THE IMPACT OF TRADE OPENNESS AND ENERGY INTENSITY ON GREENHOUSE GAS EMISSIONS: EVIDENCE FROM DEVELOPING ASIAN COUNTRIES AND IMPLICATIONS FOR VIETNAM

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Abstract

The research uses the quantitative method with secondary data from 32 developing countries in Asia over 21 years, gathered from the World Bank. Pesaran CD test confirms cross-dependence between observations, while CIPS and Westerlund test show the data is stable at I(1) and has a long-term cointegration. FMOLS and ECM are used to assess the relationship between greenhouse gas emissions and socioeconomic factors, which verifies the Pollution Haven Hypothesis and rejects EKC. Research results demonstrate income per capita, energy intensity, and trade openness have a positive relationship with greenhouse gas emissions in the short term. The research proposes a number of measures for developing Asian nations, in particular Vietnam, including developing renewable energy, simplifying legal procedures, encouraging businesses to improve energy efficiency, applying modern technology, and issuing stricter environmental regulations.

Keywords: *Greenhouse gas emission, EKC model, Pollution Haven Hypothesis, FMOLS, ECM*

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1. Introduction

After the onset of the Industrial Revolution, not only has the world economy exponentially developed, but living conditions have substantially improved. However, such rapid growth in economy and production capacity has played a key role in environmental degradation, most notably air pollution. This has become a global issue of utmost concern, requiring immediate societal attention. According to the Global Climate Report 2023, the Earth has warmed by an average of 0.5C per decade due to large carbon emissions annually, leading to serious environmental degradation. One of the main causes of climate change is the increase of greenhouse gas (GHGs), which caused the global temperature to have increased by 1,1C since the 19th century. If measures to control emissions are not found, it is predicted to reach 4,4C by 2030 (K, 2021). According to IEA's report, Vietnam's CO2 emissions have increased by 80% in the past decade, from 103 million tonnes in 2010 to almost 372 million tons in 2020. This shows an immense increase in greenhouse gases due to industrialization and fossil energy consumption. Data from the Organization for Economic Cooperation and Development suggests Vietnam is one of the largest CO2 emitters in the South East Asia (SEA) region, reaching 4.7 MJ/USD (economic output), much higher than developed countries and neighboring countries such as Thailand (3.5 MJ/USD) and the Philippines (3.0 MJ/USD). This adds to the pressure to reduce emissions to protect the environment and mitigate the impacts of climate change.

With the increasingly severe impacts of greenhouse gas emissions on climate change and environmental degradation, many countries have actively adjusted policies to reduce emissions. At COP26 2021 held in Glasglow, Scotland, parties have committed to reducing CO2 emissions by 45% by 2030 compared to 2010 levels and achieving net zero emissions by mid-century, while also significantly reducing emissions of other greenhouse gases such as N2O, CH4, and CFCs (Guo et al., 2023). On a global scale, energy efficiency standards in industry and buildings have yielded positive results. An IEA report in 2021 has indicated that measures that aim to improve energy efficiency help reduce CO2 in many countries. Similarly, the Intergovernmental Panel on Climate Change also emphasizes that energy-saving solutions and green technologies are key to reducing GHG emissions and limiting climate change's impact. However, their effectiveness depends on each country's economic conditions and policies (Bekun et al., 2021; Mehmood Mirza et al., 2022; Rahman et al., 2022). Therefore, researching the relationships between economic activities, investments, technology, energy consumption, and GHG emissions will bring better solutions to protect the environment.

For many countries, international trade is crucial to accelerating economic growth, increasing employment, facilitating technology transfers and improving the infrastructure (Amna Intisar et al., 2020; Kong et al., 2021), but its impact on the environment is still debated. Existing literature, such as (Dou et al., 2021) and (Shahbaz et al., 2015) demonstrate that international trade can also lead to excessive resource exploitation and environmental pollution, in which the process of transporting goods and expanding production to meet export needs can lead to GHG emissions and biodiversity loss. On the contrary, international trade can also expedite green technology transfers, which assist developing countries in improving environmental protection efficiency (Nguyen-Thanh et al., 2022). This study aims to evaluate the impact of trade and energy-related factors on the GHG emissions of developing Asian countries which provides rich data samples, allowing for testing the relationships between factors in different contexts. The results are highly generalizable and may contain useful policy implications for Vietnam, given its commonalities in economic, trade policy, and environmental challenges with other countries in the region.

2. Theoretical framework

2.1. Literature review

Many researches have been conducted in countries and regions across the world to understand better factors that affect emissions as well as environmental quality. On this basis, the author observes that there are three primary branches in the literature about the relationships between the economy, energy consumption and emissions of environmental pollutants. The first branch focuses on the connection between economic factors and environmental pollution. The second branch includes researches related to the nexus between energy consumption, sustainable factors and the economy. Finally, the third branch combines both approaches and investigates the validity of both relationships within the same framework. This approach examines the relationship between economic growth, emissions of environmental pollutants and energy in general.

In the first branch, research mainly concentrates on the link between environmental pollutants and economic factors. Since the first empirical research about EKC by (Grossman &

Krueger, 1991), there have been many literature that investigated economic growth and environmental pollution's relationship. (Pata et al., 2022) examined the simultaneous impact of variables including renewable energy, tourism, foreign direct investment, and income on CO2 emissions in ASEAN countries, demonstrating the validity of EKC as the income elasticity in the long run is lower than the short run. However, the results are debatable, considering some research only partially agree or even show an inverse relationship between economic factors and environmental quality. (Sterpu et al., 2018) used heterogeneous regressions for each individual country in the panel, using generalized least squares (GLS) estimation, with variables in the form of logarithms per capita, and found that the inverted U-shaped EKC hypothesis was confirmed for the panel and for 17 of the 28 EU countries. In Asia, (Chien et al., 2022) found that GDP squared (GDP^2) plays a positive role in reducing GHG emissions, but the results also showed that economic growth contributes to increasing GHG emissions in both the short and long term. This suggests that in these Asian countries, the EKC turning point may not have been reached, as economic growth continues to drive long-term emissions increases. Similarly, (Hdom & Fuinhas, 2020) also demonstrated that increasing trade openness has a positive impact on CO2 emission patterns while GDP will help reduce emissions in Brazil.

Most research in the second branch demonstrates the positive relationship between energy consumption and economic development. Research by (Okoye et al., 2021) in Nigeria showed that energy consumption is a decisive factor in economic growth. Similarly, based on the bivariate regression model, (Le Quang, 2011) studied the causal relationship between electricity consumption and economic growth in Vietnam in 1975-2010. (Loi, 2012) investigated the Granger causal relationship between energy consumption, GDP, and trade in Vietnam from 1986 to 2006. Both research provided evidence for a cointegration relationship between GDP, electricity consumption, and a long-term causal relationship between GDP and electricity consumption in Vietnam. However, when viewed from the perspective of trade openness, the research results of (Zeren & Akkuş, 2020) in developing countries proved that renewable energy consumption will reduce their trade openness levels. (Dogan et al., 2020) employed panel quantile regression estimates and confirmed that the impact of renewable energy consumption on economic growth is positive for the low and lower middle quantiles; however, it becomes negative for the middle, upper middle, and higher quantiles when renewable energy consumption is represented by absolute value. Moreover, the negative effect of renewable energy on economic growth, if represented by the ratio of renewable energy consumption to total energy consumption, is observable in all quantiles.

The third branch consists of research combining the characteristics of the two aforementioned branches to better understand the dynamic relationship between economic growth, energy consumption and environmental pollution in general. With these three factors all taken into consideration, economic growth is usually considered under the form of trade openness and GDP growth (Nguyen et al., 2022), while energy consumption, depending on research conditions, will be analyzed via total energy consumption or a combination of renewable and fossil fuel energy to assess the effect on environmental pollution (Borsha et al., 2024; Nawaz et al., 2021). Most research indicates that as trade openness, non-renewable energy consumption, and total energy use increase, greenhouse gas emissions will increase, while renewable energy plays an important role in reducing emissions of greenhouse gases (Nguyen et al., 2022; Xue et al., 2022). Specifically, (Nurgazina et al., 2021) discovered a relationship between energy consumption, trade openness, globalization, urbanization and CO2 emissions in Malaysia from 1978 and 2018. The research illustrated that a 1% increase in energy consumption, trade openness and urbanization will degrade the environment by 0,18%, 0,03% and 2,51% respectively. (Li & Haneklaus, 2022) also showed that an increase of 1% in G7 nations' renewable energy use reduces CO2 emissions by 0,33% short-term and by 0,099% long-term. In addition, the results support the thesis that trade openness increases CO2 emissions. The study by (Sarkodie & Strezov, 2019) used panel data regression with Driscoll-Kraay standard errors, U-test estimation method, and panel quantile regression with non-additive fixed effects. It found energy consumption has a strong, positive effect on greenhouse gas emissions and confirmed the validity of the "pollution haven" hypothesis in the top five greenhouse gas emitters from fuel combustion in developing countries, namely China, India, Iran, Indonesia, and South Africa. Moreover, another perspective is energy intensity, which has also been shown to increase emissions (Danish et al., 2020; Sadorsky, 2014).

The research context determines that there has been a large body of literature utilizing various econometric techniques with different sample sizes to explore the relationship between trade and energy use on environmental pollution. However, most of these studies focus on carbon dioxide emissions as the main indicator of air quality, while other emissions such as CFCs, CH4, N2O, etc. are rarely considered. In addition, many studies often classify countries according to geographical regions, neglecting the differences in income levels or economic development stages, leading to controversial and inconsistent results in empirical studies on the relationship between economic factors, energy use, and environmental quality. Overall, there is a lack of comprehensive studies that examine the relationship between economic growth, energy use intensity, and greenhouse gas emissions in the same analytical framework, especially in developing Asian countries with new data. The thesis aims to fill in this research gap.

2.2. Hypotheses Development

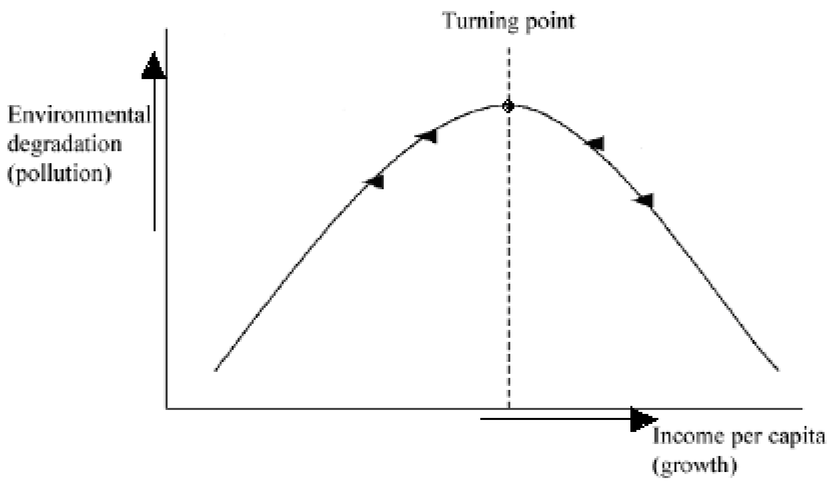
2.2.1. Environment Kutznet Curve Hypothesis (EKC)

Based on the inverted U-shaped curve developed by Kuznets in 1955, the Environmental Kuznets Curve (EKC) is one of the most popular approaches to analyzing environmental performance. It was originally designed to study the relationship between per capita income and income inequality, but became more popular when the inverted U-shape began to be applied in environmental studies. Since then, it has been widely and powerfully used as a theoretical framework for studying the relationship between productivity and environmental degradation (Grossman & Krueger, 1991).

EKC is often interpreted in two ways. The first is through dividing the economic development process into two stages, namely early and late stages. The early stages are defined, on the one hand, by the reduction in ecosystem regeneration due to the intensive use of resources, leading to increasing ecological footprints and pollution. On the other hand, the early stages are associated with lax environmental regulations, associated with low affordability for environmental conservation. At this stage, economic activity necessarily implies resource use, and resource use necessarily implies waste generation, according to thermodynamic laws. Regressions in which the index levels become zero or negative are inappropriate, except in the case of deforestation, where reforestation may occur. This restriction can be applied by using a logarithmic dependent variable. The standard EKC regression model is:

$$ln(E/P)_{it} = \alpha_i + \gamma_t + \beta_1 ln(GDP/P)_{it} + \beta_2 [ln(GDP/P)]_{it}^2 + \varepsilon_{it}$$

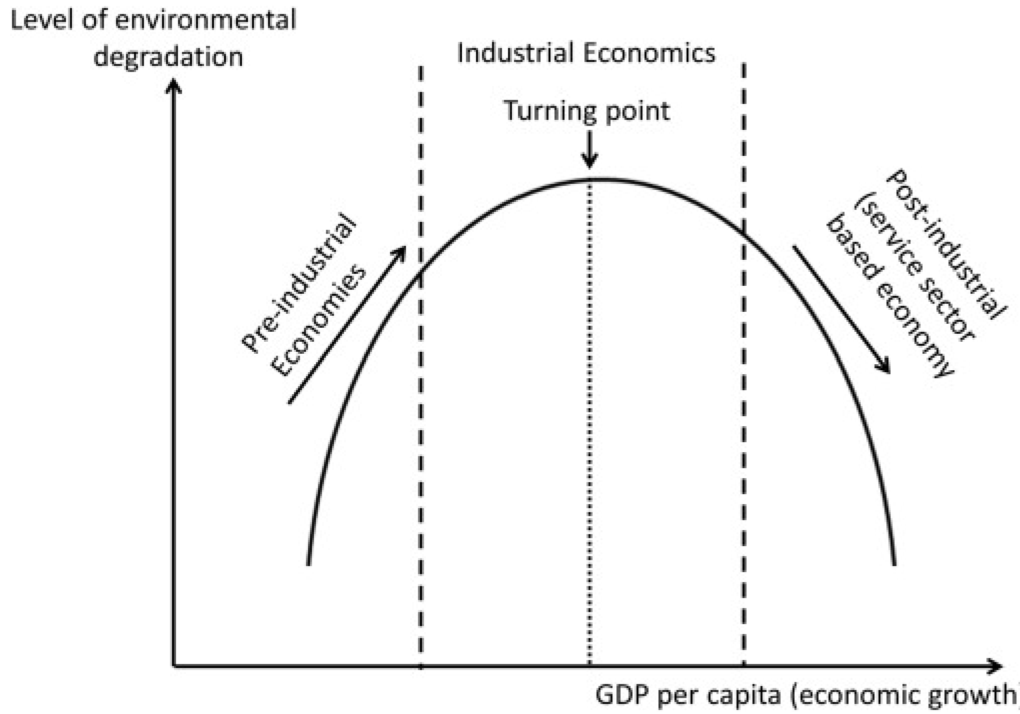
Where E is emissions, P is population, GDP is gross domestic product, e is a random error term, and ln denotes the natural logarithm. The first two terms on the right-hand side are intercept parameters that vary across country or region i and year t. The assumption is that although per capita emissions may vary across countries at any given income level, income elasticities are the same across all countries at a given income level. The time-specific intercepts are intended to account for time-varying omitted variables and random shocks common to all countries (Stern, 2004).



Later stages are characterized by a reduction in environmental degradation due to the diffusion of clean technology and innovation, social environmental awareness, and institutional efficiency and quality associated with increasing income levels (Sarkodie & Strezov, 2018). In addition, these stages are also characterized by two effects, i.e., the policy effect and the income effect. The policy effect includes greater public concern about the environment, leading to strict regulatory requirements. At the same time, the income effect includes an increase in income leading to an increase in willingness to pay for environmentally friendly features (Dasgupta et al., 2002). The "turning point" income level, when emissions or concentrations reach a maximum, can be found using the following formula:

$$\tau = exp[-\beta_1/(2\beta_2)]$$

Another way that the inverted U-shaped curve is often interpreted is when economic development is divided into three stages (Sarkodie & Strezov, 2019), namely: (i) the pre-industrial economy, which is mainly characterized by the primary sector and low income levels; (ii) the industrial economy, which includes the secondary sector and is associated with middle income levels; and (iii) the post-industrial economy, which is formed by the tertiary sector and services, and is associated with higher income levels.



2.2.2. Pollution Haven Hypothesis (PHH)

Advocates of international trade argue that open trade brings new technology, innovation, and environmental improvements to developing countries. However, the PHH paints a different picture of international trade for developing countries (Gill et al., 2018). According to the PHH, after international trade, developing countries have become pollution havens for advanced countries; the migration of dirty industries from advanced countries to developing countries occurs through trade in goods and foreign direct investment (FDI). This phenomenon is driven by the comparative cost advantage that developing countries enjoy due to lower pollution controls (Copeland & Taylor, 1994). Developing countries tend to specialize in and export polluting goods, while developed countries tend to specialize in and export clean goods. As a result, developing countries are becoming pollution havens for the dirty industries of developed countries. Critics of trade liberalization also argue that the concentration of highly polluting industries in poor and developing countries is due to the weak environmental standards of these countries. They claim that consumers in the developed world enjoy highly polluting goods at lower prices due to the low prices of environmental resources in developing countries. This phenomenon of concentration of highly polluting industries in poor and developing countries is known as Pollution Haven Hypothesis.

Meanwhile, the “pollution halo” hypothesis relates to positive assessments of the environmental impact of foreign direct investment (FDI) and international trade, based on the technological and technical spillover effects that the investing country can bring. (Eskeland & Harrison, 2003). When foreign corporations from developed economies, which have adopted more advanced and cleaner technologies, enter the markets of developing countries, they bring with them superior technologies and management processes. These technologies not only help local companies improve production efficiency but also reduce negative impacts on the environment, especially CO2 emissions. This is explained by the fact that multinational corporations are often required to comply with higher environmental standards in their home countries, and when they expand their operations to other countries, these standards are also applied, or at least partly improve, the production processes of the host country. Therefore, the negative environmental impacts that often accompany FDI inflows can be minimized or even neutralized, contributing to promoting environmental welfare (Nguyen et al., 2022; H. Wang et al., 2019; Zhang et al., 2019).

2.2.3. STIRPAT model

IPAT is a widely accepted formula for analyzing the impacts of human activities on the environment (Harrison & Pearce, 2000). IPAT emerged from the Ehrlich-Holdren/Commoner debate in the early 1970s about the main drivers of human-induced environmental impacts. It continues to be widely used as a framework for analyzing the drivers of environmental change. IPAT states that environmental impacts are the multiplicative product of three main drivers: (P) population, (A) wealth (per capita consumption or production), and (T) technology (impact per unit of consumption or production), hence I/PAT

$$I = P \times A \times T \, (I = PAT)$$

IPAT is a mathematical identity and is often used as an accounting equation, in which known values of I, P and A are used to solve the T equation (Ehrlich & Holdren, 1971; Ph.D et al., 1971). Wealth is often operationalized as per capita gross domestic product (GDP), thus PA/P(GDP/ P)/GDP. Thus, by definition, T/I/(PA) or T/I/GDP, thus T is the impact per unit of economic activity. The main limitation of IPAT is that as accounting equations (i.e. mathematical equations), they do not allow for hypothesis testing because known values of some terms determine the value of the missing term. Furthermore, they assume proportionality in the functional relationship between factors. For example, models assume that a doubling of population will lead to a doubling of impact, holding all other factors constant.

To overcome this limitation, (Dietz & Rosa, 1997) reformulated IPAT into a stochastic model, called STIRPAT, for random effects by regressing on population, wealth, and technology.

$$I_{it} = \alpha_{it} P_{it}^{\beta_1} A_{it}^{\beta_2} T_{it}^{\beta_3} \varepsilon_{it}$$

where I, P, A and T have the same meaning as in the IPAT framework for country i at time t. α denotes the country-specific impact. $\beta 1$, $\beta 2$ and $\beta 3$ are the elasticities of the environmental impact related to P, A and T, respectively. To facilitate empirical estimation and hypothesis testing, the variables in the model are transformed into logarithmic form as follows:

$$lnI_{it} = \alpha_{it} + \beta_1 lnP_{it} + \beta_2 lnA_{it} + \beta_3 lnT_{it} + \varepsilon_{it} \quad (1)$$

3. Research method

3.1. Regression model

The study takes into account the potential inverted U-shaped relationship between income and emissions, as proposed by the EKC, by explicitly considering the quadratic income variable in the baseline model, the EKC hypothesis states that environmental quality tends to deteriorate in the early stages of economic development, but as the economy continues to grow beyond a certain threshold, emissions tend to decrease and thus environmental quality improves. This implies an approximately inverted U-shaped curve for the income-emissions relationship (Thanh & Khuong, 2017). It is therefore hypothesized that:

H1: In the short term, increased income will increase greenhouse gas emissions or $\beta(GDPpc) > 0$

H2: In the long term, increased income will reduce greenhouse gas emissions or $\beta(GDPpc^2) < 0$

Simultaneously, the study also tested the validity of the Pollution Haven theory. Similar to the EKC hypothesis, (Akin, 2014; Jayanthakumaran et al., 2012) used an inverted U-shape to illustrate the impact on emissions. Openness in trade enhances pollution to a certain extent, after which it will limit environmental degradation.

H3: In the short term, increased trade openness will increase greenhouse gas emissions or $\beta(TO) > 0$

H4: In the long term, increased trade openness will reduce greenhouse gas emissions or $\beta(TO^2) < 0$

In this context, this study goes beyond EKC and PH by incorporating its ideas into the STIRPAT model where the emission determinants are examined using an extended version of the basic STIRPAT model in (1) by taking into account the potential inverted U-shaped relationship between (2) income and emissions, as proposed by EKC, and (3) trade and emissions, as proposed by PHH, by explicitly considering the quadratic variables of income and trade openness in the base model. Therefore, the research model is presented as follows:

$$lnGHG_{it} = \alpha_{it} + \beta_1 PG_{it} + \beta_2 GDPpc_{it} + \beta_3 GDPpc^2_{it} + \beta_4 TO_{it} + \beta_5 EI_{it} + \varepsilon_{it} \quad (2)$$

$$lnGHG_{it} = \alpha_{it} + \beta_1 PG_{it} + \beta_2 GDPpc_{it} + \beta_3 TO_{it} + \beta_4 TO^2_{it} + \beta_5 EI_{it} + \varepsilon_{it} \quad (3)$$

Where:

- Greenhouse gas emissions (GHG), representing I (Impact) of STIRPAT.
- GDP and Trade Openness (GDP and TO), representing A (Affluence).
- GDP^2 and Trade $Openness^2$ (GDP^2 and TO^2), representing A^2, to determine the long-run relationship between A and I.

Affluence (A) is another important factor that contributes to emissions. As discussed in the previous section, our base model combines the ideas of the EKC and PHH hypotheses by decomposing the wealth factor into a first-order exponential term and a square term to empirically explore the relationship between GHG emissions and per capita income and trade openness to test the validity of these two factors in the two models.

- Population Growth (PG), represent for P (Population)

As shown in the STIRPAT model, population growth is one of the important factors contributing to the deterioration of air quality. As the population increases, the demand for energy, food, and goods also increases, putting great pressure on natural resources. The production and consumption of goods often rely on fossil energy sources, such as coal and oil, leading to greenhouse gas emissions. Studies by (Alajmi, 2021; Rehman et al., 2021) also indicate that population growth will impact the emissions of air pollutants.

- Energy Intensity (EI), represent for T (Technology)

Energy intensity, is one of the most frequently used variables to represent technological factors (Sadorsky, 2014; Y. Wang et al., 2016). Lower energy intensity is often associated with more advanced and innovative technology, which reduces emissions, while increased energy intensity means that more energy is needed to produce a unit of product or service. This often results in more energy consumption from fossil sources, which increases greenhouse gas emissions.

3.2. Sample data

The study uses data from 32 developing Asian countries including Armenia; Azerbaijan; Bahrain; Bangladesh; Bhutan; Brunei; Cambodia; China; Cyprus; Georgia; India; Indonesia; Iran; Iraq; Jordan; Kazakhstan; Kyrgyzstan; Lebanon; Malaysia; Mongolia; Nepal; Oman; Pakistan; Philippines; Qatar; Saudi Arabia; Tajikistan; Thailand; Turkey; Turkmenistan; Uzbekistan and Vietnam within a 21-year period, from 2000 to 2020, to ensure completeness and balance of data with the number of selected countries. All data are collected from World Bank (WDI), and the variables' descriptive statistics are presented in the following table:

Table 1: Data description

Variable	Obs	Mean	Std. Dev.	Min	Max
GHG	672	540104.2	1745361	941.7338	1.29e+07
GDPpc	672	8074.672	13110.01	137.1819	98041.36
PG	672	1.717879	1.95808	-2.879866	19.36043
TO	672	86.05813	37.45889	21.45997	220.4068
EI	672	6.259107	3.587375	1.9	30.44

To mitigate the standard deviation of the data in the research model, this study takes a natural logarithm of variables including GHG; GDPpc và TO, the log-linear single-equation multivariate model được trình bày như sau:

$$lnGHG_{it} = \alpha_{it} + \beta_1 PG_{it} + \beta_2 lnGDPpc_{it} + \beta_3 lnGDPpc^2_{it} + \beta_4 lnTO_{it} + \beta_5 EI_{it} + \varepsilon_{it} \quad (1)$$

$$lnGHG_{it} = \alpha_{it} + \beta_1 PG_{it} + \beta_2 lnGDPpc_{it} + \beta_3 lnTO_{it} + \beta_4 lnTO^2_{it} + \beta_5 EI_{it} + \varepsilon_{it} \quad (2)$$

Where ε denotes the random error term and i represents the country observed at time t. β1, β2,..., β5 represent the coefficient of the corresponding variable, and α represents the estimated residual. GHG is calculated as total greenhouse gas emissions (kt of CO2 equivalent). Trade openness is the sum of exports and imports of goods and services, measured as a share of gross domestic product. $GDPpc^2$ and TO^2 are calculated through the squared value of lnGDPpc and lnTO; Energy intensity is calculated as the energy intensity level of primary energy (MJ/$2017 PPP GDP).

3.3. Research method

3.3.1. Cross dependence

(Pesaran, 2004) developed the CD statistic based on the LM statistic by(Breusch & Pagan, 1980). (Yan et al., 2019) stated that the CD statistic has many advantages because it provides accurate mean values when the number of time observations (T) and the number of cross-sectional units (N) are fixed. This statistic can also be applied to both homogeneous and heterogeneous models, as well as non-stationary data. This shows that the CD statistic is more flexible and suitable for testing cross-sectional dependence in panel data, because it can be applied to many different types of models while still ensuring the accuracy of the results.

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N}\right) \simeq N(0,1)$$

$$\hat{\rho}_{ij} = \hat{\rho}_{ji} = \frac{\sum_{t=1}^{T} \hat{\mu}_{it} \hat{\mu}_{jt}}{\sqrt{\sum_{t=1}^{T} \hat{\mu}_{it}^2}\sqrt{\sum_{t=1}^{T} \hat{\mu}_{jt}^2}}$$

Where the number of countries is represented by N, time by T, and the cross-sectional correlation estimate of countries i and j is represented by $\hat{\rho}_{ij}$.

3.3.2. CIPS panel unit root test

Cross-Sectionally Augmented IPS (CIPS) Test is a method of testing stationarity for panel data, to handle the problem of cross-sectional dependence in the data. (Pesaran, 2007).

The CIPS test is based on the extended ADF model, including a cross-sectional mean to handle cross-sectional dependence. The CIPS model is:

$$\Delta Y_{it} = \alpha_i + \beta_i Y_{i,t-1} + \gamma_i \bar{Y}_{t-1} + \sum_{j=1}^{p} \lambda_{ij} \Delta Y_{i,t-j} + \sum_{j=1}^{p} \delta_{ij} \Delta \bar{Y}_{t-j} + \varepsilon_{it}$$

Where:

- is the variable to be tested.
- is the average of all units at time t - 1, representing cross-sectional dependence.
- are the regression coefficients.
- is random noise.

3.3.3. Westerlund cointegration test

This study continues by testing for co-integration in the panel data set. Depending on the existence of CSD in the data, the panel co-integration test proposed by (Westerlund, 2007) will be performed. Westerlund will be performed if CSD exists in the data, otherwise, the Pedroni test is used.

3.3.4. FMOLS

If a cointegration relationship is found between the variables, the next step is to estimate long-run parameters. However, since OLS leads to undesirable coefficients due to cointegration, several alternative empirical methods have been proposed. One of the methods is DOLS. However, according to (Kao & Chiang, 2001), its main weakness is that it does not consider cross-sectional heterogeneity issues. (Pedroni, 2001) proposed the FMOLS estimation method for cointegrated panels, which takes into account the issues of serial correlation, endogeneity and cross-sectional heterogeneity. He proposed the following equation:

$$Y_{i,t} = \alpha_i + \beta_i X_{i,t} + \varepsilon_{i,t} \quad \forall t = 1,..., T \qquad i = 1,..., N$$

And he presumes that $Y_{i,t}$ and $X_{i,t}$ coninter co-link with β_i slope (β_i slope may or may not be homogenized for each country i. Therefore, we have the following equation:

We consider:

$\xi_{i,t} = (\hat{\varepsilon}_{i,t}, \Delta X_{i,t})$ và $\Omega_{i,t} = \lim_{T\to\infty} E[\frac{1}{T}(\sum_{t=1}^{T} \xi_{i,t}).(\sum_{t=1}^{T} \xi_{i,t})']$ is the long-run covariance for this vector process which can be decomposed into $\Omega = \Omega^{0} + \Gamma_{i} + \Gamma_{i}'$. Where, Ω_{i}^{0} is the simultaneous covariance and i is a weighted sum of the autocovariances.

$$\hat{\beta}^{*}_{FMOLS} = \frac{1}{N}\sum_{i=1}^{N}[(\sum_{t=1}^{T}(X_{i,t} - \underline{X}_{i})^{2})^{-1} (\sum_{t=1}^{T}(X_{i,t} - \underline{X}_{i})Y^{*}_{i,t} - T\hat{\gamma}_{i})]$$

Where,

$$Y^{*}_{i,t} = Y_{i,t} - \underline{Y_{i}} - \frac{\hat{\Omega}_{2,1,i}}{\hat{\Omega}_{2,2,i}}\Delta X_{i,t}$$

$$\hat{\gamma}_{i} = \hat{\Gamma}_{2,1,i} + \hat{\Omega}^{o}_{2,1,i} - \frac{\hat{\Omega}_{2,1,i}}{\hat{\Omega}_{2,2,i}}(\hat{\Gamma}_{2,2,i} + \hat{\Omega}^{o}_{2,1,i})$$

3.3.5. Error Correction Model (ECM)

The Error Correction Model (ECM) is a popular tool in econometrics used to analyze short-run relationships between variables while still accounting for long-run effects. The ECM is based on the assumption that there is a long-run relationship between the variables in the model. When one or more variables in the model experience short-run changes, the ECM allows these variables to adjust back to their long-run equilibrium over time. When variables are non-stationary but have a long-run relationship, they are said to be cointegrated. The ECM is used after it has been determined that these variables are cointegrated.

The following is a typical ECM model :

$$\Delta Y_{t} = \alpha + \beta\Delta X_{t} + \theta(Y_{t-1} - \gamma X_{t-1}) + \epsilon_{t}$$

- ΔY_{t}: Dependent variable that changes over time.
- ΔX_{t}: Independent variable that changes over time.
- $Y_{t-1} - \gamma X_{t-1}$: The adjustment term after the number, indicating the deviation from the long-run relationship (long-run equilibrium). If this term is non-zero, there is an error in the long-run relationship that needs to be adjusted.
- θ: Adjustment coefficient, which shows the rate at which the dependent variable returns to equilibrium.
- ϵ_{t}: Random error.

4. Emperical results

4.1. Model testing

Table (1) presents the results of Pesaran test of cross-sectional dependence for models (1) and (2), showing the dependence among Asian economies on the factors in the model at the 1% and 5% significance levels. The presence of cross-sectional dependence among variables suggests that the countries have similar characteristics.

Bảng 1: Pesaran Cross Dependence Test result

<table>
<tr><td rowspan="3">(2)</td><td colspan="5">Pesaran's test of cross sectional independence = 24.896</td><td colspan="2">Pr = 0.0000</td></tr>
<tr><td>Variable</td><td>lnGHG</td><td>lnGDPpc</td><td>lnGDPpc2</td><td>PG</td><td>lnTO</td><td>lnEI</td></tr>
<tr><td>CD-test</td><td>+79.067***</td><td>+91.907***</td><td>+89.897***</td><td>+6.351***</td><td>+11.764***</td><td>+37.726***</td></tr>
<tr><td rowspan="3">(3)</td><td colspan="5">Pesaran's test of cross sectional independence = 30.049</td><td colspan="2">Pr = 0.0000</td></tr>
<tr><td>Variable</td><td>lnGHG</td><td>lnGDPpc</td><td>PG</td><td>lnTO</td><td>lnTO2</td><td>lnEI</td></tr>
<tr><td>CD-test</td><td>+79.067***</td><td>+91.907***</td><td>+6.351***</td><td>+11.764***</td><td>+11.621***</td><td>+37.726***</td></tr>
</table>

*Standard errors in parentheses: * p<0.10, ** p<0.05, *** p<0.01*

Table (2) presents the results of the stationarity test of the variables at level 0 and first difference according to the CIPS test. The results show that all variables, including lnGHG, lnGDPpc2, lnGDPpc, PG, lnTO2, lnTO, and lnEI, are stationary at level I(1), because the test statistics of these variables become significant at the first difference, reaching the 1% significance level. This shows that the variables are not stationary at the initial level but become stationary after taking one difference.

Table 2: Cross-Sectionally Augmented IPS test result

Varial	Level	First Difference	Conclusion
lnGHG	-1.872	-3.605***	I(1)
lnGDPpc2	-1.819	-3.421***	I(1)

lnGDPpc	-2.125	-3.583***	I(1)
PG	-1.353	-2.698***	I(1)
lnTO2	-1.716	-3.531***	I(1)
lnTO	-1.712	-3.566***	I(1)
lnEI	-2.068	-3.955***	I(1)

*The significant values at the 10%, 5%, and 1% levels are -2.11, -2.2, and -2.36. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels.*

The Westerlund cointegration test results of models (2) and (3) with prob =0.0244 and prob= 0.0323 <0.05 also confirm the long-run relationship between the variables in the model and the dependent variable.

Table 3: Westerlund cointergration test result

(2)			**(3)**		
	Statistic	p-value		Statistic	p-value
Variance ratio	1.8483	0.0323	Variance ratio	1.9711	0.0244

4.2. Regression Results & Discussion

To examine the long-run relationship, FMOLS was used to regress the model because it was more optimal than DOLS, with the results presented in Table 4, with the reliability of the two models being 0.31 and 0.36, respectively.

Table 4: FMOLS result

	(2)	**(3)**
	dlnGHG	**dlnGHG**
dlnGDPpc	0.152*** (0.0423)	0.141*** (0.0158)
dlnGDPpc2	-0.00180 (0.00551)	

dlnTO	0.0407** (0.0197)	0.452** (0.201)
dlnEI	0.292*** (0.0256)	0.291*** (0.0266)
dPG	0.00184 (0.00205)	0.00169 (0.00215)
dlnTO2		-0.0485** (0.0235)
_cons	0.0259*** (0.00228)	0.0257*** (0.00236)
N	639	639
r2	0.310	0.360

*Standard errors in parentheses: * p<0.10, ** p<0.05, *** p<0.01*

At the same time, to examine the short-term relationship between socio-economic factors and greenhouse gas emissions, the study used the Error Correction Model (ECM), the EKC results are presented in table (6) with the results of ECM residual test are reported in table (5) showing that the model parameters except PG are generally statistically significant at the 0.05 significance level, allowing generalization of conclusions based on the calculations.

D.lnGHG	Coef.	Std. Err.	t	P>t	[95% Conf.	Interval]
lnGDPpc D1.	.1381241	.0135762	10.17	0.000	.1114643	.1647839
PG D1.	.0018247	.0018506	0.99	0.325	-.0018094	.0054588

lnTO D1.	.0432764	.0177569	2.44	0.015	.008407	.0781458
lnEI D1.	.2903216	.0229068	12.67	0.000	.2453393	.3353039
residual L1.	.0022709	.001094	2.08	0.038	.0001225	.0044193
_cons	.0260713	.0020322	12.83	0.000	.0220807	.0300618

The FMOLS results of model (2) show that income, trade openness and energy intensity have a positive relationship with greenhouse gas emissions in the long run at the 5% significance level, meaning that reducing these factors will help reduce emissions. Meanwhile, income squared ($lnGDPpc^2$) has no long-term impact, proving that the EKC model is invalid in the context of 32 developing Asian countries, when $lnGDPpc^2$ is not statistically significant, while lnGDPpc has a positive impact on emissions, indicating that income growth is not high enough to trigger positive changes in environmental protection. This may be because countries in the early stages of EKC depend on energy-intensive industries that use a lot of fossil energy, which use a large amount of fossil energy (coal, oil, natural gas) to operate, leading to high emissions. Similar results were also shown in the study of (Amna Intisar et al., 2020; Aruga, 2019; Murshed & Dao, 2022). Meanwhile, model (3) confirms the PHH hypothesis, showing that trade openness in the short run increases emissions by attracting polluting industries from developed countries. However, in the long run, lnTO2 has a reducing effect on greenhouse gas emissions, showing that when trade openness reaches a certain level, emissions begin to decline. The study of (Akin, 2014; Thanh & Khuong, 2017) also shows similar results. This can be explained by the fact that international trade helps developing countries access clean and modern technology, allowing them to adopt more efficient production processes and reduce emissions, while the economic restructuring from heavy industries to less polluting industries helps reduce pressure on the environment.

In the context of Vietnam, like many other developing countries, it is experiencing a period of rapid economic growth, but at the same time it has witnessed a significant increase in greenhouse gas emissions. Vietnam’s GDP per capita and trade have key roles in economic growth, however they also encourage the expansion of energy-intensive industries such as cement, steel manufacturing and electricity production, leading to an increase in environmental degradation. In the short term, trade attracts polluting industries from developed countries, as described by PHH theory. Vietnam's export turnover increased from about 200 billion USD in 2017 to 372 billion USD in 2022 while the cement industry, according to the General Statistics Office, contributes about 40% of the country's total CO_2 emissions. Specifically, as reported by the Ministry of Natural Resources and Environment, Vietnam recorded an increase in CO_2 emissions from 103 million tons in 2010 to nearly 327 million tons in 2020. This clearly shows that increasing energy intensity, combined with dependence on fossil fuels, is putting great pressure on the environment. Meanwhile, in the long term, trade openness can create positive opportunities for Vietnam. International trade helps developing countries, including Vietnam, access cleaner and more modern technology, which allows domestic enterprises to employ more effective and less polluting means of production. Furthermore, the restructuring of the economy, moving away from heavy industries to more environmentally friendly sectors, such as service and technology sectors has been going strong in recent times. According to the Ministry of Planning and Development, the proportion of services in the GDP structure has increased from 40% in 2010 to nearly 50% in 2022, which not only helps reduce pressure on the environment, but also creates a more effective balance between economic growth and environmental protection. Therefore, effective management of trade will be a key factor to help Vietnam achieve its sustainable development goals in the current context.

Energy intensity is also proved to have impact on greenhouse gas emission in both short and long-run by the using of outdated technology with fossil fuels of developing Asian countries which leads to higher energy consumption and greenhouse gas emissions. But in the future when these countries start to use cleaner technology and renewable energy consumption, together with shifting economic structures to energy-intensive sectors, the emissions of greenhouse gas can be strongly reduced. The similar result alsho showns in study of (Bildirici et al., 2022; Danish et al., 2020). In recent years, Vietnam is and has been facing challenges in reducing the energy intensity levels of national manufacturing industries. For example, the coal-fired power industry is still reponsible for almost half of the total electricity generated, around 49,3%, which releases immense amounts of GHG emissions into the environment. Vietnam's goal by 2030 is to have renewable energy sources account for 30% of the country's total electricity output. Currently, many solar power and wind power projects have been successfully deployed and put into use across the country. Notably, in recent years, Vietnam has managed to attract a significant sum of FDI investments into the renewable energy sector, such as solar energy generations, playing a key role in reducing overall energy intensity. Despite efforts to improve domestic technologies, transformation of production processes is still slow due to troubles with capital sources or low labour qualities, requiring more specific solutions and actions from the government.

Population growth is also shown to have no effect, both in the short term and long term, to GHG emissions of developing Asian countries. In the context of rapid economic growth, Asian countries' populations also increase annually, however regression results show that these changes do not lead to a proportional increase in GHG emissions, which can be explained by the fact that economic factors and technological advancements have limited the negative effects of the population on the environment quality. In Vietnam, businesses and industries are and have been actively adopting efficient and green technologies into their production processes, which reduce GHG emissions even when the population continues to rise. Besides this, in the long run, Vietnam's birth rate will decline, which not only reduce pressure from population growth, but also its effect on GHG emissions. According to the General Office of Statistics, birth rates have fallen, from 2,3 children/woman from 2000, to 2,1 children/woman in 2021. This demonstrates a positive change in population control, and it provides Vietnam with additional time and resources to pursue effective environment-related policies to move towards a sustainable economy with less pressure from population growth.

5. Recommendation

For Asian countries, reducing GHG emissions and maintain sustainable development are both challenges, and also opportunities to push for sustainable economic growth. These countries must increase their efforts to conserve the environment, beginning with a transition to renewable energy through investments in wind power, solar power generation and other renewable energy-related projects, while simultaneously incentivize investors into this field with tax cuts and financial aid. Improvements in energy efficiency should also be focused on through encouraging businesses to use advanced technologies and implementing education programs on energy conservation. Environmental regulations are also another concern, with a tighter legal framework needed to control emissions from heavy industries.Finally, shifting the economic structure, from energy-intensive sectors to low-emission sectors, will contribute to creating a more sustainable economy.

In the context of Vietnam, measures to reduce greenhouse gas emissions and maintain sustainable development are becoming more urgent. The government needs to promote the development of renewable energy to achieve the target of 30% of electricity output from renewable energy sources by 2030. To do this, it is necessary to establish financial support programs for wind and solar power projects. An example is policies such as FiT (Feed-in Tariff) that have been implemented for solar energy, helping to ensure stable electricity purchase prices for investors. However, simplifying legal procedures, reducing licensing time and creating favorable conditions for investors are necessary to attract more projects. In addition, improving energy efficiency in production is a top priority. The government should encourage enterprises to apply modern technology through programs such as the “National Energy Conservation Program” to raise awareness of energy saving and improve production efficiency. Businesses need financial support through preferential loans from banks or development investment funds to enable them to invest in new technologies that reduce energy consumption and greenhouse gas emissions. For example, banks such as the Vietnam Development Bank have implemented preferential loan programs for energy efficiency projects. Vietnam also needs to develop stricter environmental regulations to control emissions from large industries. Regulations such as the 2020 Environmental Protection Law have introduced stricter regulations on greenhouse gas emissions, but strengthening the capacity of environmental management agencies and implementing measures such as carbon credit systems are essential. Carbon credit systems can encourage businesses to further reduce emissions through the purchase and sale of carbon credits. Finally, shifting the economic structure away from heavy industries to high-value-added sectors such as high technology and services will create sustainable development opportunities for Vietnam. The government should implement retraining programs to meet the needs of new industries and encourage innovation through supportive policies such as investment funds for innovative startups. Learning from the successful experiences of other countries in the region such as China and India will also help Vietnam adopt more effective financial and technical measures to promote renewable energy and reduce greenhouse gas emissions. Implementing these policies will not only reduce emissions but also contribute to promoting sustainable economic development in the future.

6. Conclusion

The research used secondary data of 32 developing countries in Asia over 21 years with data of all variables in the model taken from the World Bank. After collection, the study processed and eliminated substandard observations, then the data was analyzed through appropriate testing steps and statistical analysis techniques using Microsoft Excel and Stata 15. The CD-test results confirmed the cross-sectional dependence relationship while the CIPS and Westerlund cointegration tests also showed that the data were stable at I(1) and had a long-term cointegration relationship. To assess the relationship between variables, the study used FMOLS combined with ECM panel. The long-term estimation results confirm the Pollution Haven Hypothesis while rejecting the EKC model in the context of 32 developing Asian countries. The ECM estimation results indicate a positive relationship between per capita income, energy intensity and trade openness in the short-term for greenhouse gas emissions. From there, the study makes a number of recommendations for Asian countries, especially Vietnam, including promoting the development of renewable energy, especially wind and solar power, combined with simplifying legal procedures, reducing licensing time and creating favorable conditions for investors. The government also needs to encourage enterprises to improve energy efficiency and apply modern technology through financial support and energy-saving programs, at the same time issuing stricter environmental regulations and implementing a carbon credit system to control emissions in parallel with the economic restructuring from heavy industry to high technology and services. In particular, Vietnam needs to learn from other countries' experiences to promote renewable energy and reduce emissions more effectively.

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