Asian Journal of Applied Economics Vol. 31 No. 2 (July-December 2024): 115-134

ISSN: 2985-1610 (Online)

Received: 8 May 2024
Received in revised form: 28 September 2024
Accepted: 3 October 2024

Trade Openness, Economic Growth, and Greenhouse Gas Emissions: An Empirical Examination of Carbon Dioxide and Methane Emissions

Rapeepat Manasoontorn
Rajamangala University of Technology Rattanakosin, Thailand
Aekkapat Laksanacom*
Faculty of Economics at Si Racha, Kasetsart University Si Racha Campus, Thailand

Abstract

This research investigates the complex relationships between economic factors and environmental outcomes, focusing on carbon dioxide (CO2) and methane (CH4) emissions across 24 countries from 1998 to 2019. Utilizing data from the World Development Indicators and the Penn World Table, the study employs a regression model incorporating scale, technique, and composition effects to analyze the determinants of emissions. The findings reveal nuanced dynamics: while income per capita positively correlates with emissions, an inverted U-shaped relationship between income and CO2 emissions supports the Environmental Kuznets Curve hypothesis. Furthermore, disparities in factor abundance and technological innovation demonstrate varying impacts on emissions. Importantly, the study highlights the need for policy interventions that foster economic development while promoting environmental sustainability, reducing emissions from international trade, and encouraging the widespread adoption of low-carbon technologies.

Keywords: economic growth; trade openness; environmental degradation; emissions analysis; sustainable development
JEL Classification: F18; O44; Q54; Q56

* **Corresponding Author,** Address: Department of Applied Economics, Faculty of Economics, Kasetsart University, Sri Racha Campus, 199 Moo 6, Sukhumvit Road, Tung Sukla, Sri Racha, Chon Buri, 20230, Thailand, Email: aekkapat.l@ku.th

1. Introduction

The debate surrounding the impact of trade openness on environmental degradation has been a significant topic of discussion among environmentalists and economists. This discourse originally emerged during negotiations concerning the North American Free Trade Agreement (NAFTA) and the Uruguay Round of the General Agreement on Tariffs and Trade (GATT) negotiations (Colyer, 2011; Krist, 2013). These negotiations occurred at a time when concerns about global warming, species extinction, and industrial pollution were on the rise. In response to these issues, the United Nations initiated efforts to achieve the Sustainable Development Agenda by 2030, with environmental quality being one of the 17 goals aimed at sustainable development (Independent Group of Scientists appointed by the Secretary-General, 2023).

Increased trade openness has the potential to boost economic development for both developing and developed countries. However, a critical issue in international climate negotiations revolves around establishing emissions reduction targets for all countries, guided by the principle of Common But Differentiated Responsibilities (CBDR) (Castro, 2016). This principle largely hinges on quantifying the historical contributions of developed and developing countries to climate change.

This study builds upon these considerations by analyzing both developing and developed countries. Several empirical studies have suggested a correlation between capital-abundant countries and pollution, particularly with respect to capital-intensive goods such as manufactured products (Antweiler et al., 2001; Bekoe & Jalloh, 2023; Korves et al., 2011). Consequently, countries with a relatively high capital-labor ratio are expected to excel in the production of capital-intensive goods, potentially leading to higher emissions. Trade openness plays a crucial role in enhancing their comparative advantage in this regard, especially within industrial economies. Conversely, in countries with stringent environmental regulations, typically higher-income countries, trade openness may diminish the comparative advantage of capital-intensive goods while strengthening this advantage in countries with more lenient environmental policies.

Furthermore, while the focus on industrial sectors is essential, it is equally important to consider other significant sectors impacted by trade and environmental policies. This study also addresses the agricultural sector, which presents distinct challenges for national inventory compilers, particularly in developing countries. Compiling and regularly updating national statistics for agriculture, forestry, and land use is a fundamental yet complex step in estimating national methane (CH4) emissions.

The primary aim of this paper is to explore the environmental implications of economic growth and trade openness. It critically evaluates both theoretical frameworks and empirical research to examine the interplay between trade and the environment, specifically in terms of carbon dioxide (CO2) and methane emissions in selected developing and developed countries.

The structure of this paper is as follows: Section 2 offers a brief review of the theoretical and empirical literature. Section 3 covers the data and econometric model. Section 4 presents the estimation results, and the final section provides the conclusion.

2. Literature Review

The examination of the factors influencing emissions involves both theoretical and empirical investigations. This section aims to present the theoretical framework and empirical research required to effectively analyze and break down these determinants.

2.1 Theoretical framework

In the theoretical realm of trade and environmental studies, numerous papers discuss how either income disparities or policy variations among countries lead pollution-intensive industries to relocate to nations with lenient regulations or lower incomes. Antweiler et al. (2001) initially establish the theoretical foundation for empirically dissecting emissions into scale, technique, and composition effects.

Effects of scale, technique, and composition

Due to the intricate connection between economic activity and environmental well-being, it is beneficial to start by breaking down the overall impact of a pollution change into scale, composition, and technique effects.

We can outline the equilibrium conditions for the production sector of the economy at this point. We presume that the government employs pollution emission taxes, which are determined within the system, to mitigate pollution. With the pollution tax (τ) established, the profits (π^x) for a company engaged in the production of (x) can be calculated as the revenue minus production costs, pollution taxes, and abatement costs:

$$\pi^x = px - c^x(w,r)x - \tau[1 - \lambda a(\theta)]x - p\theta x \qquad (1)$$

Companies will collectively decide on the gross output (x) and the proportion of abatement to maximize their profits.

Define

$$\tilde{p} = p(1-\theta) - \tau[1 - \lambda a(\theta)]$$

Then (1) becomes:

$$\pi^x = \tilde{p}x - c^x(w,r)x$$

Due to constant returns to scale, the individual firm's output is not fixed, but for any given output level, the first-order condition for the choice of (θ) implies

$$p = \lambda\tau a'(\theta) \qquad (2)$$

The optimal abatement (θ^*) is implicitly determined by (2) and is characterized as a rising function of $\frac{\tau}{p}$:

$$\theta^* = \theta(\lambda\frac{\tau}{p}) \qquad (3)$$

where $\theta' > 0$. As anticipated, the level of abatement activity rises with the increase in the pollution tax.

Under conditions of unrestricted entry, companies will participate in each industry until their profits reach zero. Utilizing equation (1), we obtain the following for the X industry:

$$c^x(w,r) = \tilde{p} \tag{4}$$

and for the Y industry, we obtain:

$$c^y(w,r) = 1 \tag{5}$$

It assumes both industries are active, so equations (4) and (5) establish factor prices w and r as functions of $\tilde{p}$. These factor prices subsequently determine the unit input coefficients for each sector. For instance, according to Shepherd's Lemma, the unit labor requirement in X is expressed as $c_w^x = \frac{\partial c^x}{\partial w}$, and so on. The conditions for full employment then dictate the outputs:

$$c_w^x x + c_w^y y = L \tag{6}$$

$$c_r^x x + c_r^y y = K \tag{7}$$

To investigate further, define the scale of economic activity (S) as the value of the economy's gross output at world prices

$$S = px + y \tag{8}$$

To define the composition effect it is convenient to work with $\frac{x}{y}$ ratios. Let $\mathcal{X} = \frac{x}{y}$ denote the relative supply of X. Solving (6) and (7) for (x) and (y) and subsequently dividing, we obtain:

$$\frac{x}{y} = \frac{c_w^y k - c_r^y}{c_r^x - c_w^x k} \equiv \mathcal{X}(k, \tilde{p}) \tag{9}$$

where $k = \frac{K}{L}$ is the capital-labor ratio of the economy. It is worth noting that (c) increases with both (k) and ($\tilde{p}$)and consequently, it increases with (p) and decreases with (τ). Any modification in the economy that affects $\mathcal{X}(k, \tilde{p})$ is referred to as generating a composition effect. Employing equations (8) and (9), we can now rewrite our expression for pollution (z) as:

$$z = \frac{[1 - \lambda a(\theta)]\mathcal{X}S}{1 + p\mathcal{X}} \tag{10}$$

To obtain our decomposition, totally differentiate (10) to yield:

$$\hat{z} = \hat{S} + \varphi_y \hat{X} - \zeta \varepsilon_{a,\theta} \hat{\theta} \tag{11}$$

where "^" denotes "percent change", $\varphi_y = \frac{y}{(px+y)}$ is the share of y in the value of gross output, $\varepsilon_{a,\theta}$ is the elasticity of (a) with respect to (θ), and $\zeta = \frac{\lambda a(\theta)x}{z}$ is the ratio of abated pollution to actual pollution. The initial term represents the scale effect. Assuming constant pollution abatement techniques and the mix of produced goods, an expansion in the scale of economic activity will result in increased pollution. Following is the composition effect. While keeping the scale and techniques constant, a shift in the production composition towards more pollution-intensive goods will elevate pollution levels. Lastly, the technique effect involves a decrease in pollution levels when the intensity of pollution abatement increases, with the scale and composition of economic activity held constant.

As per equation (11), the observed variations in our pollution data stem from fluctuations in the scale, composition, and techniques of economic activity across countries and over time. In our empirical work, we will use a quantity index of output, an economic density index, and a trade intensity index as a proxy for scale. To establish a connection between the composition and technique effects with observable variables, we differentiate (3) and (9) to derive expressions for $\widehat{X}$ and $\widehat{\theta}$, which are then substituted into (11). This yields:

$$\hat{z} = \hat{S} + \varphi_y \varepsilon_{\chi,k}\hat{k} - (\varphi_y a_\tau \varepsilon_{\chi,\tilde{p}} + \zeta \varepsilon_{a,\theta}\varepsilon_{\theta,\tau})\hat{\tau} \tag{12}$$

,where ε_{ij} denotes the elasticity of i with respect to j, and $a_\tau = \frac{\tau\lambda[1-a(\theta)]}{\tilde{p}}$. As policy is not directly observable in our dataset, we need to substitute $\hat{\tau}$ in equation (12) with its determinants and represent $\hat{\tau}$ as:

$$\hat{\tau} = \varepsilon_{T,\tau^*}[\widehat{N} + \varepsilon_{\phi,I}\hat{I} + \hat{\delta}] \tag{13}$$

The pollution tax is contingent on population size $\widehat{N}$, real per capita income $\hat{I}$, and consumer preferences $\hat{\delta}$. Now, substitute equation (13) into (12) to obtain:

$$\hat{z} = \gamma_1\hat{S} + \gamma_2\hat{k} - \gamma_3\hat{I} - \gamma_4\widehat{N} - \gamma_5\hat{\delta} \tag{14}$$

where $\gamma_1 = 1$, $\gamma_2 = \varphi_y\varepsilon_{\chi,k} > 0$, $\gamma_3 = \varepsilon_{\phi,I}\gamma_4 > 0$, $\gamma_4 = \varepsilon_{T,\tau^*}(\varphi_y\theta_\tau\varepsilon_{\chi,\tilde{p}} + \zeta\varepsilon_{a,\theta}\varepsilon_{\theta,\tau}) > 0$, and $\gamma_5 = \gamma 4 > 0$

The initial term in equation (14) is the scale effect, as previously discussed. The second term assesses the impact of an augmented capital/labor ratio on pollution, representing a composition effect. Given that the carbon-polluting industry is capital-intensive, a country with a greater abundance of capital generates more carbon-pollution, all else being equal. The remaining terms all delineate the consequences of alterations in pollution policy, denoted as technique effects. A rise in per capita income augments the demand for environmental quality, prompting more stringent pollution policies ($\varepsilon_{\phi,I} > 0$). Similarly, an increase in the population exposed to pollution ($\widehat{N}$>0) intensifies pollution policy through the Samuelson rule[1] (Samuelson, 1954). Moreover, a heightened marginal disutility of pollution ($\hat{\delta} > 0$), potentially stemming from increased awareness about pollution, elevates the demand for environmental quality and amplifies the pollution tax. It is noteworthy that the efficacy of these last three technique effects is contingent on ε_{T,τ^*}, which denotes the government's responsiveness to the representative agent's preferences.

Equation (14) succinctly outlines our predictions regarding how pollution varies across countries and over time in response to observable variables with fixed prices and abatement technology. Pollution escalates with the economic scale and capital abundance. Conversely, increases in income, the marginal disutility of pollution, and the population exposed to pollution induce a tightening of policy, leading to a reduction in pollution.

2.2 Empirical literature

Numerous studies have investigated the relationship between trade and environmental quality. These studies focus primarily on two main areas. The first area is the association between CO2 emissions and economic growth, often explored through the Environmental Kuznets Curve (EKC) hypothesis. The second area examines the interplay between emissions, trade openness, capital-labor ratio, and environmental policy.

Adding to this body of research, Shahbaz et al. (2017) investigate the relationship between trade openness, economic growth, and CO2 emissions in 105 countries across different income groups, finding that trade openness generally worsens environmental quality with varying impacts. Similarly, Wang and Zhang (2021) examine the impact of protectionism on decoupling carbon emissions from economic growth, revealing that trade openness reduces carbon emissions in wealthier countries while increasing emissions in poorer countries. These findings highlight the heterogeneity in the impact of trade openness on environmental quality across different economic contexts.

The EKC hypothesis suggests that pollution emissions initially increase during economic growth but eventually decrease beyond a certain income threshold (Kuznets, 1955). Research by Lean and Smyth (2010) and studies in ASEAN countries by Heidari et al. (2015) support the EKC hypothesis. Conversely, studies by Narayan and Narayan (2010) and Chandran and Tang (2013) challenge the validity of the EKC hypothesis. While studies have produced mixed findings regarding the hypothesis, these examples highlight the ongoing debate in the literature.

Regarding emissions, trade openness, and comparative advantage, research reveals that major developed countries tend to be net CO2 importers; while developing and resource-rich developed countries are net exporters (Chen et al., 2023). Studies show varied impacts of trade on carbon emissions across

[1] According to this rule, a public good should be provided up to the point where the sum of the marginal rates of substitution (MRS) between the public good and a private good, across all individuals, equals the marginal cost (MC) of providing the public good. Thus, the Samuelson Rule can be expressed as: $\sum_{i=1}^{n} MRS_i = MC$

countries. For instance, Atici (2012) finds that foreign direct investment affects CO2 emissions differently across ASEAN countries, while Managi et al. (2009) find that the impact of trade openness on environmental quality varies by pollutant and country.

In addition to trade, environmental policy's impact on CO2 emissions has been explored using the Environmental Policy Stringency index[2]. Despite significant findings, research gaps persist, particularly in assessing the combined effectiveness of policies, especially in emerging economies. Studies by Ahmed and Ahmed (2018) and Ahmed (2020) suggest that stringent environmental policies can contribute to emissions reduction and foster green innovations. However, research by Wang et al. (2020) highlights limitations in policy effectiveness, particularly regarding certain pollutants.

Various studies emphasize the influence of environmental and energy policies on economic outcomes such as innovation, productivity, and energy efficiency. While stringent environmental policies may not significantly impact aggregate productivity, they can stimulate innovation, particularly in technologically advanced industries and firms, as observed by Albrizio et al. (2014, 2017). Kara et al. (2008) find that stringent environmental regulations may enhance conservation practices in agriculture.

The association between economic development, trade openness, environmental policy stringency, capital-labor intensity, and CO2 emissions has been studied within the EKC framework, yielding diverse outcomes. However, existing research often focuses on singular emission effects and uses real GDP per capita as the metric for economic development. To address this gap, our research aims to provide a more comprehensive analysis of emissions, considering scale, technique, and composition effects. This study moves beyond a singular focus on CO2 emissions by incorporating multiple pollutants, including methane emissions, to provide a more detailed environmental impact assessment. Moreover, it comprehensively examines how different economic factors influence emissions by including Gross Domestic Product per unit Area (GDPA) and Trade Intensity to GDP (TI) as indicators of the scale effect.

3. Methodology

3.1 Data

The dataset utilized in this research is sourced from the World Development Index and the Penn World Table, encompassing data from 24 countries spanning the years 1998 to 2019. These countries are deliberately selected to comprise a balanced representation, including 12 developed nations such as the United States of America, Canada, Italy, France, Germany, the United Kingdom, Finland, Australia, Japan, South Korea, Malaysia, and Singapore, alongside 12 developing nations including China, India, Thailand, Vietnam, Indonesia, the Philippines, Brazil, Argentina, Chile, South Africa, Turkey, and Egypt. The selection of 24

[2] This index measures the stringency of environmental policies across OECD countries, focusing on policies related to air and water pollution, waste management, and biodiversity conservation.

countries for the dataset aims to ensure a balanced and comprehensive analysis by representing both developed and developing economies, capturing a wide range of economic conditions and stages of development. The chosen countries provide global coverage, including major economies like the United States and China, as well as emerging markets like India and Brazil. This selection allows for an examination of regional differences in environmental policies, economic structures, and emissions patterns. Additionally, the countries vary in policy stringency, emission profiles, trade intensities, and technological advancement levels, ensuring a thorough exploration of the relationships between economic growth, trade openness, environmental policies, and emissions. Data reliability and quality from sources like the World Development Index and the Penn World Table were also crucial criteria for selection.

The principal variables of interest in this study are the Real GDP per capita at constant dollar values for the year 2015, derived from the World Development Indicators data, denoted as S and its quadratic equivalent S^2, which serve as proxies for income and production effects on emissions. These variables are pivotal in estimating the scale effect, as they capture the potential non-linear relationship between carbon emissions and income per capita. Furthermore, Gross Domestic Product per unit Area at constant dollar values for the year 2015 (GDPA) and Trade Intensity to GDP (TI) are also considered as indicators of scale effect.

The Country's Capital-Labor Ratio (KL) serves to represent the composition effect within each country's economy. A higher capital-labor ratio suggests a propensity towards capital-intensive production processes, which typically entail higher CO2 emissions, while a lower ratio indicates a predisposition towards labor-intensive goods, associated with higher methane emissions.

Moreover, countries exhibiting a comparative advantage in low carbon technology products (LC1) and demonstrating a relatively higher total trade volume in low carbon technology products as a percentage of GDP (LC2) are expected to benefit from a favorable technique effect. This effect implies a reduction in pollution levels when there is an intensification in pollution abatement efforts.

The aforementioned variables constitute the core components of the regression model employed in this study, aiming to elucidate the intricate relationships between economic factors and environmental outcomes. The variables being analyzed in this model are detailed in the Table 1.

Table 1: List of dependent variable and explanatory variables

Variable	Definition	Unit	Source
CO2	Carbon dioxide emissions (CO2)	(Kilotons)	World Development Indicators
ME	Methane emissions (CH4)	(Kilotons of CO2 equivalent)	World Development Indicators
GDPA	Gross Domestic Product per Area constant dollar at 2015	(Millions of US Dollar)	World Development Indicators
S, S^2	Real GDP per capita constant dollar at 2015 and its quadratic	(Thousands of US Dollar)	World Development Indicators
TI	Trade intensity to GDP	(Percentage of GDP)	World Development Indicators
KL	Country's capital-labor ratio	(Thousands of US Dollar /worker)	Penn World table
LC1	Comparative advantage in low-carbon technology products	(Index)	World Development Indicators
LC2	Total trade in low-carbon technology products as percent of GDP	(Percentage of GDP)	World Development Indicators

3.2 The determinants of CH_4 and CO_2 emissions

This investigation adopts a framework wherein the factors influencing emissions are disaggregated into three distinct components: scale, technique, and composition effects. Within this framework, denoted as CO2 and ME representing carbon dioxide and methane emissions per country per annum, the variables S, S2, GDPA, and TI represent scale effects, while KL signifies the composition effect. Additionally, LC1 and LC2 are indicative of technique effects. A detailed elucidation of each model is presented in equation 15 and 16 respectively.

$$\mathrm{CO2} = C_1 + \beta_1\mathrm{GDPA} + \beta_2\mathrm{S} + \beta_3\mathrm{S2} + \beta_4\mathrm{TI} + \beta_5\mathrm{KL} + \beta_6\mathrm{LC1} + \beta_7\mathrm{LC2} \quad (15)$$

$$\mathrm{ME} = C_2 + b_1\mathrm{GDPA} + b_2\mathrm{S} + b_3\mathrm{S2} + b_4\mathrm{TI} + b_5\mathrm{KL} + b_6\mathrm{LC1} + b_7\mathrm{LC2} \quad (16)$$

4. Empirical Results

Table 2 presents summary statistics encompassing data from 24 selected developed and developing countries spanning the period 1998-2019. The analysis primarily focuses on the dependent variables pertaining to carbon dioxide and methane gas emissions. Carbon dioxide emissions exhibit a considerable range, from approximately 37 to 10,800 kilotons, with an average emission of around 900 kilotons. Similarly, methane gas emissions range from 1.2 to 1,200 kilotons, with an average emission of approximately 160 kilotons when measured in carbon dioxide equivalent units. However, when considering the country groups separately, it was found that the average carbon dioxide emissions of developing countries were approximately 930 kilotons, while those of developed countries averaged about 860 kilotons. For developing countries, average methane emissions were approximately 220 kilotons, compared to about 100 kilotons in developed countries. Both methane and carbon dioxide emissions are highest in developing countries and lowest in developed countries.

Regarding explanatory variables, they are categorized into three groups. Firstly, the average GDP per area for the sample of developing countries was found to be $0.45 million, compared to $3.16 million for developed countries. Interestingly, both the highest and lowest GDP per area values were recorded in developed countries. On an overall average, GDP per area is around $1.6 million. All observations showed that GDP per capita stands at approximately $21,510. Developed countries have significantly higher average GDP per capita than developing countries, with figures of $37,410 and $5,600, respectively. Additionally, the study on trade intensity, which investigates the influence of openness to international markets on pollution levels, indicates an average figure of 76.39 percent of GDP. Developed countries exhibit a higher concentration of international trade compared to developing countries, with trade averaging 91.04 percent of GDP and reaching a peak of 437.33 percent of GDP. All variables in this scale-effect group are analyzed in real value terms to eliminate the effects of prices, aligning with the study's aim to analyze the impacts of the real economy.

Secondly, the measure of KL, derived from the ratio of physical capital stock per labor sourced from the Penn World Table, represents the composition effect, the overall country's capital-labor ratio, ranges from $8,400 to $693,180 per worker. Developed countries have accumulated significantly higher capital stock compared to developing countries. The average capital per worker in developed countries is a substantial $403,010, compared to just $99,250 in developing countries.

Lastly, comparative advantage in low carbon technology product, LC1, and total trade in low carbon technology products, LC2, are indicative of cleaner production methods, representing the technique effect. The LC1 ranges from 0.01 to 3.20, while the LC2 ranges from 0.3 to 13.97 percent of GDP for each country. Comparative advantage and total trade of low-carbon technology products as a percentage of GDP are both higher in developed countries than in developing countries. This suggests that developed countries are generally more advanced in environmentally friendly technology and production processes.

Table 2: Descriptive statistics

All Observations						
Variable	Observations	Mean	Median	Maximum	Minimum	Std. Dev.
CO2	528	891.73	353.18	10,762.82	36.90	1,782.53
ME	528	157.64	65.74	1,163.22	1.20	242.30
GDPA	528	1.60	0.64	4.82	0.10	67.31
S	528	21.51	12.14	61.39	0.69	18.55
KL	528	251.12	202.87	693.19	8.40	178.69
TI	528	76.39	56.76	437.33	16.44	70.26
LC1	528	0.84	0.78	3.16	0.01	0.59
LC2	528	2.38	1.49	13.79	0.30	2.41
Selected Developing Countries						
Variable	Observations	Mean	Median	Maximum	Minimum	Std. Dev.
CO2	264	927.68	261.230	10,762.82	45.47	2,101.56
ME	264	218.42	77.73	1,163.22	5.020	282.14
GDPA	264	0.45	0.33	1.49	0.12	29.71
S	264	5.60	4.72	14.20	0.69	37.81
KL	264	99.25	92.74	344.24	8.40	65.96
TI	264	61.76	53.06	164.70	16.44	33.83
LC1	264	0.50	0.33	3.16	0.01	0.45
LC2	264	1.65	1.19	8.54	0.30	1.34
Selected Developed Countries						
Variable	Observations	Mean	Median	Maximum	Minimum	Std. Dev.
CO2	264	855.77	436.434	5,775.81	36.90	1,395.62
ME	264	96.85	49.940	784.50	1.20	174.97
GDPA	264	3.16	0.53	4.82	0.10	926.07
S	264	37.41	37.86	61.39	5.88	12.65
KL	264	403.01	404.28	693.19	137.46	115.43
TI	264	91.04	61.70	437.33	18.13	90.82
LC1	264	1.17	1.15	2.58	0.16	0.52
LC2	264	3.11	1.88	13.79	0.66	2.94

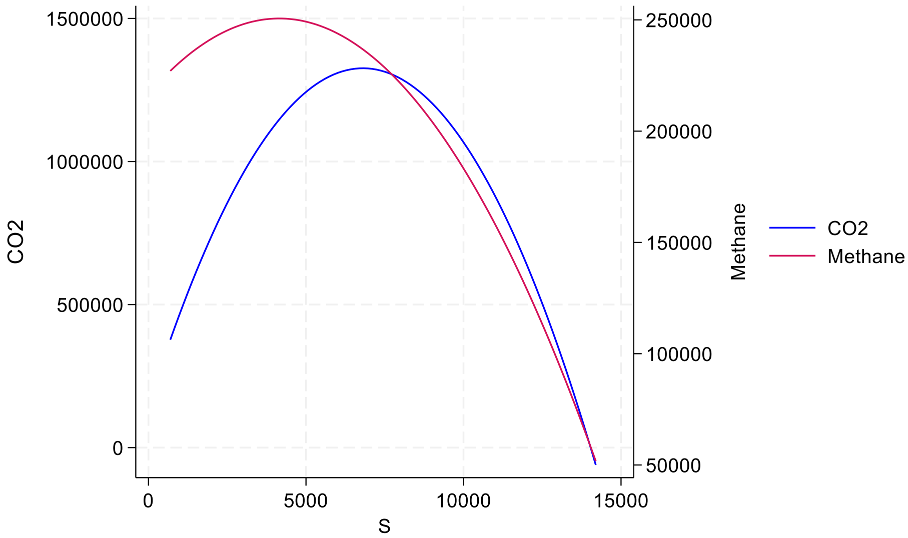

Figure 1: The predicted relationship plot of CO2 and Methane with GDP per capita in developing countries

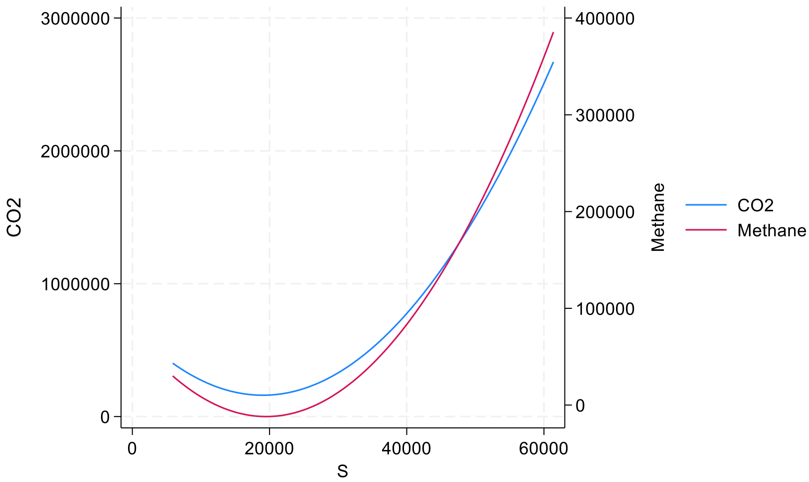

Figure 2: The predicted relationship plot of CO2 and Methane with GDP per capita in developed countries

From the estimation of the econometric model using the balanced panel method, the results are shown in Table 3. The Haussman test determined that the appropriate model was a fixed effects model for both greenhouse gases. Multicollinearity was detected among the independent variables, particularly between the quadratic terms S and S^2, as well as between S and KL, and TI and LC2. This high correlation increases the likelihood of biased model estimates. Additionally, a serial correlation problem was identified. The Wooldridge test rejected the null hypothesis of no serial correlation, indicating that the main model suffers from this issue, leading to an inflated R-squared value (see Appendix). Consequently, the model was modified to a fixed effects linear model with an AR(1) disturbance, as shown in Table 3. The individual influence of the dependent variables carbon dioxide and methane can be elucidated as follows.

Table 3: Estimation results

Variable	Carbon Dioxide (CO2)		Methane (ME)	
	Coefficient	P > | t |	Coefficient	P > | t |
Intercept	1,330.82 (38.81)***	0.000	51.47 (4.03)***	0.000
GDPA	- 0.01 (0.01)	0.946	-0.02 (0.01)**	0.051
KL	2.03 (0.74)***	0.006	0.14 (0.07)**	0.031
S	0.12 (0.19)***	0.000	0.04 (1.80)**	0.027
S^2	- 0.01 (0.01)***	0.000	-0.01 (0.01)	0.476
TI	0.57 (0.68)	0.404	0.03 (0.65)	0.647
LC1	34.20 (26.30)	0.194	3.09 (2.55)	0.226
LC2	- 22.77 (13.08)*	0.082	-1.73 (1.26)	0.170
Observation	528			
R^2	0.19		0.14	
F- test (Prob > F)	8.34 (0.000)		3.53 (0.001)	

Note: The standard errors are shown in parentheses. * Significance at 90 percent confidence interval.

** Significance at 95 percent confidence interval. *** Significance at 99 percent confidence interval

4.1 Carbon dioxide

The outcomes derived from the examination of the scale effect, encompassing variables GDPA, S, and TI, reveal a positive correlation between income per capita and carbon dioxide emissions. The coefficient for income per capita (S) is 0.12 and is highly significant, indicating that an increase in income per capita by $1,000 leads to a 0.12 kiloton rise in CO2 emissions. This underscores the substantial impact of income per capita on environmental degradation. On the other hand, GDP per area (GDPA) and trade intensity (TI) are not statistically significant predictors of carbon dioxide emissions. Thus, the examination of the scale effect, through variables GDPA, S, and TI, demonstrates a pronounced only positive relationship between income per capita and CO2 emissions. This correlation is predicated upon the presumption that heightened per capita income stimulates aggregate demand, subsequently fostering increased production and carbon dioxide emissions.

Additionally, this study scrutinizes Kuznet's hypothesis through the inclusion of the quadratic variable of income per capita. The findings indicate that the association between carbon dioxide emissions and income per capita aligns with the Environmental Kuznets Curve hypothesis, manifesting an inverted U-shaped relationship. Specifically, as national income per capita escalates, emissions exhibit a concurrent increase until reaching a certain threshold; thereafter, further income expansion corresponds to a decline in carbon dioxide emissions. The quadratic predicted relationship plot of CO2 and methane with GDP per capita in developing countries, as shown in Figure 1, demonstrates an inverted U-shaped curve, supporting the EKC hypothesis for carbon dioxide emissions. Descriptive statistics indicate that the average GDP per capita in developing countries is approximately $5,600, suggesting these economies may be nearing the EKC turning point. However, in developed countries, the predicted relationship plot of CO2 and methane with GDP per capita does not demonstrate an inverted U-shaped curve, as shown in Figure 2, indicating that the EKC hypothesis may not apply universally.

The findings stemming from the analysis of the composite effect, employing the capital-labor ratio variable, indicate that disparities in factor abundance exert a discernible impact on the quantity of carbon dioxide emissions. These findings align with the observation regarding the GDP per capita, which similarly demonstrates a positive effect. Consequently, countries characterized by capital-intensive industrial sectors exhibit higher carbon dioxide emissions compared to those with lower capital-labor ratios.

The analysis of technique effects is conducted through the examination of two key variables: comparative advantage in low-carbon technology products and total trade in low-carbon technology products as a percentage of GDP. The study reveals that the total trade in low-carbon technology products as a percentage of GDP exhibits statistically significant inverse associations with carbon dioxide emissions. This implies that carbon-reducing technology is effective and that such products have the potential to mitigate carbon dioxide emissions.

This study posits that distinct categories of greenhouse gas emissions are likely governed by distinct mechanisms in their relationship with independent variables. Hence, the investigation is separated into distinct analyses, focusing on models tailored to carbon dioxide and methane gas emissions, respectively. These two gases emanate from disparate sources, with carbon dioxide predominantly stemming from industrial activities and methane largely emanating from agricultural operations. Despite this disparity in origin, the study reveals that analogous independent variables exert comparable effects on both carbon dioxide and methane emissions. This convergence of effects on methane emissions can be elucidated as follows.

4.2 Methane

The scale effect variables demonstrate a parallel impact on methane emissions akin to their influence on carbon dioxide emissions. Specifically, an escalation in per capita income tends to correlate with heightened methane emissions. Interestingly, this relationship with methane emissions does not align with the EKC hypothesis. Furthermore, heightened levels of economic activity per area correspond to decreased methane emissions; however, the influence is barely perceptible. Notably, the significance of international trade intensity in explaining methane emissions appears to be negligible. This observation underscores that disparities in a nation's degree of openness do not exert a discernible effect on methane emissions into the atmosphere.

The outcomes of the composition effects analysis, focusing on the capital-labor ratio, reveal that countries with higher capital-to-labor ratios demonstrate statistically significant increases in methane emissions. This finding implies that even methane, predominantly linked to agricultural sources, is correlated with capital-intensive economies. While agricultural activities are typically labor-intensive, methane emissions from agriculture do not predominantly originate from countries with labor-intensive economies. This discrepancy can be attributed to the fact that some developed countries have large-scale industrial agricultural operations that produce significant methane emissions and industries that are inherently high in methane emissions. Additionally, countries with mixed economic structures and diverse sectors may also contribute to methane emissions without being predominantly labor-intensive. Geographical and environmental factors further influence methane emissions independently of a country's economic characterization as labor-intensive.

The assessment of technique effects on methane emissions employs measures such as the comparative advantage in low-carbon technology and the trade value of low-carbon products. Notably, the impact of low-carbon technology on methane emissions appears to be negligible. This observation highlights that differences in the advancement of environmentally friendly technologies do not have a significant effect on methane emissions into the atmosphere.

5. Conclusions

5.1 General discussion

The examination of various effects on greenhouse gas emissions, particularly carbon dioxide and methane, reveals nuanced relationships between these gases and independent variables. First, the scale effect analysis demonstrates a positive correlation between income per capita and carbon dioxide emissions. This association stems from the premise that higher per capita income stimulates aggregate demand, leading to increased production and, consequently, higher carbon dioxide emissions. Additionally, the study supports the Environmental Kuznets Curve hypothesis, indicating an inverted U-shaped relationship between carbon dioxide emissions and income per capita. Interestingly, trade openness is not associated with increased carbon dioxide emissions. Moreover, economic activity per area shows no significant influence on carbon dioxide emissions, suggesting that the intensity of economic activity does not substantially affect carbon dioxide release.

The analysis of composite effects using the capital-labor ratio variable reveals a discernible impact on the quantity of carbon dioxide emissions. This finding aligns with observations on economic development, indicating that countries with capital-intensive industrial sectors tend to exhibit higher carbon dioxide emissions.

Regarding technique effects, total trade in low-carbon technology products shows a statistically significant inverse relationship with carbon dioxide emissions. However, the comparative advantage in low-carbon technology products exhibits no correlation with carbon dioxide emissions, suggesting that nations may promote trade in low-carbon technology products to reduce their carbon dioxide emissions.

The study also explores methane emissions separately, revealing similar dynamics to carbon dioxide emissions in terms of their relationship with independent variables. Despite originating from different sources, methane emissions exhibit a parallel response to changes in income per capita. Interestingly, economic activity per area shows a small but significant negative impact on methane emissions, suggesting that disparities in economic development levels somewhat influence methane emissions.

Additionally, the analysis of composition effects using the capital-labor ratio variable indicates statistically significant associations with methane emissions, suggesting that capital-abundant countries significantly influence methane levels. The study's findings align with Fernandez-Amador et al. (2017), who identified inconclusive relationships between greenhouse gas emissions and economic growth, further highlighting the complexity of these interactions and the need for a nuanced approach to policy-making.

However, the technique effects analysis reveals that neither comparative advantage in low-carbon technology products nor total trade in low-carbon technology products significantly influences methane emissions. This underscores the notion that low-carbon technologies, primarily developed to reduce CO2 emissions, may not be directly applicable to methane reduction.

5.2 Policy suggestions

Despite the association between higher per capita income and increased greenhouse gas emissions, it is imperative for governments to implement policies that promote development and augment per capita income while simultaneously fostering environmental sustainability. The study validates the Environmental Kuznets Curve hypothesis, indicating that as per capita income reaches a certain threshold, carbon emissions tend to decrease (Grossman & Krueger, 1995). This highlights the need to balance economic growth with environmental stewardship to achieve sustainable development.

Moreover, capital-intensive industries, which significantly contribute to carbon dioxide and methane emissions, require stricter regulations and the promotion of low-emission technologies. Governments should enforce emission standards and invest in research and development (R&D) to mitigate industrial emissions. Additionally, since trade in low-carbon technology products has been shown to inversely correlate with carbon dioxide emissions, implementing trade policies that reduce tariffs and provide subsidies for these products will help promote their global adoption (Lau et al., 2021). International cooperation is also essential to ensure that low-carbon technologies are accessible to developing countries.

Finally, policies should be tailored to the economic structures of individual countries, recognizing that the impact of economic activity on emissions varies. Countries with mixed economic structures require comprehensive policies that address emissions across all sectors (Stechemesser et al., 2024). Increasing funding for R&D in environmental technologies targeting both carbon dioxide and methane emissions, and fostering innovation, will help develop technologies that address multiple greenhouse gases. By implementing these policy suggestions, governments can promote sustainable development while effectively mitigating greenhouse gas emissions.

References

Ahmed, K. (2020). Environmental policy stringency, related technological change and emissions inventory in 20 OECD countries. *Journal of Environmental Management*, *274*, 111209.

Ahmed, K., & Ahmed, S. (2018). A predictive analysis of CO2 emissions, environmental policy stringency, and economic growth in China. *Environmental Science and Pollution Research*, *25*(16), 16091-16100.

Albrizio, S., Botta, E., Koźluk, T., & Zipperer, V. (2014). *Do environmental policies matter for productivity growth? Insights from new cross-country measures of environmental policies* (OECD Economics Department Working Papers No. 1176). Paris: OECD.

Albrizio, S., Kozluk, T., & Zipperer, V. (2017). Environmental policies and productivity growth: Evidence across industries and firms. *Journal of Environmental Economics and Management*, *81*, 209-226.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *The American Economic Review*, *91*(4), 877–908.

Atici, C. (2012). Carbon emissions, trade liberalization, and the Japan–ASEAN interaction: A group-wise examination. *Journal of the Japanese and International Economies*, *26*(1), 167–178.

Bekoe, W., & Jalloh, T. (2023). Assessing the economic implications of free trade on environmental quality: Empirical evidence from Africa. *Environmental and Resource Economics*, *84*(1), 19–36.

Castro, P. (2016). Common but differentiated responsibilities beyond the nation state: How is differential treatment addressed in Transnational Climate Governance Initiatives? *Transnational Environmental Law, 5(2)*, 379–400.

Chandran, V.G.R., & Tang, C. F. (2013). The impacts of transport energy consumption, foreign direct investment and income on CO2 emissions in ASEAN-5 economies. *Renewable and Sustainable Energy Reviews, 24, 445–453.*

Chen, J., Lin, X., Wang, X., Peng, L., & Yu, A. (2023). Characteristics and transfer paths of CO2 emissions embodied in trade and China's carbon reduction strategies. *Environmental Science and Pollution Research*, *30*(20), 58077–58089.

Colyer, D. (2011). Environment and GATT/WTO. In D. Colyer (Ed.), *Green Trade Agreements* (pp. 48-63). London, UK: Palgrave Macmillan.

De Vries, F. P., & Withagen, C. (2005). *Innovation and environmental stringency: The case of sulfur dioxide abatement* (CentER Discussion Paper Series No. 2005-18). Retrieved from https://doi.org/10.2139/ssrn.670158

Fernández-Amador, O., François, J.F., Oberdabernig, D. A., & Tomberger, P. (2017). Carbon dioxide emissions and economic growth: An assessment based on production and consumption emission inventories. *Ecological Economics, 135, 269–279.*

Frankel, J.A., & Rose, A.K. (2005). Is trade good for the environment? Sorting out the causality. *The Review of Economics and Statistics, 87*(1), 85–91.

Grossman, G.M., & Krueger, A.B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics, 110*(2), 353–337.

Heidari, H., Katircioglu, S.T., & Saeidpour, L. (2015). Economic growth, CO2 emissions, and energy consumption in the five ASEAN countries. *International Journal of Electrical Power & Energy Systems, 64*, 785–791.

Hyun-Sik, C., & Hae-Chun, R. (2001). Carbon dioxide emissions of Korea and Japan and its transmission via international trade. *International Economic Journal, 15*(4), 117–136.

Independent Group of Scientists appointed by the Secretary-General. (2023). *Global sustainable development report 2023: Times of crisis, times of change: Science for accelerating transformations to sustainable development*. New York: United Nations.

Kara, E., Ribaudo, M., & Johansson, R. C. (2008). On how environmental stringency influences adoption of best management practices in agriculture. *Journal of Environmental Management*, *88*(4), 1530-1537.

Kondo, Y., Moriguchi, Y., & Shimizu, H. (1998). CO2 emissions in Japan: Influences of imports and exports. *Applied Energy*, *59*(2–3), 163–174.

Korves, N., Martinez-Zarzoso, I., & Monika, A. (2011). Is free trade good or bad for the environment? New empirical evidence. In B. Juan & K. Houshang (Eds.), *Climate Change - Socioeconomic Effects (*pp. Ch. 1). Rijeka: Intech.

Krist, W. (2013). *Globalization and America's trade agreements*. Woodrow Wilson Center Press with Johns Hopkins University Press.

Kuznets, S. (1955) Economic growth and income inequality. *The American Economic Review, 45*(1), 1-28.

Lau, H. C., Ramakrishna, S., Zhang, K., & Radhamani, A. V. (2021). The role of carbon capture and storage in the energy transition. *Energy & Fuels*, *35*(9), 7364–7386.

Lean, H. H., & Smyth, R. (2010). CO2 emissions, electricity consumption and output in ASEAN. *Applied Energy, 87*(6), 1858–1864.

Managi, S., Hibiki, A., & Tsurumi, T. (2009). Does trade openness improve environmental quality? *Journal of Environmental Economics and Management*, *58*(3), 346–363.

Narayan, P. K., & Narayan, S. (2010). Carbon dioxide emissions and economic growth: Panel data evidence from developing countries. *Energy Policy*, *38*(1), 661–666.

Samuelson, P. A. (1954). The pure theory of public expenditure. *The Review of Economics and Statistics*, *36*(4), 387–389.

Shahbaz, M., Nasreen, S., Ahmed, K., & Hammoudeh, S. (2017). Trade openness–carbon emissions nexus: The importance of turning points of trade openness for country panels. *Energy Economics*, *61*, 221–232.

Stechemesser, A., Koch, N., Mark, E., Dilger, E., Klösel, P., Menicacci, L., Nachtigall, D., Pretis, F., Ritter, N., Schwarz, M., Vossen, H., & Wenzel, A. (2024). Climate policies that achieved major emission reductions: Global evidence from two decades. *Science*, *385*(6711), 884–892.

Wang, K., Yan, M., Wang, Y., & Chang, C. P. (2020). The impact of environmental policy stringency on air quality. *Atmospheric Environment*, *231*, 117522.

Wang, Q., & Zhang, F. (2021). The effects of trade openness on decoupling carbon emissions from economic growth – evidence from 182 countries. *Journal of Cleaner Production*, *279*, 123838.

Appendix

Table A1 Correlation Matrix

	gdpa	kl	s	s2	ti	lc1	lc2
gdpa	1.000						
kl	0.239	1.000					
s	0.323	0.878	1.000				
s2	0.364	0.780	0.970	1.000			
ti	0.797	0.081	0.120	0.141	1.000		
lc1	0.108	0.455	0.420	0.324	0.049	1.000	
lc2	0.716	0.130	0.149	0.141	0.926	0.304	1.000

Table A2 Haussman Test for Carbon Dioxide Model

	(b) Fix	(B) Random	(b-B) Difference	sqrt(diag(V_b - V_B)) Std. err.
gdpa	0.001	0.001	- 0.000	0.000
kl	- 1.324	- 1.278	- 0.046	.
s	313.379	222.054	91.326	12.300
s2	- 0.004	- 0.003	- 0.001	0.000
ti	4,135.031	2,740.053	1,394.977	.
lc1	330,994.400	435,658.500	-104,664.200	.
lc2	- 205,033.700	- 170,351.800	- 34,681.850	.

b = Consistent under H0 and Ha; obtained from xtreg.

B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

chi2(4) = (b-B)'[(V_b-V_B)^(-1)](b-B)

= 60.08

Prob > chi2 = 0.0000 (V_b-V_B is not positive definite)

Table A3 Serial correlation Test for Carbon Dioxide Model

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

F (1, 23)	=	54.447
Prob > F	=	0.0000

Table A4 Haussman Test for Methane Model

	(b) Fix	(B) Random	(b-B) Difference	sqrt(diag(V_b - V_B)) Std. err.
gdpa	-0.000	-0.000	0.000	.
kl	-0.103	-0.105	0.002	.
s	15.091	13.515	1.576	0.192
s2	-0.000	-0.000	-0.000	.
ti	218.830	183.430	35.400	.
lc1	15,786.480	17,613.370	-1,826.888	.
lc2	-11,325.780	-10,733.800	-591.974	.

b = Consistent under H0 and Ha; obtained from xtreg.

B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

chi2(4) = (b-B)'[(V_b-V_B)^(-1)](b-B)

= 40.39

Prob > chi2 = 0.0000

(V_b-V_B is not positive definite)

Table A5 Serial correlation Test for Methane Model

Wooldridge test for autocorrelation in panel data

H0: no first-order autocorrelation

F (1, 23)	=	14.302
Prob > F	=	0.0010