



THE IMPACT OF FOREIGN DIRECT INVESTMENT TO AIR POLLUTION IN SOUTHEAST ASIA

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ABSTRACT

This study investigates the environmental impacts in air pollution aspect of foreign direct investment (FDI), economic growth, renewable energy usage, industrial structure, trade openness, and population in Southeast Asia, including fine particles (PM_{2.5}), carbon dioxide emissions, and nitrous dioxide emissions. The research aims to explore both short-term and long-term effects, with a particular focus on the diverse dynamics across countries in the region. The study uses a Pooled Mean Group Autoregressive Distributed Lags model (PMG-ARDL) to estimate long- and short-run relationships in panel data and employs Fully Modified Ordinary Least Squares (FMOLS) as a robustness check for the long-term findings. The results reveal that FDI contributes to increased pollution in the long term, particularly for fine particle and nitrogen dioxide emissions, supporting the pollution haven hypothesis. Economic growth demonstrates mixed effects, reducing fine particle and nitrogen dioxide emissions while increasing carbon emissions in some cases. Short-run analyses reveal considerable variability across countries, focusing on the importance of policy interventions. The study concludes by recommending policies that prioritize renewable energy expansion, enforce stricter environmental regulations on foreign investments, and promote cleaner industrial practices. These measures are critical for achieving sustainable development in Southeast Asia while addressing the environmental challenges caused by rapid economic growth and industrialization.

INTRODUCTION

Air pollution is a recurring environmental challenge in Southeast Asia, particularly during the dry season when limited precipitation coincides with pollutants from fossil fuel combustion, biomass burning, and other anthropogenic sources. The World Health Organization (WHO) reports that air pollution levels across the region exceed its recommended guidelines. For instance, Jakarta ranked as the most polluted city in the world in August 2023 (Chen, 2023), while northern cities of Thailand such as Chiang Mai, Chiang Rai, and Lampang regularly record “unhealthy” air quality levels during dry months (Ng, 2024). Similarly, Singapore has issued public warning regarding transboundary haze events resulting from agricultural burning in Malaysia and Indonesia (Ng J., 2023). Alongside these local air quality concerns, The region’s rapid economic growth led to a sharp increase in carbon dioxide (CO₂), from 1,038 million metric tons (Mt) in 2010 to 1,429 million metric tons in 2018, emphasizing the dual challenges of sustaining economic development while mitigating environmental degradation.

Southeast Asian economies still rely on Foreign Direct Investment (FDI) as a driver of industrial growth and export expansion. The region has consistently ranked among the top recipients of FDI in the developing world for the three consecutive years, attracting inflows of approximately 230 billion dollars in 2023. FDI has fueled the growth of key export-oriented sectors such as electronics, semiconductors, automotive manufacturing and electrical vehicle production. (The ASEAN Secretariat & United Nations Conference on Trade and Development, 2024). While these investments stimulate economic growth, they also raise concerns regarding potential environmental consequences, particularly in countries with less stringent environmental regulations.

The environmental impact of FDI in developing regions is contested in the research. According to the Pollution Haven Hypothesis (Copeland & Taylor, 1994), multinational firms may relocate pollution-intensive production to countries with weaker environmental

regulations, enabling increased emissions. Empirical evidence from this region supports this view, with studies reporting a positive relationship between FDI inflows and air (Huynh and Hoang, 2019; Nguyen et al., 2023; Ding, 2022). For instance, Bui Minh et al. (2023) found that the increase in FDI in Vietnam correlated with the increase of carbon emissions. Conversely, The Pollution Halo Hypothesis indicates that FDI can reduce pollution emissions due to introducing cleaner technologies and production practices. Zhu et al. (2016) found evidence supporting this hypothesis in parts of Southeast Asia. These divergent findings suggest that the net environmental impact of FDI may depend on host country characteristics, such as regulatory stringency and technological capacity.

Despite extensive research on FDI and environmental pollution, important gaps remain. With the limited of data, most of the scholars used Carbon dioxide emission as an environmental pollutant measure. In fact, there are also other pollutant measure such as Nitrous dioxide emission or Particulate matter (PM_{2.5}). These pollutants also bring the negative health impact on respiratory system. According to WHO data, there is estimation that outdoor air pollution may cause 4.2 million premature deaths in global per year in 2019, because of fine particle matter which causes respiratory and cardiovascular disease. Moreover, some of studies used the data before 2020 which covid-19 occurred. The result from these studies might not reflect the current situation after this pandemic.

This study has three objectives. First, the researcher examines the short-term and long-term impacts of FDI on air pollution, measured through multiple pollutants, which are carbon dioxide (CO₂), nitrogen dioxide (NO₂), and fine particle (PM_{2.5}), in Southeast Asia. Second, investigating the heterogenous effects on air pollution across different Southeast Asia countries. Third, assess the role of control variables in influencing air pollution levels. This study employs advanced econometric techniques, including Pooled Mean Group Autoregressive Distributed Lags model (PMG-ARDL) and Fully Modified Ordinary Least Squares, to capture both immediate and lagged effects of FDI on air pollution across different measures. By analyzing panel data spanning several years and pollutant types, the research provides insights into the temporal dynamics of FDI's environmental consequences. Additionally, the inclusion of institutional quality variables offers a deeper understanding of the governance factors influencing these outcomes.

The findings aim to contribute to the ongoing discourse on sustainable development by providing evidence-based recommendations for policymakers to balance economic growth and environmental preservation in the post-pandemic era. The paper is structured as follows: the next section reviews relevant literature on FDI and air pollution, with emphasis on multiple pollutants and temporal dynamics. The third section describes the data and methodology by using Pooled Mean Group Autoregressive Lags (PMG-ARDL). The fourth section present empirical results and discuss findings with other relevant research paper. The last section is conclusion with policy implications and directions for future research.

LITERATURE REVIEW

FDI and Southeast Asia

A foreign direct invest or FDI refers to an investment in the form of a controlling ownership in business, real estate or productive estate such as factories in one country which entity is based in another country. Southeast Asia has seen as a significant surge in FDI inflows over the past decade, with 220 billion dollar per year for foreign investments in this region. This enables the status of southeast Asia as the top FDI recipients in developing economies for three consecutive years since 2021 to 2023. By 2023, Southeast Asia region share the global FDI as much as 17 percent. This rapid influx has driven FDI stock in the region to \$3.9 trillion by 2023, up from \$1.7 trillion in 2015. (ASEAN Secretariat and United Nation Committee Trade and Development, 2024). Developing countries dominate Southeast Asia region which are highly dependent on foreign investment. There are many studies that reveal the importance of FDI implications for economic growth in Southeast Asia countries (Lestari et al., 2022; Pata et al., 2022; Wong et al., 2023)

To attract increase in FDI, the host country must offer profitable opportunities for investors (M.-L. T. Nguyen, 2022). According to the neoclassical perspective, economic growth depends on the interplay of capital, labor, and technology (Solow, 1956). This model emphasizes that without technological advancements, achieving long-term growth in income per capita is unlikely (Sredojević et al., 2016). Building on this foundation, the endogenous growth theory suggests that future investment flows can be fostered by allocating resources to research projects, especially those involving advanced technologies (Romer, 1990). These innovations stimulate economic growth in host countries. However, while economic growth brings many benefits, it also has a dual effect that must be considered: alongside its potential for improving living standards, it often contributes to environmental degradation (Stern, 2018). Balancing these competing outcomes is crucial for sustainable development.

Air pollution

Air pollution in Southeast Asia is a significant threat to human health and the environment. Key pollutants include fine particulate matter (PM_{2.5}), carbon dioxide (CO₂), and nitrogen dioxide (N₂O). PM_{2.5} is the fine particulate matter less than 2.5 nanometer in diameter which mostly are from open biomass burning, anthropogenic sources, and log-range transportation with about 48%, 27%, and 25% respectively (Yin et al., 2019). Southeast Asia region mostly has experienced severe PM_{2.5} pollution in the dry season, especially in March (Pani et al., 2019). With its ability to penetrate deep into the lungs, PM_{2.5} is a major concern, linked to respiratory illnesses, cardiovascular problems, and even premature death. The finding from N. Nguyen et al. (2022) shows that the highest estimated number of mortalities due to short-term exposure to PM_{2.5} is in Myanmar with 3,152 cases, followed by Thailand with 1,045 cases. PM_{2.5} not only impact on the health but also on economics, which Thailand is the highest impact on economic with 4.14 billion dollars.

Carbon dioxide, a primary greenhouse gas, contributes to climate change. The energy industry in Southeast Asia region is major contributor to carbon dioxide emission with accounting for more than 60% of total emission, followed by the industrial sector with 20% of total emission. Carbon dioxide emission in Southeast Asia region tend to increase continuously up to 2030 (ASEAN Secretariat, 2023). The research from Zaekhan and Nachrowi (2015) shows that Gross Domestic Production per capita can increase carbon emission significantly which is driven by increases in fossil fuel consumption.

Nitrogen dioxide, another potent greenhouse gas, is one of the most critical gaseous pollutants that affects the regional and global air quality, health, and climate change (Wang et al., 2021). Nitrous oxide can fade the fabrics and be harmful to vegetation and crops since it has been found to decrease crop production and plant growth efficiency (Chen et al.,2007). Moreover, the combination of sulfur dioxide and nitrogen dioxide can provide acid rain and also damages the ozone layer.

Foreign Direct Investment and air pollution theory

The relationship between FDI and air pollution is complex with the suggestion from some studies that FDI can reduce pollution while others suggest it can increase emission. Many studies explained the relationship between FDI and environmental pollution in developing countries by the Pollution Haven and Pollution Halo hypothesis (Copeland and Taylor,1994). According to Pollution Haven hypothesis, the level of economic growth will lead to an increase in environmental pollution. Therefore, FDI has positive impact on increase in pollution because foreign companies tend to shift production to developing countries where environmental constraint is less strict. The reason is that these foreign companies need to decrease the cost of fulfilling with environmental requirements, reducing production cost. There are many studies whose results align with this hypothesis. The study by Nasir et al. (2019) and Shabir et.al (2022) shows that FDI can increase carbon emission in five ASEAN countries. These results are also aligned with the study of impact of FDI on carbon emission in Southeast Asia countries. (Nguyen et al.,2023). In the other hand, Pollution halo hypothesis shows that FDI can reduce the environmental pollution by using advanced environmentally friendly technologies and production procedures to host countries. The study by Zhu et al. (2016) showed that FDI has positive effect on reducing carbon emission in Indonesia, Malaysia, Singapore, Philippines, and Thailand. Additionally, the findings from Shabir et al. also shows that FDI can decrease carbon emission in Singapore. There were a study shows that the Pollution Haven hypothesis only worked in developing countries, while the Pollution Halo hypothesis works in developed countries. (Zakia B. et al. 2021)

Beside Pollution haven and halo hypothesis, Environmental Kuznets Curve (EKC) is also another hypothesis that widespread used. (Grossman and Krueger, 1995) This hypothesis suggests that economic development and environmental degradation have an inverted U-shaped relationship. It explains that environmental degradation increases in the early stages of economic growth, while decrease as income rises and countries become more aware of environmental problems. There are plenty of researchers validated between economic development and carbon emission. The result from Arif G. (2020) shows that the increase of FDI have positive effect on environmental pollution in ASEAN-5 countries (Indonesia, Thailand, Malaysia, Philippines, and Singapore). This study also found that there is an inverted U-shaped relationship in income and carbon emission which validate the existence of the EKC hypothesis. Moreover, the study from Apergis and Ozturk (2014) shows that their finding supports the EKC hypothesis which found the inverted U-shape association between pollution emission and income per capita

previous studies in Southeast Asia region

The Table 1 shows research in the latest decade that discuss the relationship between FDI and Air pollution in Southeast Asia region. The research by Nguyen et al, (2023) using a two-step general method of moments (GMM) shows that FDI has a positive effect in increasing the level of Carbon emissions. This method is widely used in studies which examine dynamic relationships in panel data. GMM is made to address endogeneity by using lagged variables as instruments, enabling it suitable for models where independent variables and lagged dependent variables may be correlated with the error term. However, GMM assumes cross-sectional independence, which can be a limitation when analyzing regional phenomena such as air pollution. Additionally, while GMM focuses in dynamic effects, it may not fully capture long-term equilibrium relationships, which are essential to understand the impact of FDI on air pollution. Related to other air pollutant emission, the study from Lu Liu et al. (2024) also showed that the air pollution caused by receiving foreign industrial sector in Southeast Asian developing countries increased unsteadily from 1990 to 2018.

In the other research with different method, the research from Sitthavanh and Srithilat (2022) who used the Pedronic Cointegration approach and the Panel Vector Error Correction Model by using Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) found the same result as the study from Y. Nguyen et al. (2023). However, research by Zhu et al. (2016) which used fixed effect panel quantile regression shows that FDI can have a positive impact on reducing CO2 level in ASEAN-5. These approaches are specifically made for panel time series data, suitable for identifying long-term relationships among variables

Because most studies focus on FDI and carbon emission which, in fact, there were another air pollutants that can affect climate change and human health such as PM2.5 or Nitrogen dioxide. And in the last decade, several research consider some countries of Southeast Asia countries as samples. Lastly, there have not been many studies on Southeast Asia countries studying about FDI and air pollutant on short and long run. Thus, this study uses the Pool Mean Group-Autoregressive Distributed Lag (PMG-ARDL) approach. The PMG-ARDL model explicitly incorporates both short-run and long-run components for panel data, making it well-suited for analyzing the dynamic adjustment process.

Reference	Countries	Method	Variable	Control	Hypothesis supports
Zhu et al. (2016)	ASEAN-5	Fixed effect panel quantile regression	CO ₂ , energy consumption, GDP, FDI	Trade openness, population size, industrial structure, and financial development	Pollution Halo Hypothesis
Nasir et al. (2019)	ASEAN-5	DOLS and FMOLS	CO ₂ , GDP, FDI, Bank	Number of companies	Pollution

Sitthivanh and Srithilat (2022)	ASEAN-9	FMOLS and DOLS	credit, and company CO ₂ and FDI	Fuel consumption, GDP, and population	Haven Hypothesis
Shabir et al. (2022)	ASEAN-5	Nonlinear Autoregressive Distributive Lag model (NARDL)	CO ₂ , transportation energy consumption and FDI	GDP	Pollution Haven Hypothesis
Lu Liu et al., (2024)	ASEAN-8	Pooled Ordinary Least Square (POLS), FMOLS, and DOLS	GDP, FDI, population, Total factor productivity, human capital index, number of persons engaged, Gross industrial output	Linear regression	Pollution Haven Hypothesis
Nguyen et al. (2023)	ASEAN countries	GMM	CO ₂ and FDI	Industry, urbanization, domestic investment, trade openness, energy consumption, infrastructure, and GDP	Pollution Haven Hypothesis
Ahmad F. et al. (2024)	5 highest FDI in ASEAN countries	Autoregressive Distributive Lag model (ARDL)	CO ₂ and FDI	GDP, industrial structure, trade openness, Renewable energy	Pollution Haven Hypothesis

Table 1 previous studies about impact of FDI on air pollution in Southeast Asia region

METHODOLOGY

Data

This study aims to examine the impact of Foreign Direct Investment (FDI) on air pollution measures which are Particle matter (PM 2.5), carbon dioxide (CO₂), and Nitrous oxide (NO₂). The study area is countries in Southeast Asia region except Myanmar and Brunei Darussalam because of limitation of data. However, Myanmar and Brunei Darussalam have low foreign direct investment in southeast Asian countries, so it makes not much impact for analyzing in region level. Besides usage of two variables, FDI and CO₂, this study also considers four control variables which are GDP, Trade Open, and Industrial structure, following the study from Ahmad F. et al. (2024). The observation period spans for the last 20 years, from 2004 to 2023. The data were all obtained from the World Development Bank. This research was conducted in quantitative method, relying on secondary data sources.

Variables

The main focus of this research is on the impact of FDI on air pollution. In this study, the role of FDI is independent variable, and air pollution as dependent variable, while others are control variable. Each of variables were standardized by transforming into a natural logarithm form to induce stability in covariance-variance matrices (Fatai et al., 2004). The detail of variables is explained in Table 2

Variable	Definition	Source
CO2	Carbon dioxide emission (metric tons per capita)	World development Bank
PM2.5	Fine particle or PM 2.5 (metric tons)	World development Bank
NO2	Nitrous oxide (metric tons)	World development Bank
FDI	Net foreign direct investment, net inflows (% of GDP)	World development Bank
GDP	Gross domestic Product per capita	World development Bank
Trade	Trade openness (% of GDP)	World development Bank

POP	Total Population	World development Bank
RNW	Renewable energy consumption on total final consumption (% of total final energy consumption)	World development Bank
INDUS	Industrial structure (the share of the tertiary industry sector in GDP)	World development Bank

Table 2 The detail of variables

Method

In this study, the investigation was conducted by applied the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) method. This model is a statistical method that can simultaneously estimate short-run and long-run in panel data. Before using this method, it is required to test unit root or integration at either the level I(0) or the first difference I(1) level (Bui Minh et al.,2023) to check long term association. Integrating the unit root test allows to avoid the endogeneity problem (Peseran and Shin,1999). This study conducts the unit root test by using the Augmented Dickey -Fuller (ADF) and Phillips-Perron (PP) tests (Park and Fuller, 1995) which these tests show stationarity of each variable. Stationary indicates the trend or time serious that has a constant mean and bounded variance. Stationarity is critical because non-stationary data can provide superior regression result.

Within the PMG-ARDL approach, the estimation of lag length was conducted by using Akaike Information Criterion (AIC) (Bui Minh et al.,2023).

After determining the optimal lag, both long-run and short-run impact assessments were conducted. Equation (1) shows the formula that use for examining the enduring relationship between air pollution and FDI over the long term

$$AP_{it} = \alpha_{it} + \beta_1 FDI_{it} + \beta_2 GDP_{it} + \beta_3 INDUS_{it} + \beta_4 TRADE_{it} + \beta_5 POP_{it} + \beta_6 RNW_{it} + \xi_{it} \quad (1)$$

Where i and t are country and year. AP is Air pollution index such as Carbon emission per capita (tons per person), Fine Particle (PM2.5), and nitrogen dioxide. FDI is a direct investment in foreign countries, and X is control variables, including GDP per capita, industrial structure, trade openness, and population

RESULTS

Stationarity test

The Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were conducted to assess the stationarity of the variables across different pollution indicators, including carbon dioxide emissions, fine particles, and nitrogen dioxide. The results which show in Table 3 reveal a mix of stationary variables at levels and first differences, justifying the use of the ARDL model to account for both I(0) and I(1) variables in the analysis.

For carbon emissions, GDP, renewable energy, and industrial structure (INDUS) are stationary at their first differences (p=0.05, p=0.01, and p=0.01 respectively), indicating that these variables are I(1). In contrast, FDI, Trade Openness, and population are stationary at levels (p=0.01), classifying them as I(0) variables. A similar pattern is observed for fine particle, where GDP, renewable energy, and industry structure are stationary at first differences (p=0.05, p=0.01, and p=0.01), while FDI, trade openness, and population remain stationary at levels (p=0.01 p = 0.01 p=0.01). For Nitrogen dioxide, all variables, including GDP, renewable energy, industrial structure, FDI, Trade Openness, and population, are stationary at levels (p=0.01, p= 0.05, p=0.01, p = 0.01, p=0.01). This indicates that none of the variables require differencing, suggesting stationarity across all indicators

In summary, GDP is predominantly an I(1) variable, requiring differencing under Carbon emissions, fine particle, and nitrogen dioxide, while Renewable energy and industrial structure also require differencing under certain indicators. FDI, Trade Openness, and population remain stationary at levels across all pollution indicators. These results confirm the appropriateness of the ARDL model for examining long-term relationships and short-term dynamics in the presence of mixed stationarity.

ADF Unit Root Test						
Country	FDI	GDP	RNW	INDUS	TRADE	POP
PM2.5	0.01	0.05*	0.01*	0.01*	0.01	0.01
Carbon emission	0.01	0.05*	0.01*	0.01*	0.01	0.01
Nitrogen dioxide	0.01	0.05	0.01	0.01	0.01	0.01
PP Unit Root Test						
Country	FDI	GDP	RNW	INDUS	TRADE	POP
PM2.5	0.01	0.05*	0.01*	0.01*	0.01*	0.01
Carbon emission	0.01	0.05*	0.01*	0.01*	0.01	0.01
Nitrous oxide	0.01	0.01*	0.01*	0.01*	0.01	0.01

* shows the first difference

Table 3 The P-value of cointegration for each variable by ADF and PP test

Long run and short run result

1. Fine particle

Variables	Coefficient	SE	Z	Probability
Long run				
FDI	0.168159	0.0044645	3.77	0.000
GDP	-0.1942249	0.0328161	-5.92	0.000
RNW	-0.0065247	0.0028222	-2.31	0.021
INDUS	-0.03518	0.0088248	3.99	0.000
TRADE	-0.0010521	0.0010611	-0.99	0.321
Short run				
FDI	0.0210744	0.0055895	3.77	0.000
GDP	0.0770784	0.1979027	0.390	0.697
RNW	0.362684	0.0761529	0.48	0.634
INDUS	0.0222154	0.0197015	1.13	0.259
TRADE	-0.0046676	0.0017633	-2.65	0.008

Table 4 the result of long run and short run on fine particle

The PMG-ARDL analysis reveals significant long-term and short-term relationships between economic indicators and PM2.5 emissions in Southeast Asia. In the long run, FDI shows a significant positive effect (0.168, $p=0.000$), indicating that FDI contributes to increasing PM2.5 emissions which is consistent with Nguyen et al. (2023). Similarly, GDP has a significant negative impact (-0.194 , $p=0.000$), supporting the Environmental Kuznets Curve (EKC) hypothesis that economic growth leads to improved environmental outcomes. Renewable energy use (-0.007 , $p=0.021$) also significantly reduces PM2.5 pollution, while industrial structure (0.035, $p=0.000$) increases it, emphasizing the environmental costs of industrialization. Trade openness, however, has no significant long-term effect (-0.001 , $p=0.321$).

In the short term, FDI has a significant positive effect (0.021, $p=0.000p$), suggesting that it temporarily increases PM2.5 emissions. Trade openness reduces emissions in the short term (-0.0047 , $p=0.008$), likely due to cleaner production standards in traded goods. Other variables, including GDP, renewable energy, and industrial activity, do not show statistically significant short-term effects.



2. Carbon dioxide emission

Variables	Coefficient	SE	Z	Probability
Long run				
FDI	-0.1962248	.0709049	-2.77	0.006
GDP	-0.4102071	.1571395	-2.61	0.009
RNW	-1.425406	.2751966	-5.18	0.000
INDUS	-0.4792797	1.029064	-0.47	0.641
TRADE	-0.0744257	0.4006275	0.19	0.853
POP	3.180536	1.198227	2.65	0.008
Short run				
FDI	-0.0494325	0.0852931	-0.58	0.562
GDP	-0.2644793	1.069304	-0.25	0.805
RNW	-0.53377	0.430508	-1.24	0.214
INDUS	-1.29319	0.9266184	-1.40	0.163
TRADE	0.7854374	0.5706222	1.38	0.169
POP	49.92227	58.8005	0.85	0.396

Table 5 the result of long run and short run on carbon dioxide emission

For carbon dioxide emissions, the long-term results indicate that FDI has a significant negative impact (-0.196 , $p=0.006$), suggesting that foreign investment facilitates the adoption of cleaner technologies. The study from Pata et al. (2022) reveals that the Ministry of Trade and Industry of Singapore launched green economic regulation in 2018, which supports reducing carbon emissions. As same as Vietnam, Foreign investments demonstrate a commitment to enhance environment quality with project infrastructure development (V.T. Nguyen, 2020). GDP also shows a negative long-term relationship (-0.41 , $p=0.009$), aligning with the EKC hypothesis that economic growth eventually reduces emissions. Renewable energy use (-1.425 , $p=0.214$) has the strongest negative effect, underscoring its critical role in mitigating CO2 emissions. Population growth (3.18, $p=0.008$) has a significant positive relationship with CO2 emissions, reflecting the pressure of increasing population on the environment. However, industrial structure (-0.479 , $p=0.641$) and trade openness (-0.074 , $p=0.853$) have no significant long-term impacts. In the short term, none of the variables exhibit significant effects on carbon emissions. This suggests that the determinants of carbon emissions primarily operate through long-term dynamics rather than

immediate changes in economic or energy-related factors.

3. Nitrogen dioxide emission

Variables	Coefficient	SE	Z	Probability
Long run				
FDI	0.0629884	.025912	2.43	0.015
GDP	-0.0172297	.0771192	0.22	0.823
RNW	-0.2399122	.0631599	-3.80	0.000
INDUS	0.6855707	0.2107679	-3.25	0.001
TRADE	-0.0290595	0.1468934	-0.20	0.843
POP	1.494919	0.568976	2.63	0.009
Short run				
FDI	-0.0189941	0.733218	0.26	0.796
GDP	-0.7395008	0.4285637	-1.73	0.084
RNW	-0.9789101	0.6782329	-1.44	0.148
INDUS	-0.0844751	0.4929607	-0.17	0.864
TRADE	0.2816669	0.3052959	0.92	0.356
POP	2.544256	12.48417	0.20	0.839

Table 6 the result of long run and short run on nitrous dioxide emission

The long-term results for nitrogen dioxide emissions show a mixed pattern. FDI has a significant positive relationship (0.063, p=0.015), indicating that foreign investments increase nitrogen dioxide emissions, potentially due to industrial activities. Renewable energy use (-0.240, p=0.000) significantly reduce nitrogen dioxide emissions, suggesting that cleaner energy is being adopted. Population growth (1.495, p=0.009) and industrial structure (0.686, p=0.001) both contributes positively to nitrogen dioxide emissions which align with the study from Dominick et al.(2012) shows that nitrogen dioxide can be high in industrial and urban environment due to the burning of fossil fuels, while GDP (-0.017, p=0.823) and trade openness (-0.029, p=0.843) show no significant long-term impacts. In the short term, none of the variables show significant effects on NO2 emissions. This implies that the dynamics influencing nitrogen dioxide emissions require sustained changes over time to display in measurable outcomes.

The statistically insignificant short-run effect at the regional level in the PMG-ARDL analysis suggests that the relationship between FDI and air pollution may exhibit significant heterogeneity varying levels of economic development, different environmental regulation and enforcement, and distinct industrial structure across the region.

Robustness test

Variable	Fine Particle		Carbon dioxide		Nitrogen dioxide	
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic
FDI	0.94	2.91	-0.01	2.12	0.03	2.47
GDP	-0.00	-28	-0.00	2.06	-0.00	32.17
RNW	-1.26	-16.20	-0.23	-44.10	-0.12	-46.65
INDUS	0.84	27.32	-0.03	9.15	0.02	-21.92
TRADE	0.00	1.54	-0.00	1.28	0.00	1.32
POP	0.00	6.99	0.00	1.43	0.00	2.98

Table 7 shows the result of robustness test

The FMOLS results largely validate the findings from the PMG-ARDL analysis which is suitable for estimating heterogeneous cointegration in panel data (Hamit- Hagggar, 2012), demonstrating the robustness of the long-term relationships between economic factors and pollution indicators across Southeast Asia. For fine particle emissions (PM2.5), FDI has a positive and significant effect ($\beta=0.94$, $t=2.91$), aligning with the pollution haven hypothesis that foreign investments contribute to pollution-intensive industrial activities. GDP growth exhibits a negative and highly significant impact ($\beta=-0.00$, $t=-28.00$), supporting the Environmental Kuznets Curve (EKC) hypothesis that economic growth reduces emissions through improved technologies and stricter regulations (Grossman and Krueger, 1995). Renewable energy use ($\beta=-1.26$, $t=-16.20$) strongly mitigates PM2.5 emissions, while industrial activity ($\beta=0.84$, $t=27.32$) and population growth ($\beta=0.00$, $t=6.99$) increase pollution, consistent with PMG-ARDL results.

For carbon dioxide emissions, FDI has a slight but negative effect ($\beta=-0.01$, $t=2.12$), indicating that foreign investments contribute to reducing emissions, though to a lesser extent than for PM2.5. GDP growth also has a negative and significant impact ($\beta=-0.00$, $t=2.06$), suggesting potential variability in the effects of economic growth on carbon dioxide emissions. Renewable energy ($\beta=-0.23$, $t=-44.10$) remains a critical factor in reducing emissions, while industrial activity ($\beta=-0.03$, $t=9.15$) significantly increase CO2 emissions, confirming their robustness across models.

For Nitrogen dioxide emissions, FDI ($\beta=0.03$, $t=2.47$) significantly increases pollution, reinforcing the pollution haven hypothesis. GDP growth reduces emissions ($\beta=-0.00$, $t=32.17$), consistent with the EKC hypothesis, while renewable energy ($\beta=-0.12$, $t=-46.65$) strongly mitigates nitrogen dioxide emissions. Industrial activity ($\beta=0.02$, $t=-21.92$) shows limited significance, while population growth ($\beta=0.00$, $t=2.98$) exhibits a slight increasing effect on nitrogen dioxide emissions, similar to the PMG-ARDL results.

Overall, the FMOLS results align closely with the PMG-ARDL findings, particularly for the effects of renewable energy, industrial activity, and FDI on pollution indicators. Minor discrepancies, such as the effect of GDP on CO2 emissions and population on NO2, suggest areas

for further exploration. These results reinforce the critical role of renewable energy in mitigating pollution and highlight the environmental costs of industrialization and population growth. The findings underscore the importance of policies that promote sustainable foreign investments and cleaner industrial practices.

Conclusion

This study examines the impact of foreign direct investment (FDI), economic growth, renewable energy, industrial activity, trade openness, and population on various environmental pollutants in Southeast Asia, including fine particles (PM_{2.5}), carbon emissions, and nitrogen dioxide emissions. Using PMG-ARDL and FMOLS models, the findings highlight both long-term and short-term dynamics, with significant implications for regional sustainability policies. The results reveal that FDI contributes to increased pollution in the region, as evidenced by its positive long-term relationship with PM_{2.5} and NO₂ emissions, supporting the pollution haven hypothesis. However, its impact on CO₂ emissions appears more significant, with smaller effects observed.

Economic growth shows mixed environmental outcomes. While GDP growth reduces fine particle and NO₂ emissions in the long term, consistent with the Environmental Kuznets Curve (EKC) hypothesis, it increases carbon emissions in some models, focusing on the varying environmental consequences of economic expansion. Renewable energy plays a crucial role in mitigating pollution, demonstrating significant negative effects across all pollutants studied. This finding underscores the need for greater investment in clean energy technologies to achieve sustainable development goals.

Industrial structure remains a key contributor to environmental degradation, showing consistent positive relationships with all pollutants, particularly fine particles and carbon emissions. Trade openness and population growth exhibit less consistent effects, with population generally increasing emissions, while the impact of trade depends on the pollutant studied and the model used. The short-run analyses reveal that immediate effects vary significantly across countries, emphasizing the importance of tailored policies that account for country-specific dynamics.

Overall, the study underscores the critical role of renewable energy and environmental regulations in mitigating the adverse effects of FDI and industrial activity on pollution. Policymakers should prioritize cleaner industrial practices, enforce stricter environmental standards for foreign investments, and promote sustainable economic growth strategies. By addressing these key factors, Southeast Asia can balance economic development with environmental preservation, fostering long-term sustainability.

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