	18.77	17.61	18.22	16.72	14.86	15.27	15.19	14.56	15.11	15.48	15.37	16.05	15.30	14.05	14.38	15.41	16.18	17.85	19.51	18.10	17.58	19.18	20.21	19.20
Indonesia	1.02	1.11	1.18	0.86	1.05	1.02	1.12	1.21	1.27	1.32	1.34	1.40	1.50	1.57	1.57	1.72	1.94	2.01	1.90	1.95	1.90	1.88	1.99	2.19
Korea	8.92	9.57	9.14	6.55	7.94	9.58	9.54	10.07	10.18	10.38	10.90	11.40	11.58	10.88	10.22	11.50	11.90	11.41	11.31	11.07	10.85	10.93	11.55	11.51
Lao PDR	0.29	0.27	0.23	0.19	0.21	0.36	0.35	0.36	0.34	0.37	0.40	0.42	0.49	0.56	0.64	0.79	0.85	1.14	1.22	1.25	1.54	1.63	1.64	1.67
Malaysia	3.38	3.59	3.62	2.41	2.55	2.88	3.29	3.55	3.40	3.55	3.64	3.58	3.97	4.08	4.10	5.03	4.94	5.32	5.82	5.91	5.69	5.66	5.60	5.88
Philippines	1.12	1.23	1.36	1.22	1.21	1.09	1.04	1.04	1.01	1.00	0.97	0.91	0.94	0.98	0.97	1.04	1.06	1.08	1.16	1.20	1.31	1.47	1.56	1.62
Singapore	16.61	16.40	17.46	14.99	16.27	18.85	17.62	17.41	15.12	15.52	15.29	15.21	15.70	17.23	16.01	17.52	18.61	18.48	18.51	18.38	15.41	15.39	16.25	16.30
Thailand	2.69	2.86	2.54	1.95	2.11	2.14	2.28	2.45	2.57	2.78	2.90	2.92	2.91	3.07	2.84	3.39	3.16	3.37	3.38	3.11	3.22	2.87	3.00	3.14
Viet Nam	0.41	0.44	0.51	0.53	0.53	0.57	0.62	0.70	0.74	0.87	0.88	0.90	1.13	1.15	1.27	1.37	1.35	1.35	1.45	1.53	1.83	1.88	1.85	2.05

Source: Authors from TECO2 (OECD, 2021 edition).