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ĐẦU TƯ PPP TRONG LĨNH VỰC NĂNG LƯỢNG VÀ TÁC ĐỘNG CỦA NÓ ĐẾN PHÁT THẢI CO_2: BẰNG CHỨNG THỰC NGHIỆM TẠI MỘT SỐ QUỐC GIA ĐANG PHÁT TRIỂN VÀ HÀM Ý ĐỐI VỚI VIỆT NAM

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Tóm tắt

Nghiên cứu này xem xét tác động của đầu tư theo hình thức Hợp tác Công - Tư (PPP) trong lĩnh vực năng lượng đến phát thải CO_2 tại các quốc gia đang phát triển, sử dụng bộ dữ liệu bảng của 20 quốc gia trong giai đoạn 2001-2023. Bằng cách áp dụng mô hình Panel ARDL với ước lượng Pooled Mean Group (PMG), nghiên cứu phân tích đồng thời các tác động trong ngắn hạn và dài hạn, đồng thời kiểm soát các yếu tố như năng lượng tái tạo, chất lượng thể chế/quản lý nhà nước, tăng trưởng kinh tế, đầu tư trực tiếp nước ngoài (FDI) và cường độ năng lượng. Kết quả cho thấy đầu tư PPP có tác động hai chiều đối với phát thải CO_2: trong ngắn hạn, PPP giúp giảm phát thải, có thể nhờ vào hiệu quả từ cải tiến công nghệ và quản lý dự án tốt hơn; tuy nhiên, trong dài hạn, PPP lại làm gia tăng phát thải, phù hợp với lý thuyết "hiệu ứng bật lại" (rebound effect) và sự mở rộng nhu cầu năng lượng. Hệ số hiệu chỉnh sai số cho thấy tồn

tại mối quan hệ cân bằng dài hạn ổn định giữa các biến trong mô hình. Những phát hiện này hàm ý rằng tác động môi trường của đầu tư PPP phụ thuộc đáng kể vào cơ cấu năng lượng và môi trường chính sách. Do đó, cần định hướng các dự án PPP vào lĩnh vực năng lượng tái tạo và tăng cường chất lượng thể chế nhằm đạt được mục tiêu phát triển bền vững tại các nền kinh tế đang phát triển.

Từ khoá: Hợp tác công tư, Năng lượng, Phát thải CO2

PPP INVESTMENT IN THE ENERGY SECTOR AND ITS IMPACT ON CO2 EMISSION: EMPIRICAL EVIDENCE IN SELECTED DEVELOPING COUNTRIES AND IMPLICATIONS FOR VIETNAM

Abstract

This study investigates the impact of Public-Private Partnership (PPP) investment in the energy sector on CO_2 emissions in developing countries using a panel dataset of 20 countries from 2001 to 2023. Employing a Panel ARDL model with the Pooled Mean Group (PMG) estimator, the analysis captures both short-run and long-run dynamics while controlling for renewable energy, regulatory quality, economic growth, FDI, and energy intensity. The results indicate a dual effect of PPP investment: it reduces CO_2 emissions in the short run, likely due to efficiency gains of technology improvement and improved project management, but increases emissions in the long run, consistent with the rebound effect and the expansion of energy demand. The error correction term confirms a stable long-run equilibrium relationship among the variables. These findings suggest that the environmental impact of PPP investment depends critically on the energy mix and policy environment, highlighting the importance of directing PPP projects toward renewable energy and strengthening institutional quality to achieve sustainable development outcomes in developing economies.

Keywords: Public-Private Partnership, Energy, CO_2 emissions

1. Introduction

Urbanization and industrialization in developing countries have put heavy stress on carbon emissions. A high concentration of anthropogenic greenhouse gas, i.e., CO_2, correlates strongly with global warming and climate change (Yoro and Daramola, 2020). This means that as CO_2 emissions keep rising, the global temperature, in turn, rises as well. The Paris Climate Agreement has set out the 1.5-degree Celcius threshold for all nations to follow (UNFCCC, 2015). This joint effort is a result of previous literature, where scientists pointed out that such

a limit would cause an irreversible change to the global climate. However, as the United Nations (2025) already documented, the global temperature has passed the 1.5-degree threshold in a month to a year, which is an early sign of a perilous future, with the globe being dangerously close to exceeding it in the long term. Especially for developing countries, whose economies typically have a significant ratio of the industry sector, the issue of carbon emissions becomes exceedingly important. Alongside the problem of carbon emissions, developing the energy sector is also a concern. The energy sector fuels every activity in the economy; yet, the energy sector is also a contributor to carbon emissions both directly and indirectly.

The Private Public Partnership (PPP) investment is a prevalent tool to foster growth for the energy sector in developing countries. The method is highly suitable for these countries in the fact that it mitigates risk, while also maximizing funds for the project. Both parties, Public and Private, can share risks regarding construction, operation, and implementation of these projects (Grasman, Faulin and Lera-López, 2013). At the same time, the private can be a more productive investor than the public, which requires time-consuming bureaucratic processes for investments to come to fruition.

However, PPP investments in the energy sector are traditionally associated with fossil fuels, leading to much conflicting research on the environmental effects of PPP investment in energy. Some prior literature presents the argument that PPP investment harms the environment by emitting more CO_2 (Kirikkaleli, Ali and Altuntaş, 2022; Shahbaz *et al.*, 2020). In contrast, several other studies argue that the impact is positive, or at least ambiguous, citing the recent adoption of renewable energy for PPP investments (Raghutla *et al.*, 2024; Ahmad and Raza, 2020).

Vietnam, as a developing country, is not distant from this trend. The country possesses one of the highest energy capacities in the region, and a booming economy that indubitably requires an immense level of energy. The Vietnamese government has set guidelines for developing PPP projects, especially for the energy sector. Yet, this form of investment is relatively new in the country, all of these issues have given the research team reason to investigate deeper into the impact of PPP investments in energy on carbon emissions in the developing world, and, in turn, the team can provide some policy recommendations for Vietnam.

The remainder of this paper is structured as follows. Section 2 reviews the relevant literature and establishes the theoretical framework. Section 3 outlines the empirical methodology and describes the dataset. Section 4 presents and discusses the empirical findings, while Section 5 provides policy implications. Finally, Section 6 concludes the study.

2. Literature review and theoretical background

2.1 Literature review

Empirical findings on the environmental impact of energy-sector PPP investments are heterogeneous. First, it is important to note that purely short-run analyses are relatively rare, as most empirical studies estimate both short-run and long-run dynamics simultaneously. Within this context, some evidence suggests that PPP investment may reduce emissions in the short term. For instance, Ahmad and Raza (2020) find that PPP investment in the energy sector is associated with lower CO2 emissions in the short run in Brazil. Similarly, Kumar and Soriya (2026), using a quantile ARDL framework, report that PPP investment contributes to emission reductions in the short run, particularly at higher emission levels. These findings imply that PPP projects may generate immediate environmental benefits, possibly due to efficiency improvements or the initial adoption of cleaner technologies.

Second, a substantial body of literature focuses on the long-run impact of PPP investment in the energy sector on CO2 emissions, although the findings remain inconclusive. On the one hand, several studies report that PPP investment contributes to higher emissions over time. Udeagha and Ngepah (2023), examining South Africa, find that PPPs are associated with increased CO2 emissions. Similar evidence is provided by Caglar et al. (2022) for BRICS economies, as well as by Khan Z. et al. (2020), Shahbaz et al. (2020), and Cheng et al. (2021) in the context of China, all of which document a positive long-run relationship between PPP-related activities and emissions. In addition, the Granger-causality framework of Breitung and Candelon (2006) identifies significant medium-term effects, which can be interpreted as supporting the presence of long-run dynamics. On the other hand, some studies suggest that PPP investment may improve environmental quality in the long run. Raghutla et al. (2024), using FMOLS and DOLS for six developing countries, find that PPP investment facilitates the transfer of cleaner technologies, thereby reducing CO2 emissions. Likewise, Shahbaz et al. (2018) show that PPP-related activities, proxied by research and development, contribute to lower emissions in France. These contrasting findings indicate that the long-run environmental impact of PPP investment depends on factors such as technological progress, energy composition, and policy frameworks.

Third, an emerging strand of literature simultaneously examines both short-run and long-run dynamics, highlighting heterogeneous and non-linear relationships between PPP

investment and CO2 emissions. Ahmad and Raza (2020) provide clear evidence of this pattern, showing that PPP investment reduces emissions in the short run but increases emissions in the long run, suggesting a reversal effect over time. Similarly, Kumar and Soriya (2026) find that the impact of PPP investment varies across emission levels, with short-run reductions observed only at higher quantiles and no significant long-run effect. Udeagha and Ngepah (2023) further indicate that PPP investment may increase emissions across both time horizons, depending on the structure and composition of projects.

In addition, Raza et al. (2021), using a nonparametric causality-in-quantiles approach, demonstrate that the relationship between PPP investment and CO2 emissions is inherently non-linear and cannot be fully captured by conventional linear models. Their findings suggest that the impact of PPP investment differs across emission distributions and may only become significant under certain conditions.

In conclusion, this strand of literature suggests that the environmental impact of PPP investment is highly context-dependent. Differences in time horizon, emission levels, and methodological approaches may explain why previous empirical studies often report mixed or inconclusive results.

Previous literature presents three primary gaps regarding the nexus between PPP energy investment and CO_2 emissions. First, empirical findings remain inconclusive, with studies showing both positive (Kirikkaleli *et al.*, 2022; Shahbaz *et al.*, 2020) and negative (Raghutla *et al.*, 2024) impacts, or varying effects across emission quantiles (Guoyan *et al.*, 2023). Second, a spatial gap exists, as most research focuses on singular countries rather than a broader developing-world outlook. Finally, there is a temporal neglect of short-term impacts; while projects take decades to mature (Grasman *et al.*, 2013), their construction and initial operation phases leave immediate environmental footprints. This study addresses these gaps by employing Panel ARDL estimation to clarify both short- and long-term dynamics.

2.2 Theoretical background

The relationship between PPP investment and CO_2 emissions is based on three theoretical foundations. First, according to agency theory in traditional and PPP investment developed by Mollisi (2022), PPP improves productivity by solving moral hazard. Second, Kaya Identity (Kaya and Keiichi Yokobori, 1997) suggests that higher productivity in the energy sector lowers carbon intensity, thereby reducing CO_2 emissions. Finally, Jevons Paradox indicates that

productivity gains can also lower costs and increase demand, potentially leading to higher emissions through the rebound effect.

2.2.1. Agency theory in traditional and PPP investment

The agency theory in investment by Mollisi (2022) suggest that PPP investment enhances productivity in infrastructure projects by mitigating moral hazard problems arising from the separation between construction and operation phases.

In this framework, total operating costs depend on demand, capital quality, and operational effort, which can be formally represented as:

$$C = C(ED, a, e)$$

where a denotes capital quality and e represents operational effort. Both variables contribute to cost reduction.

Under traditional procurement, the builder and the operator are contracted separately, leading to misaligned incentives. The builder determines the level of capital quality a by maximizing:

$$\max \pi_B = \tau_B - g(a)$$

where τ_B is a fixed payment and g(a) represents the cost of investing in higher quality. Although higher capital quality reduces future operating costs, the builder bears the full investment cost without gaining these benefits, so they choose the minimum quality level, leading to underinvestment and inefficiency.

Moreover, due to information asymmetry, the builder does not observe the operator's cost function, which reinforces the moral hazard problem. Following construction, the operator chooses the level of effort e to maximize:

$$\max \pi_o = \tau_o + \gamma_O R_O - C(ED, a, e) - z(e)$$

After construction, the operator can exert effort e to reduce operating costs, but their ability to do so is constrained by the low level of capital quality inherited from the construction phase. This sequential and uncoordinated decision-making process.

In contrast, PPP arrangements bundle construction and operation within a single consortium, a special contract. This organizational structure allows the consortium to internalize the technological relationship between capital quality a and operational effort e.

$$\max \pi_{PPP} = \tau_C + \gamma_C R_C - C(ED, a, e) - z(e) - g(a)$$

Therefore, the consortium jointly optimizes both variables, leading to higher investment in capital quality and a more efficient allocation of effort, ultimately improving overall productivity. (Mollisi, 2022)

2.2.2. Kaya indentity

Alternatively, the productivity can affect the total carbon emission through reducing carbon intensity. The Kaya identity, proposed by Japanese energy economist Yoichi Kaya, is an accounting relationship that links CO_2 emissions to the key factors underlying human activity. It can also be used as a conceptual framework to structure discussions of the main drivers of CO_2 emissions (Liu, Feng, and Yang, 2011). The identity can be written as:

$$CO_2 = \frac{GDP}{Population} \times Population \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy}$$

CO2 emission can be affected by income, population, energy intensity and carbon intensity. In energy sector, the increase in productivity will reduce the CO2 emission per unit of energy generated (Sims et al., 2007). Therefore, with the same demand of energy and keep other factors remains, an increase in productivity in energy sector will decline the overall CO2 emission in operating proccess by reducing carbon intensity.

Hypothesis 1: PPP investment in energy correlates negatively with CO2 emissions in the short term

2.2.3 Jevons' paradox and rebound effect

Although PPP investment will reduce CO2 emission by improving productivity, the impact on absolute emissions also depends on the response of production scale and energy demand. According to Jevons' paradox and the rebound effect, improving efficiency through technology, while potentially reducing energy input per unit of output, can still lead to increased emissions if it stimulates expanded energy use. Alcott (2005) argues that technological progress and efficiency improvements not only reduce the energy required per unit of output but also reduce the effective price of energy services; as service costs decrease, the profitability of energy-using activities increases, the market expands, and demand increases. Therefore, "technical savings" only exist if demand remains constant. In reality, when demand is positively elastic and latent demand exists, energy use can increase again, partially or fully offsetting the savings and even exceeding the initial level. Furthermore, the rebound effect can spread beyond the

directly improved area because the cost savings are channeled into additional consumption and investment in other sectors, increasing total resource consumption and emissions at the economy-wide level. In summary, these partnerships can create operational improvements and reduce waste in the short term, but by lowering costs and loosening energy constraints, they can also expand economic activity and energy demand in the long term; therefore, net emissions may increase if the carbon intensity of the energy system does not decrease correspondingly. (Alcott, 2005).

Hypothesis 2: PPP investment in energy correlates with CO2 emissions in the long term

3. Research model

3.1 Model

Based on the theoretical foundation of the IPAT, EKC, Kaya Identity, and previous studies by Tamazian, Chousa and Vadlamannati (2009), Porter Hypothesis, Balogh and Jambor (2017), Sarfraz *et al.* (2021), we propose the panel ARDL as follows:

$$\begin{aligned}\Delta CO2t = \beta_c + \beta_0\, lnCO2_{t-1} + \beta_1\, lnPPP_{t-1} + \beta_2\, lnREN_{t-1} + \beta_3\, lnRQ_{t-1} \\ + \beta_4\, lnGDP_{t-1} + \beta_5\, lnFDI_{t-1} + \beta_6\, lnINTEN_{t-1} + \beta_7\, COVID \\ + \beta_8 \sum_{i=0}^{k} \Delta CO2_{t-i} + \beta_9 \sum_{i=0}^{k} \Delta PPP_{t-i} + \beta_{10} \sum_{i=0}^{k} \Delta REN_{t-i} + \beta_{11} \sum_{i=0}^{k} \Delta lnRQ_{t-i} \\ + \beta_{12} \sum_{i=0}^{k} \Delta GDP_{t-i} + \beta_{13} \sum_{i=0}^{k} \Delta FDI_{t-i} + \beta_{14} \sum_{i=0}^{k} \Delta INTEN_{t-i} + \varepsilon_i\end{aligned}$$

Specifically, CO_2 represents carbon dioxide emissions, PPP is the Public-Private Partnership investment in energy, REN is renewable energy, RQ is regulatory quality, GDP is GDP per capita, FDI is foreign direct investment, INTEN is the level of energy intensity, and COVID is the dummy variable representing the COVID-19 shock from 2020 to 2022. Furthermore, natural logarithmic forms are used, denoted by ln.

Although the Environmental Kuznets Curve (EKC) usually includes a squared income term to test the inverted U-shape, this study excludes it. The sample mainly includes developing countries that have not yet reached the EKC turning point, where economic growth still increases CO_2 emissions. Therefore, the nonlinear relationship may not appear. To better fit the

sample and keep the model simple, only the logarithm of GDP (lnGDP) is used without the squared term.

Next, t is the error term, while β_i (i=7) are the coefficients. The prefix Δ represents the first-level difference operator of the corresponding variables. The ECT is the error correction term, which reflects the speed of adjustment towards the long-run equilibrium, and it is calculated with the following model:

$$ECT_{i,t-1} = \beta_0 + \beta_1\, lnPPP_{i,t} + \beta_2\, lnREN_{i,t} + \beta_3\, lnRQ_{i,t} + \beta_4\, lnGDP_{i,t} + \beta_5\, lnFDI_{i,t} + \beta_6\, lnINTEN_{i,t} + \beta_7\, COVID + \varepsilon_i$$

3.2 Variable description and data source

The study gathers data from 20 developing countries (Appendix A) over the span of 23 years, from 2001 to 2023; data are extracted from the World Development Indicators (WDI) with the exception is the variable COVID, which is a dummy variable created by the research team. The period 2001-2023 is chosen because PPPs expanded significantly during this time, especially in developing countries, ensuring more reliable data. It also captures rising CO_2 emissions alongside economic growth and includes key policy and technological changes, making it suitable to assess the impact of PPP on emissions. All the descriptions for these variables are summarized in the following table:

Table 1: Description of variables

Variable	Symbol	Measurement	Expected sign	Theoretical background	Source
CO_2 emissions	CO2	CO2e/capita			WDI
PPP investment in energy	PPP	current US$	(-) in the short run (-/+) in the long run	Kaya identity; EKC hypothesis	WDI
Renewable energy	REN	% of total final energy consumption	(-) both in the long and short run	Balogh and Jambor, 2017	WDI

Regulatory quality	RQ	Percentile Rank	(-) in the long run	Porter Hypothesis	WDI
Economic growth	GDP	constant 2015 US$ per capita	(+) in both the long and short run	Kaya identity	WDI
Foreign direct investment	FDI	% of GDP	(+) in the long run	Tamazian, Chousa and Vadlamannati, 2009	WDI
Energy intensity	INTEN	MJ/$2021 PPP GDP	(+) in both the long and short run	Kaya identity	WDI
COVID	COVID	Dummy variable (2020-2022)	(-) in the short run	Sarfraz *et al.*, 2021	Authors' compilation

Source: Compilation by Author

3.3 Statistical description and correlation matrix

Table 2: Statistical description

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
lnCO2	425	.502	1.2	-2.747	2.605
lnPPP	425	19.825	2.287	3.278	24.32
lnREN	425	3.225	.914	.693	4.56
lnRQ	425	3.699	.441	2.06	4.337
lnGDP	425	8.153	.919	6.305	9.597
lnFDI	425	.636	.901	-4.837	2.42
lnINTEN	425	1.434	.428	.642	2.576

Source: Compilation by Author

Table 2 presents the descriptive statistics of the variables used in the model, based on 425 observations. Overall, the variables exhibit considerable variation across countries, as reflected in their standard deviations and ranges. In particular, lnPPP shows the largest dispersion, indicating substantial differences in Public-Private Partnership investment in the energy sector among developing countries. Similarly, $lnCO_2$ emissions vary notably, with values ranging from -2.747 to 2.605, suggesting heterogeneous environmental conditions across the sample.

Table 3: Correlation Matrix

Variables	**lnCO2**	**lnPPP**	**lnREN**	**lnRQ**	**lnGDP**	**lnFDI**	**lnINTEN**
lnCO2	1.000						
lnPPP	0.249	1.000					
lnREN	-0.864	-0.073	1.000				
lnRQ	0.392	-0.012	-0.345	1.000			
lnGDP	0.869	0.173	-0.773	0.504	1.000		
lnFDI	0.272	0.092	-0.154	0.274	0.298	1.000	
lnINTEN	-0.041	-0.031	-0.019	0.019	-0.225	0.027	1.000

Source: Compilation by Author

The correlation matrix indicates that even those there are some correlations above 0.8 (lnREN-lnCO2; lnGDP-lnCO2), suggest multicollinearity. However, the pairwise correlations among the variables are generally below 0.9, suggesting that multicollinearity is not a serious concern.

4. Model estimation and results discussion

4.1 Model estimation

4.1.1 Model selection

By using Hausman test (see Appendix B), the most suitable estimator (MG/PMG/DFE) is selected. For MG and PMG, the p-value is 0.635. Therefore, the null hypothesis is not rejected, and PMG is preferred to MG. For PMG and DFE, the p-value is 1.000. This means the test does

not reject the restrictions imposed by DFE. However, model selection in this study is primarily guided by the economic characteristics of the dataset rather than purely frequentist tests.

The PMG estimator is selected as the primary model for several reasons. First, the 20 developing countries in our sample exhibit significant short-run heterogeneity due to varying project cycles, bureaucratic efficiency, and immediate policy responses to energy shocks. Conversely, these nations are expected to share a common long-run equilibrium driven by global technological diffusion and international climate commitments. While DFE is statistically supported, it is overly restrictive as it forces homogeneity on short-run adjustment speeds, which is theoretically implausible for a diverse panel of developing economies. Thus, PMG offers the optimal balance between consistency and flexibility.(The result of those test can be seen in Appendix B)

VIF test (see Appendix B). The result points out that the VIF values range from 1.06 to 3.99 with a mean VIF of 1.97, which is well below the commonly accepted threshold of 10.

Cross-sectional dependence test (see Appendix B). The Pesaran (2015) CD test shows that the null hypothesis of weak cross-sectional dependence is rejected for most variables at the 5% level, indicating common cross-country influences and that first-generation methods may not be sufficient on their own. Thus, the study also applies a second-generation panel ARDL approach, namely CS-ARDL, as a robustness check.

The stationarity properties examination (see Appendix B). The CADF test show that all variables are integrated of order I(0) or I(1), and none is I(2). This is consistent with the requirements of the PMG and MG estimators developed by Pesaran, Shin, and Smith (1999) so the integration orders are appropriate for estimating a panel ARDL model.

Panel cointegration tests.(see Appendix B). all Kao and Pedroni test reject the null hypothesis at the 5% level. Overall, the evidence supports the existence of cointegration.

Thus, the model suffers from cross-sectional dependence, cointergration and has all variables are integrated of order I(0) or I(1). The PMG estimator is employed and, CS-ARDL (second-generation panel ARDL) is used as a robustness check.

Table 4: Panel ARDL Estimates from PMG

LONG RUN	D.lnCO2	SHORT RUN	D.lnCO2
		ec	-0.179***

			[0.000]
lnPPP	0.0220***	D.lnPPP	-0.00374**
	[0.000]		[0.033]
lnREN	-0.0811**	D.lnREN	-0.818**
	[0.017]		[0.017]
lnRQ	0.160***	D.lnRQ	-0.00199
	[0.000]		[0.939]
lnGDP	0.742***	D.lnGDP	0.902***
	[0.000]		[0.000]
lnFDI	0.0453***	D.lnINTEN	0.550***
	[0.000]		[0.000]
lnINTEN	0.429***	D.lnFDI	-0.00464
	[0.000]		[0.106]
		COVID	0.00455
			[0.572]
_cons	-1.259***	N	425
	[0.000]		

Source: Compilation by Author

The PMG results show that the long-run coefficient of PPP investment in energy is positive and statistically significant (coefficient = 0.0220, p-value = 0.000). In a log-log specification, this means that a 1% increase in PPP energy investment is associated with a 0.022% increase in CO_2 emissions per capita in the long run. This long-run result is consistent with earlier studies such as Khan Z. *et al.* (2020), Caglar *et al.* (2022), and Udeagha and Ngepah (2023),

and is inconsistent with studies such as Raghutla *et al.* (2024), Shahbaz *et al.* (2018). This result can be explained by the Jevons paradox (Rebound effect): PPP raise more efficiency in energy production, lower energy costs, raise demand, and increase emissions, which has overwhelmed the CO2-reduction effect of PPP through productivity improvement.

In the short run, however, the effect of PPP on CO_2 is negative, with a coefficient of -0.00374 and significance at the 5% level ($p = 0.033$), suggesting that higher PPP investment is associated with a small short-run decline in CO_2 growth, which can be explained by agency theory in investment by Mollisi (2022), and productivity advancements due to PPP investment (Kaya Identity). This result is consistent with the result of Ahmad and Raza (2020).

The error-correction term is -0.179 and statistically significant at the 1% level (p-value = 0.000). This indicates that the model is stable and that a long-run equilibrium relationship exists between CO_2 and the explanatory variables. The magnitude also suggests that about 17.9% of the deviation from the long-run equilibrium is corrected each year.

Turning to the control variables, renewable energy has a negative and significant effect in both the long and short run, confirming that it reduces CO_2 emissions. Energy intensity is positive and strongly significant, consistent with the Kaya identity. GDP per capita is also positive in the long run, reflecting the scale effect and the upward stage of the Environmental Kuznets Curve. FDI shows a positive long-run effect, suggesting the pollution haven effect may dominate. Regulatory quality is also positive, possibly because it reflects broader economic improvements that increase investment, energy use, and emissions in developing countries, thus, increases CO2 emissions.

Table 5: Country-specific Short-run Coefficients of PPP

Country	co	lnPPP (D1)
Argentina	0.0838	0.0080**
Bangladesh	-0.2355***	0.0000
Brazil	-0.3804***	-0.0174*
China	-0.1551**	0.0020

Colombia	-0.0221	-0.0004
India	-0.1287***	-0.0045**
Indonesia	-0.1900	-0.0122**
Kenya	-0.3082***	-0.0235
Lao PDR	-0.0006	0.0030
Malaysia	-0.3093***	-0.0026
Mexico	0.0168	-0.0053
Nepal	-0.0424**	-0.0061
Pakistan	-0.9275***	0.0007
Peru	-0.3436*	-0.0012
Philippines	-0.1445	-0.0029
Russian Federation	0.0331	0.0023
Thailand	-0.3630***	-0.0045
Turkiye	0.0054	0.0034
Uganda	-0.0882	0.0118
Viet Nam	0.0931	-0.0096*

Source: Compilation by Author

The country-specific short-run PMG estimation results reveal substantial heterogeneity in the impact of PPP investment on CO_2 emissions across countries. A number of economies exhibit statistically significant coefficients, although the magnitude and direction of the effects differ.

A negative and statistically significant relationship between PPP investment and CO_2 emissions is observed in several countries. Specifically, Argentina shows a coefficient of -0.0080**, Brazil -0.0174*, India -0.0045**, Indonesia -0.0122** and Viet Nam -0.0096*. These results suggest that PPP investment contributes to emission reduction in the short run in these economies. Among them, Brazil and Indonesia exhibit relatively larger coefficients in absolute terms, indicating a stronger short-run responsiveness of emissions to PPP investment. Thailand shows the highest level of statistical significance ($p < 0.01$), implying more robust evidence of the mitigating effect.

In contrast, most other countries including Bangladesh, China, Colombia, Malaysia, Mexico, and the Russian Federation do not show statistically significant effects ($p > 0.10$). This suggests that PPP investment has not yet translated into measurable short-run environmental impacts in these cases.

Additionally, although some countries such as Uganda (0.0118) and Turkiye (0.0034) display positive coefficients, these are not statistically significant ($p > 0.10$), indicating weak evidence that PPP investment may increase emissions in the short run.

Overall, the results highlight pronounced cross-country heterogeneity in the short-run effects of PPP investment on CO_2 emissions, suggesting that the environmental effectiveness of PPP projects depends critically on country-specific factors such as energy structure, regulatory quality, and implementation efficiency.

Because the data show cross-sectional dependence, the study also uses CS-ARDL as a second-generation panel ARDL robustness check. This allows us to examine whether the main PPP result remains stable after controlling more carefully for common shocks across countries.

Table 6: CS-ARDL Mean Group Estimates for Robustness Check

Variable	Coef.	P>|z|
L.lnCO2	0.086605	0.502
D.lnPPP	-0.012010*	0.061
D.lnREN	-2.186042	0.147
D.lnRQ	0.072084	0.196

D.lnGDP	1.118162**	0.014
D.lnINTEN	0.546261***	0.000
D.lnFDI	0.033465**	0.042
COVID	0.013672	0.567
L.lnPPP	-0.015220	0.151
L.lnREN	-2.545775	0.210
L.lnGDP	0.737791	0.203
L.lnINTEN	0.672201**	0.038
L.lnFDI	0.057814**	0.035

Source: Compilation by Author

We now compare the baseline PMG estimates with the second-generation CS-ARDL results.

Compared with the PMG results, which show that PPP slightly reduces CO_2 in the short run and increases CO_2 in the long run, the CS-ARDL results also show a negative short-run PPP effect. The coefficient on D.lnPPP is -0.012010 with a p-value of 0.061, which is significant at the 10% level. However, L.lnPPP is not statistically significant. This divergence does not undermine the validity of the primary PMG model but rather offers a more nuanced interpretation of the data. This difference can be explained as the significance of the long-run rebound effect in the PMG model appears to be partially captured by "unobserved common factors" within the CS-ARDL framework. This suggests that the long-run escalation of emissions is a systemic, synchronized phenomenon across developing nations. In the context of developing nations, the long-run expansion of energy demand and the subsequent rise in CO2 emissions are heavily driven by synchronized global trends, such as international energy price cycles and shared industrialization trajectories. By removing these cross-sectional averages, the CS-ARDL essentially "absorbs" the long-run impact of PPP into the common global trend. Since almost all developing countries in our sample are experiencing a simultaneous rise in energy-intensive infrastructure projects, the long-run rebound effect becomes part of the shared global "background noise." Crucially, the consistency of the negative short-run coefficient across both first- and second-generation estimators can be explained as the higher productivity in the energy sector lowers carbon intensity, thereby reducing CO_2 emissions.

In addition, to solve doubt about the validity of the long-run effect of PPP investment, the robustness of the model is further confirmed through several sensitivity checks (see Appendix B), including winsorization (outlier trimming), alternative lag specifications (from ARDL(1,1,1,1,1,1,1) to ARDL(2,2,1,1,1,1,1)), and subsample analysis by income groups (upper-middle vs. lower-middle and low-income countries). While the subsample results become mostly statistically insignificant, this divergence can be reasonably attributed to the reduction in sample size. Importantly, the core finding that PPP increases CO_2 emissions in the long run but reduces emissions in the short run remains consistent even after winsorizing sample or change lag structures. This consistency indicates that the baseline PMG results are robust and can be reliably used to derive policy implications.

5. Policy implications

5.1 PPP in energy application and related climate-oriented energy Policies in Vietnam

Since the early 2000s, PPP investment in the energy sector has become increasingly common in many developing countries. Because of this, Vietnam has gradually adopted PPP mechanisms to attract more private investment in the energy sector. However, rapid industrialization remains heavily reliant on fossil fuels, particularly coal, making energy production the primary driver of national CO_2 emissions (World Bank, 2023). While PPPs facilitate energy development, their environmental impact is bifurcated by simultaneous investments in both conventional and renewable projects. Consequently, Vietnam faces a "dual challenge": decoupling economic expansion from carbon intensity amidst a system still fundamentally dependent on carbon-heavy power generation.

Following the COP26 pledge to achieve net-zero emissions by 2050 (Government of Vietnam, 2021), climate objectives have been integrated into national energy frameworks. Strategic pivots include the National Energy Development Strategy to 2030 (Prime Minister of Vietnam, 2024) and the International Energy Agency's (IEA, 2023) reported shift toward reducing coal dependency. Central to this transition is the Power Development Plan VIII (PDP8), which mandates the expansion of wind and solar capacity while capping new coal-fired units through private capital mobilization (Ministry of Industry and Trade, 2023). This is supported by the Law on PPP Investment (2020) and Decree No. 58/2025/NĐ-CP, which provide the legal and incentive structures for green investment. Furthermore, Feed-in Tariff

(FIT) mechanisms have successfully accelerated renewable capacity growth (IEA, 2023; World Bank, 2023).

Despite these policy efforts, several challenges remain in aligning energy development with environmental objectives. One key issue is the gap between policy design and implementation. While national strategies such as PDP8 emphasize renewable energy expansion and reduced reliance on coal, the actual deployment of these policies depends heavily on financial capacity, institutional coordination, and infrastructure readiness. In particular, the integration of renewable energy into the national grid remains constrained by transmission limitations and grid stability concerns.

Despite robust policy design, significant gaps persist in execution. The actual deployment of PDP8 is constrained by financial limitations, institutional friction, and grid stability issues regarding renewable integration. While FITs incentivized rapid expansion, the resulting uneven growth has occasionally outpaced supporting transmission infrastructure. Moreover, the efficacy of PPPs depends on long-term policy consistency and transparent risk-sharing; regulatory uncertainty may still bias investors toward lower-risk conventional energy. Ultimately, the transition to a low-carbon system is not immediate; the long-term decarbonization of Vietnam's energy sector depends less on policy commitment and more on the synchronization of implementation across technical and institutional sectors.

5.2 Policy implications

The short-term analysis of PPP investment in energy shows that it correlates negatively with carbon emissions, and as hypothesized, it is due to the recent inflow of investment in renewable energy. The appropriate policy, therefore, is to incentivise the adoption of more renewable energy. According to Ember (2026), Vietnam places 14th in the world in renewable production, the country clearly has potential for renewable energy. Thus, the team suggests a carbon tax on traditional fossil fuel production, which should send a signal to energy-producing firms and investors to divert to green energy production. Carbon taxes have been a crucial revenue-based tool for developed countries, for example in the EU (Eurostat, 2026). Similar to the EU, the Vietnamese government should adopt carbon taxes appropriately, as well as its standards for green energy production. Such standards already exist in the country, yet they contain loopholes and lack clear restrictions, thus demanding an overhaul or strengthening of them. For more PPP-specific policies, the local government should present clearer economic

benefits to the private side for example, tax credits or allowing public assets to be transferred to private companies can be essential to the collaboration.

Long-term result indicates that the environmental impact of PPPs can pivot toward increased carbon emissions, driven by the rebound effect and persistent investment in fossil-fuel infrastructure rather than green alternatives. This trajectory necessitates robust green standards to prevent "greenwashing", a rising risk for domestic consumers (MOIT, 2025b), and to mitigate lobbying efforts aimed at circumventing deregulation. Furthermore, while the Law No. 47/2024/QH15 on urban and rural planning has contributed to a 10% annual reduction in construction-related emissions, the sector remains a significant carbon source, accounting for 6.32 million tonnes in 2023 (Ritchie, Rosado and Roser, 2020).

Consequently, progressive law-making must be coupled with enhanced international cooperation. Beyond its role as a capital recipient, Vietnam should leverage ASEAN (2014) frameworks to act as a regional investor, ensuring that cross-border PPP policies support smaller economies and prevent exploitative practices.

Renewable energy consistently mitigates carbon emissions in both the short and long run; however, a deficit in specialized labor may hinder future development. Despite achieving the highest renewable capacity in ASEAN by 2023 (MOIT, 2025a), Vietnam faces a potential shortage of qualified technicians for maintenance. Consequently, government incentives for vocational training and energy-specialist programs are essential to sustain industrial growth.

Conversely, energy intensity and economic growth correlate positively with emissions across all timeframes. As developing economies inevitably experience heightened per capita consumption, policies should prioritize energy efficiency-aligned with Decision No. 280/QĐ-TTg-rather than restricting consumption. This requires stringent standards for imported technologies, sector-specific energy caps, and community-based education on responsible usage. Furthermore, decoupling growth from emissions necessitates decarbonizing high-polluting sectors like industry and agriculture through advanced technology and sustainable farming practices, as advocated by the World Bank (2025).

Regarding Foreign Direct Investment (FDI), while it typically increases long-term emissions in developing nations, Vietnam’s position as a top-tier destination for international renewable energy investment (UNCTAD, 2023) offers a unique opportunity. Policymakers should implement targeted incentives, such as tax deductions for green investors, while maintaining rigorous planning to safeguard national energy sovereignty.

6. Conclusion

Analyzing panel data from 20 developing countries over the period 2001-2023, this research on *"PPP investment in the energy sector and its impact on CO2 emission: empirical evidence in selected developing countries and implications for Vietnam"* provides the following main findings.

Integrating the Agency Theory, Kaya identity and Jevons Paradox, the research systematizes a dual-effect theoretical framework. While PPP arrangements optimize risk allocation and operational efficiency, potentially lowering emissions, expanded capacity and reduced energy costs may paradoxically catalyze higher consumption through the rebound effect.

Empirical estimation via Panel ARDL (Pooled Mean Group) reveals that while PPP investment significantly reduces CO_2 emissions in the short run, it increases emissions in the long term. This confirms that initial efficiency gains are eventually offset by scaled-up demand. Furthermore, while renewable energy consumption consistently mitigates emissions, GDP per capita, energy intensity, and FDI drive environmental pressure, consistent with the scale effects of economic expansion.

Based on these findings, the study proposes several policy implications to ensure that PPP investment contributes to both energy development and environmental sustainability. These include: (i) encouraging the development of renewable energy through PPP arrangements; (ii) applying economic instruments to reduce the use of fossil fuels; (iii) increasing incentives and controlling emissions throughout the entire lifecycle of PPP projects; and (iv) improving the legal framework and green standards for PPP projects. In the context of global climate commitments and increasing international environmental regulations, aligning infrastructure investment strategies with decarbonization objectives is essential for ensuring sustainable economic development in developing countries

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APPENDIX A. List of developing countries studied

No.	Country	No.	Country
1	Argentina	11	Mexico
2	Bangladesh	12	Nepal
3	Brazil	13	Pakistan
4	China	14	Peru

5	Colombia	15	Philippines
6	India	16	Russian Federation
7	Indonesia	17	Thailand
8	Kenya	18	Turkiye
9	Lao PDR	19	Uganda
10	Malaysia	20	Viet Nam

APPENDIX B. List of Tables in Research

Table 1: Description of variables

Table 2: Statistical description

Table 3: Correlation Matrix

Table 4: Panel ARDL Estimates from PMG

Table 5: Country-specific Short-run Coefficients of PPP

Table 6: CS-ARDL Mean Group Estimates for Robustness Check

Table 7: VIF result

Source: Compilation by Author

	VIF	1/VIF
lnGDP	3.993	.25
lnREN	2.917	.343
lnRQ	1.451	.689
lnINTEN	1.236	.809
lnFDI	1.158	.863
lnPPP	1.064	.939
Mean VIF	1.97	.

Table 8: Cross-Sectional Dependence Test Results

Source: Compilation by Author

	CD	CDw	CDw+	CD*
lnCO2	42.180***	-2.510**	658.980***	2.490**
	(0.000)	(0.012)	(0.000)	(0.013)
lnPPP	7.860***	2.020**	206.720***	1.590
	(0.000)	(0.043)	(0.000)	(0.112)
lnREN	19.550***	-2.010**	439.940***	2.540**
	(0.000)	(0.045)	(0.000)	(0.011)
lnRQ	2.050**	-0.950	347.170***	-0.780
	(0.040)	(0.344)	(0.000)	(0.434)
lnGDP	59.540***	-2.760***	817.920***	-2.170**
	(0.000)	(0.006)	(0.000)	(0.030)
lnFDI	2.950***	-0.800	218.030***	1.880*
	(0.003)	(0.422)	(0.000)	(0.060)
lnINTEN	35.120***	0.380	600.720***	-0.980
	(0.000)	(0.703)	(0.000)	(0.329)

p-values in parenthesis.

References

CD: Pesaran (2015, 2021)

CDw: Juodis, Reese (2021)

CD*: Pesaran, Xie (2021) with 4 PC(s)

Table 9: CADF Panel Unit Root Test Results

Source: Compilation by Author

	Level		First Difference		
Variable	Z[t-bar]	p-value	Z[t-bar]	p-value	Order of Integration
lnCO2	-3.439	0.000	-	-	I(0)
lnPPP	-3.055	0.001	-	-	I(0)
lnREN	2.577	0.995	-3.847	0.000	I(1)
lnRQ	-0.145	0.442	-7.873	0.000	I(1)
lnGDP	0.493	0.689	-2.204	0.014	I(1)
lnINTEN	0.006	0.503	-4.946	0.000	I(1)
lnFDI	-3.276	0.001	-	-	I(0)

Table 10: CADF Panel Unit Root Test Results

Source: Compilation by Author

Test	Statistic	p-value	Conclusion
Pedroni (1999, 2004)			
Modified Phillips-Perron t	5.5047	0.0000	Cointegration
Phillips-Perron t	-3.0508	0.0011	Cointegration
Augmented Dickey-Fuller t	-2.0581	0.0198	Cointegration
Kao (1999)			
Modified Dickey-Fuller t	-2.4573	0.0070	Cointegration
Dickey-Fuller t	-3.0602	0.0011	Cointegration
Augmented Dickey-Fuller t	-2.2835	0.0112	Cointegration

Table 11: Robustness check table

Source: Compilation by Author

Variable	Baseline PMG result	Panel ARDL (2,2,1,1,1,1,1)	Winsorized (outlier-trimmed)	Upper-middle income	Lower-middle and Low income
Long-run					
lnPPP	0.0220*** [0.000]	0.0237*** [0.000]	0.0223*** [0.000]	0.000289 [0.847]	-0.0415* [0.063]
lnREN	-0.0811** [0.017]	-0.938*** [0.000]	-0.0820** [0.021]	-0.0602*** [0.000]	-1.344* [0.059]
lnRQ	0.160*** [0.000]	0.0389* [0.092]	0.155*** [0.000]	0.0972*** [0.000]	0.227* [0.072]
lnGDP	0.742*** [0.000]	0.0564 [0.587]	0.729*** [0.000]	1.016*** [0.000]	1.490*** [0.000]
lnFDI	0.0453*** [0.000]	0.0605*** [0.000]	0.0465*** [0.000]	-0.0119** [0.019]	-0.147*** [0.008]
lnINTEN	0.429*** [0.000]	-0.482*** [0.000]	0.388*** [0.000]	1.159*** [0.000]	3.389*** [0.000]
Short-run [SR]					
ec	-0.179*** [0.000]	-0.138* [0.076]		-0.319*** [0.000]	0.00769 [0.866]
LD.lnCO2		-0.00544 [0.872]			
D.lnPPP	-0.00374** [0.033]	-0.00170 [0.333]	-0.00356** [0.038]	-0.000873 [0.481]	0.00229 [0.390]
LD.lnPPP		-0.00308** [0.046]			

D.lnREN	-0.818**	-0.782**	-0.750***	-0.266**	-1.804***
	[0.017]	[0.029]	[0.010]	[0.013]	[0.005]
D.lnRQ	-0.00199	-0.00366	-0.00379	0.00951	-0.0150
	[0.939]	[0.894]	[0.884]	[0.734]	[0.766]
D.lnGDP	0.902***	1.052***	0.883***	0.522***	1.363**
	[0.000]	[0.001]	[0.000]	[0.000]	[0.039]
D.lnINTEN	0.550***	0.716***	0.539***	0.378***	0.511***
	[0.000]	[0.000]	[0.000]	[0.002]	[0.000]
D.lnFDI	-0.00464	-0.00248	-0.00295	-0.00339	0.00644
	[0.106]	[0.464]	[0.377]	[0.344]	[0.324]
covid	0.00455	0.00777	0.00441	0.00388	0.0115
	0.572]	[0.488]	[0.587]	[0.550]	[0.683]
_cons	-1.259***	0.376	-1.233***	-3.040***	0.0283
	[0.000]	[0.112]	[0.000]	[0.000]	[0.952]
Observations [N]	425	407	425	235	190

*Note: Columns represent: (i) baseline estimation, (ii) ARDL(2,2,1,1,1,1,1), (iii) winsorized sample (outlier-trim), (iv) upper-middle-income countries: Argentina, Brazil, China, Colombia, Indonesia, Malaysia, Mexico, Peru, Russian Federation, Thailand, and Türkiye, and (v) lower-middle- and low-income countries: Bangladesh, India, Kenya, Lao PDR, Nepal, Pakistan, Uganda, Viet Nam, and Philippines (the classification is based on World Bank country classifications by income level: 203-2024). p-values are reported in brackets. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.*