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Article

Unlocking CO_2 emissions in East Asia Pacific-5 countries: Exploring the dynamics relationships among economic growth, foreign direct investment, trade openness, financial development and energy consumption

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Abstract: The increase in world carbon emissions is always in line with national economic growth programs, which create negative environmental externalities. To understand the effectiveness of related factors in mitigating CO_2 emissions, this study investigates the intricate relationship among macro-pillars such as economic growth, foreign investment, trade and finance, energy, and renewable energy with CO_2 emissions of the high gross domestic product economies in East Asia Pacific, such as China, Japan, Korea, Australia and Indonesia (EAP-5). Through the application of the Vector Error Correction Model (VECM), this research reveals the long-term equilibrium and short-term dynamics between CO_2 emissions and selected factors from 1991 to 2020. The long-term cointegration vector test results show that economic growth and foreign investment contribute to carbon reduction. Meanwhile, the short-term Granger causality test shows that economic growth has a two-way causality towards carbon emissions, while energy consumption and renewable energy consumption have a one-way causality towards carbon emissions. In contrast, the variables trade, foreign direct investment, and domestic credit to the private sector do not have two-way causality towards CO_2 emissions. The findings reveal that economic growth and foreign investment play significant roles in carbon reduction, which are observed in long-term causality relationships, while energy consumption and renewable energy are notable factors. Thus, the study offers implications for mitigating environmental concerns on national economic growth agendas by scrutinizing and examining the efficacy of related factors.

Keywords: East Asia Pacific; carbon emissions; economy; investment; energy

1. Introduction

Increasing social welfare can be seen from economic growth, which is the target of development throughout the world economy (Noor and Saputra, 2020). However, along with the national economic growth program, it will undoubtedly create negative environmental externalities, primarily by increasing CO_2 carbon emissions (Mitić et al., 2023; Nguyen et al., 2024). The development of carbon emissions in the world is increasing every year. According to the International Energy Agency report in 2022 and 2023, total energy-related greenhouse gas emissions increased by 1.0% to an all-time high of 41.3 Gt CO_2 (for global warming potential value) (see more **Figure 1**). CO_2 emissions from energy combustion and industrial processes account for 89% of energy-related greenhouse gas emissions in 2022.

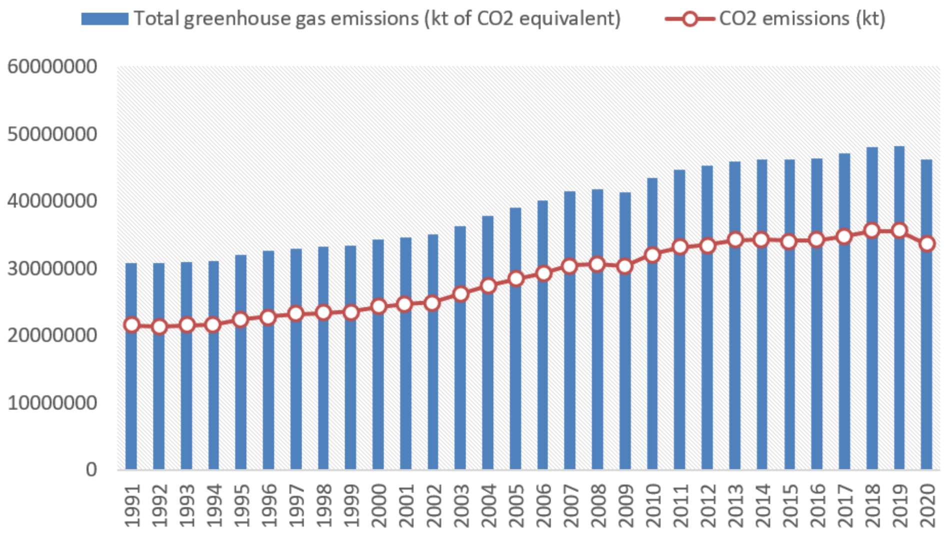


Figure 1. Development of greenhouse gas emissions and CO_2 emissions in the world from 1991–2020.

Source: Global Carbon Budget (2022).

The increase in CO_2 emissions worldwide is mainly caused by accelerating CO_2 emissions from burning fossil fuels and industrial processes, driven by the cessation or reversal of downward trends in energy intensity and carbon intensity, coupled with growth in population and GDP per capita (Sanchez and Stern, 2016; Voumik et al., 2023). The impact of the global financial crisis on emissions proved transient due to robust emissions growth in developing nations and a resurgence of emissions growth in developed countries (Habiba and Xinbang, 2022; Peters et al., 2011). Additionally, burning fossil fuels has humanity's most considerable impact on the climate, accounting for 80% of anthropogenic greenhouse gas emissions, and recent trends show a dynamic increase in emissions, particularly in developing countries (Alamoush et al., 2022; Liu et al., 2022). Global emissions can also originate from internationally traded fossil fuels contained in traded goods, highlighting the vulnerabilities and benefits associated with current energy use patterns (Maeno et al., 2022; Tran, 2023). In addition, the impact of population and economic growth on CO_2 emissions is very significant across regions, with emissions decreasing at higher levels of renewable energy intensity (Dong et al., 2018). The main drivers of CO_2 emissions worldwide are economic growth, population growth, energy intensity, and clean and renewable energy (Dong et al., 2020).

This study aims to analyze the East Asia Pacific region because it is one of the most densely populated regions and has fast growth in the world. Several countries that have large populations in East Asia Pacific include China, Japan, South Korea, and Indonesia. Based on 2020 World Bank data, economic growth states that 05 countries have the highest GDP out of several East Asia Pacific economic countries, namely China, Japan, Korea, Australia, and Indonesia. The development of high GDP in the Asia Pacific-5 economies is a challenge in the development of carbon emissions, which continue to increase. The rapid industrialization and economic development witnessed in the EAP-5 countries have led to substantial increases in energy consumption and carbon emissions (Zafar et al., 2020; Zheng et al., 2023), followed by urbanization during the development played a primary driver of CO_2 emissions

(Mehmood and Mansoor, 2021). This combination of dense population and robust economic activity underscores the significance of studying CO_2 emissions dynamics in the EAP-5 economies. Moreover, EAP-5 countries have a unique energy mix and transition policy influencing CO_2 emissions (Wei et al., 2023; Sandu et al., 2019). For instance, China relies heavily on coal for its energy needs, whereas Japan has been investing on CO_2 emission sources following the Fukushima nuclear disaster. By focusing on this region, the study can shed light on the challenges and opportunities associated with emissions management in the rapidly growing East Asia-Pacific and developing economies. **Figure 2** below shows the average GDP and CO_2 emission of 05 highest GDP in the East Asia-Pacific economy from 1991 to 2020.

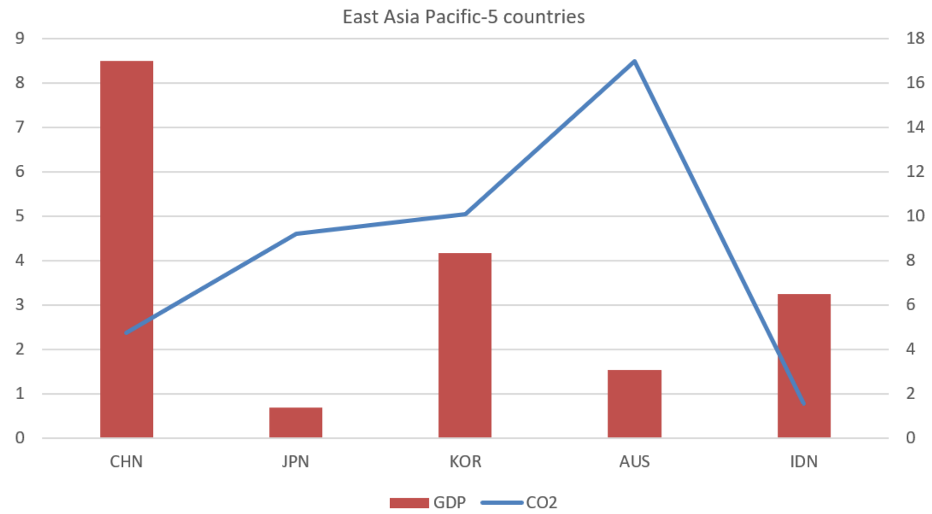


Figure 2. The average of GDP per capita growth (annual %) and CO_2 emission (metric tons per capita) in the EAP-5 economies.
Source: Global Carbon Budget (2022).

Previous researchers have carried out various analyses. Based on Kuznets' theory in 1995, it was stated that there was a relationship between income levels and environmental degradation or environmental quality (Grossman and Krueger, 1995). Investment activities carried out by Asian countries have a significant positive effect on increasing carbon emissions (Luo et al., 2021). In energy efficiency, research by Khezri et al. (2021) in Asia Pacific countries states that financial growth has an impact on increasing carbon emissions from increasing energy efficiency. However, the study of Rahman and Alam (2022) shows that financial growth has no causality in increasing carbon emissions. In contrast, Tran (2023) suggests that the impact of financial development on CO_2 emissions varies based on economic growth and the utilization of renewable energy based on income levels. While fossil fuels still dominate the energy pattern in many countries, Zhao et al. (2023) confirm that a growing shift towards renewable energy sources enhances environmental quality. However, this transition needs to be driven by increasing fiscal policy and environmental stringent policy on consumption-based carbon emissions (Li, Samour, et al., 2023). Therefore, energy consumption, including renewable energy, is a topic that needs to be further clarified to supplement empirical evidence on the role of energy patterns in sustainable development in the case of EAP-5, as pointed out by previous studies of Adebayo et al. (2023) and Radmehr et al. (2023) in other countries.

Thus, several of these studies show a research gap on increasing carbon emissions, especially in the casual relationship among macro pillars, such as economic growth, foreign investment, trade and finance, energy, and renewable energy. As seen in **Figure 2**, some countries have higher levels of GDP than CO_2, while others have contrasting situations. Moreover, this kind of research needs to be carried out in East Asia Pacific countries to determine the magnitude of the growth factor in CO_2 carbon emissions in the world and analyze the role of macro pillars in managing energy dynamics that can affect the EAP-5 economy. The panel data collection looks at the East Asia Pacific economy from 1990–2020 or for 30 years. By understanding the factors that influence carbon emissions and energy-economic dynamics, policymakers can develop effective strategies to control and reduce CO_2 emissions in the East Asia Pacific economy. The rest of the paper is constructed as follows: Section 2 presents a literature review to give general views on CO_2 and related macro factors, Section 3 illustrates the empirical method, and Section 4 discusses findings. Section 5 gives the conclusions and implications.

2. Literature review

The relationship between CO_2 emissions and key macroeconomic pillars is complex and interdependent. This symbiotic relationship emphasizes the interconnectedness of economic growth, investment and finance, and energy usage with environmental sustainability (Bach and Cong, 2024; Bui et al., 2023; Paudel et al., 2023). It underscores how alterations in one domain can reverberate through others, molding casual relationships and paths toward sustainable development. As countries pursue economic expansion, the makeup of macro factors and energy consumption patterns wield significant influence over CO_2 emission levels. Policy measures that align economic goals with environmental concerns are indispensable for nurturing a harmonious equilibrium between economic advancement and ecological robustness.

Indeed, the relationship between CO_2 emissions and GDP is dynamic and contingent upon various factors such as time period and specific context. Research conducted by Niyonzima et al. (2022) suggests a negative short-term relationship between CO_2 emissions and GDP, implying that higher GDP levels are associated with reduced CO_2 emissions. However, in the long term, there is often a positive correlation between GDP and CO_2 emissions, indicating that economic development can lead to increased emissions due to heightened economic activities (Torun et al., 2022). This phenomenon may be exacerbated by increased energy consumption and rising national GDP, resulting in higher CO_2 emissions (Huang, 2021). Additionally, evidence suggests the existence of a cyclical relationship between GDP and CO_2 emissions during increasing business cycles, where emissions may spiral out of control (Khalfaoui et al., 2021). Overall, the relationship between CO_2 emissions and GDP is intricate and influenced by increased economic activity. Thus, the first our hypothesis is stated by:

- H1: There is a significant relationship between GDP and CO_2 emissions.

In terms of trade openness, several studies also link the relationship between CO_2 carbon emissions and trade openness, which is a complex issue. Shen et al. (2022) assert that international trade significantly impacts logistics carbon emissions, particularly in sectors like textile manufacturing and the chemical industry, which exhibit substantial increases in embodied carbon during export trade (Rehan et al., 2023). However, conflicting findings emerge from other research, suggesting that trade liberalization has no significant influence on CO_2 emissions (Duan et al., 2022), with some studies even disputing the existence of a Granger causal relationship between trade openness and CO_2 emissions (Ahmad et al., 2023). Moreover, Wang et al. (2023) shed light on the nuanced dynamics at play, indicating that the effect of trade openness on CO_2 emissions hinges on factors such as reliance on export trade, shifts in economic structure, and the adoption of clean technology. They underscore the significance of enhancing energy consumption structures and bolstering system efficiency to mitigate carbon emissions associated with trade, highlighting indirect influences over direct impacts of trade openness. Drawing upon these diverse findings, the second hypothesis is formulated:

- H2: There is no significant relationship between trade openness and CO_2 emissions.

When associated with increasing carbon emissions, the impact of Foreign Direct Investment (FDI) on CO_2 emissions varies significantly depending on a country's level of development. Essandoh et al. (2020) observe a negative long-term relationship between FDI and CO_2 emissions in developed countries, suggesting that heightened foreign investment can lead to reductions in emissions over time. Conversely, in developing nations, FDI tends to be positively associated with CO_2 emissions in the long term, primarily due to the absence of stringent regulations governing emissions reduction (Xie et al., 2020). However, it is worth noting that the spillover effect of FDI manifested through economic growth, has the potential to mitigate CO_2 emissions (Adekantari and Amar, 2022), illustrating how foreign investment can serve as both a pollution haven and a pollution halo, contingent upon specific circumstances. Overall, the relationship between CO_2 emissions and FDI is intricate, influenced by factors such as country development, economic growth, and spillover effects (Gyamfi, 2021; Khan et al., 2022). Thus, we stated third hypothesis following by:

- H3: There is a significant relationship between Foreign Direct Investment (FDI) and CO_2 emissions

Apart from foreign investment in a country, providing domestic credit to the private sector emerges as a vital strategy for decreasing CO_2 emissions. Several studies indicate that domestic credit and financial development yield a long-term positive impact on CO_2 emissions (Rehman et al., 2023; Shoaib et al., 2020). However, Cheng et al. (2019) reveal a nuanced perspective, suggesting that while domestic credit may initially increase carbon emissions per capita, it can gradually mitigate their impact over time. Moreover, Safiullah et al. (2021) find that companies with high carbon emissions often face challenges in securing credit due to uncertainties in private company cash flows. The structure of the financial system also plays a crucial role, as a bank-based system concentrated on providing loans to households may hinder the development of eco-friendly technologies, exacerbating energy use and CO_2 emissions (Kim et al., 2021). Conversely, increasing loans to private non-financial companies within the banking sector can foster the adoption of environmentally friendly technologies, ultimately reducing energy consumption and CO_2 emissions (Kim et al., 2020). Therefore, the impact of domestic credit to the private sector on CO_2 emissions is contingent upon various factors, including the specific country, institutional quality, credit composition, and energy usage (Chien et al., 2023; Farooq et al., 2022; Sithole et al., 2021). To test this relationship in our research, the next hypothesis is stated:

- H4: There is no significant relationship between domestic credit to the private sector and CO_2 emissions.

The relationship between CO_2 carbon emissions and energy consumption is a topic of interest in several studies. Several studies reveal that there is a positive correlation between CO_2 emissions and energy consumption (Li, Irfan, et al., 2023; Nguyen, Tu, et al., 2023; Sharif et al., 2023). According to Lyazzat et al. (2023), if a country's energy consumption is high, it will have an environmental impact and increase CO_2 emissions from energy use. In addition, research by Martins et al. (2021) shows that different energy sources have different impacts on CO_2 emissions. They also stated that gas consumption will cause more pollution than coal and oil consumption. For example, in the BRICS nations, economic progress and natural resource extraction diminish ecological quality, while renewable energy consumption and trade globalization enhance it (Adebayo et al., 2023; Li, Irfan, et al., 2023). However, it is important to note that reducing CO_2 emissions without adversely impacting economic growth requires the rapid adoption of environmentally friendly alternative energy sources (Salari et al., 2021). Most researchers reveal that renewable energy consumption significantly negatively impacts CO_2 emissions (Balsalobre-Lorente et al., 2018; Saidi and Omri, 2020). In the EU, Radmehr et al. (2023) reveal that renewable energy consumption significantly promotes domestic ecological sustainability, with positive spillover effects from neighboring nations.

The use of renewable energy source such as biomass, biofuel, geothermal, hydroelectric power, solar power, wind, wood, and waste has been proven to reduce CO_2 emissions (Radmehr et al., 2023; Sharif et al., 2021). According to Szetela et al. (2022) and Majewski et al. (2022), implementing renewable energy in a country, apart from increasing economic growth, can also reduce carbon emissions. Other findings show that a one percentage point increase in renewable energy to a 0.5% reduction in CO_2 emissions (Guo et al., 2022; Huang et al., 2021). In addition, countries also need to consider various types of renewable energy sources to maximize the effectiveness of renewable energy policies in combating CO_2 emissions. Previously, research by Vo et al. (2019) and Gao and Chen (2023) further emphasized the importance of transitioning to cleaner energy sources to reduce CO_2 emissions and mitigate environmental degradation. A country needs sustainable energy practices to reduce CO2 carbon emissions and promote environmental sustainability. Thus, the next hypotheses are stated following by:

- H6: There is a significant relationship between energy consumption and CO_2 emissions.
- H7: There is a significant relationship between renewable energy consumption and CO_2 emissions.

3. Method

This research uses quantitative research methods with panel data on the East

Asia-Pacific economy. This research presents a comprehensive analysis of CO_2 emission factors in 5 East Asia-Pacific countries from 1991 to 2020, focusing on the impacts of macro pillars on CO_2 emission in dynamic relationships. Data sources in this research, which can be seen in **Table 1**, include the World Bank and International Energy Agency (IEA) databases, which provide data on CO_2 emissions, GDP, trade, foreign investment, renewable energy, domestic credit to the private sector, energy consumption, and renewable energy.

Table 1. Variable definitions and source.

Variables	Indicators	Definitions	Source
CO_2	CO_2 emissions (metric tons per capita)	Carbon dioxide emissions arise from the burning of fossil fuels and cement production. These emissions include the release of carbon dioxide during the use of solid, liquid, and gaseous fuels, as well as during gas combustion.	Worldbank
GDPPC	GDPPC per capita growth (annual %)	The annual percentage increase in GDPPC per capita is calculated using consistent local currency.	Worldbank
TR	Trade Openness (% of GDPPC)	Trade represents the combination of exports and imports of goods and services, measured as a proportion of gross domestic product (GDPPC).	Worldbank
FDI	Foreign direct investment, net inflows (% of GDPPC)	Foreign direct investment involves net investment income that includes 10 percent or more shares in a company operating in the economy.	Worldbank
FD	Financial development (% of GDPPC)	Domestic credit to the private sector by banks (% of GDPPC) is a financial metric that measures the total amount of credit extended by domestic banking institutions to private companies and individuals.	IMF, WDI
EC	Energy Consumption (BTU)	Direct supply or use of energy sources that have not undergone any conversion or transformation process	IEA
RE	Renewable energy consumption (% of total final energy consumption)	Renewable energy consumption represents the proportion of energy originating from renewable sources in overall final energy consumption	IEA

The data analysis model for this research uses the Vector Autoregression (VAR) or the Vector Error Correction Model approach (VECM), which aims to test the influence of research variables on understanding long- and short-term trends in the East Asia Pacific. VAR and VECM models are chosen for their ability to analyze the intricate dynamics among multiple time series variables, making them ideal for examining the complex interplay between macro factors and CO_2 emissions over time. By addressing potential unit roots and cointegration among variables, VAR or VECM enables a more accurate estimation of long-term equilibrium relationships and short-term dynamics, as applied in previous studies by Sherif et al. (2022) and Shahbaz et al. (2016). Specifically, VAR and VECM models allow for assessing both the immediate and lasting impacts of economic growth, investment, trade, and energy consumption on CO_2 emissions, which is crucial for understanding emission patterns across various time horizons. If the variables exhibit long-term relationships and deviations from these relationships are mean-reverting, suggesting cointegration, then VECM should be used. Additionally, by incorporating Granger causality tests, the study can discern the direction and strength of causal relationships between macro variables and CO_2 emissions, elucidating the underlying mechanisms shaping environmental outcomes in the East Asia Pacific.

3.1. Models

Based on Kuznet's curve theory in 1995, it is stated that there is a relationship between income levels and environmental degradation or environmental quality (Grossman and Krueger, 1995). Meanwhile, economic growth is encouraged by government and private investment activities to stimulate economic activity, especially short-term and long-term growth (Nguyen and Trinh, 2018). In this research, we study the determining factors of CO_2 carbon emissions by adopting a linear model in the following equation:

$$\mathrm{CO_2} = f(\mathrm{GDP}, \mathrm{TR}, \mathrm{FDI}, \mathrm{DC}, \mathrm{EC}, \mathrm{RE})$$

where CO_2, GDPPC, TR, FDI, DC, EC, and RE show carbon emissions, economic growth, trade, foreign direct investment, domestic credit to the private sector, energy consumption, and renewable energy. Meanwhile, this research uses the VECM equation model in matrix notation as follows:

$$\begin{bmatrix} \Delta \mathrm{CO_2} \\ \Delta \mathrm{GDP} \\ \Delta \mathrm{TR} \\ \Delta \mathrm{FDI} \\ \Delta \mathrm{DC} \\ \Delta \mathrm{EC} \\ \Delta \mathrm{RE} \end{bmatrix} = \begin{bmatrix} \alpha_{10} \\ \alpha_{20} \\ \alpha_{30} \\ \alpha_{40} \\ \alpha_{50} \\ \alpha_{60} \\ \alpha_{70} \end{bmatrix} + \begin{bmatrix} \alpha_{11}\alpha_{12}\alpha_{13}\alpha_{14}\alpha_{15}\alpha_{16}\alpha_{17} \\ \alpha_{21}\alpha_{22}\alpha_{23}\alpha_{24}\alpha_{25}\alpha_{26}\alpha_{27} \\ \alpha_{31}\alpha_{32}\alpha_{33}\alpha_{34}\alpha_{35}\alpha_{36}\alpha_{37} \\ \alpha_{41}\alpha_{42}\alpha_{43}\alpha_{44}\alpha_{45}\alpha_{46}\alpha_{47} \\ \alpha_{51}\alpha_{52}\alpha_{53}\alpha_{54}\alpha_{55}\alpha_{56}\alpha_{57} \\ \alpha_{61}\alpha_{62}\alpha_{63}\alpha_{64}\alpha_{65}\alpha_{66}\alpha_{67} \\ \alpha_{71}\alpha_{72}\alpha_{73}\alpha_{74}\alpha_{75}\alpha_{76}\alpha_{77} \end{bmatrix} \begin{bmatrix} \Delta \mathrm{CO2}_{t-1} \\ \Delta \mathrm{GDP}_{t-1} \\ \Delta \mathrm{TR}_{t-1} \\ \Delta \mathrm{FDI}_{t-1} \\ \Delta \mathrm{DC}_{t-1} \\ \Delta \mathrm{EC}_{t-1} \\ \Delta \mathrm{RE}_{t-1} \end{bmatrix} + \begin{bmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \\ e_7 \end{bmatrix}$$

- CO_2 = Growth in carbon emissions (metric tons per capita);
- GDPPC = Economic growth per capita (percent);
- TR = Trade growth to GDPPC (percent);
- FDI = Growth of foreign investment to GDPPC (percent);
- DC = Growth of domestic credit to the private sector by banks (% of GDPPC);
- EC = Energy Use (BTU);
- RE = Growth on CO2 emission use (% of total energy use).

3.2. Data analysis techniques

This research uses a data analysis method in the form of VAR or VECM. There are several stages in the analysis of this research, including:

3.2.1. Stationarity test

Time series data analysis comes with crucial assumptions and can only determine the extent to which a null hypothesis can be rejected or accepted in the unit root test, necessitating careful interpretation for meaningful insights. A unit root, a common feature in stochastic processes like random walks, poses challenges in statistical inference for time series models. This research uses panel data unit root testing by (Levin et al., 2002) to determine each variable's stationarity level. The form of regression in the Levin, Lin, and Chu (LLC) unit root test is as follows:

$$\Delta y_{it} = \delta y_{it-1} + \sum_{L=1}^{P_i} \theta_{iL} \Delta y_{it-L} + \varepsilon_{it}$$

where Δ and P_i denote the first difference and max-lag operators, respectively. According to (unit root), it is necessary to calculate a combined *t*-statistic by estimating the above equation for each cross-section. The *t*-statistic θ_{iL} is to determine that the smaller, the better the lag. While the t-statistic has a standard norm under the null hypothesis $\theta_{iL} = 0$, when $\delta_i = 0$ and when $\delta_i < 0$. The data stationarity test at this stage is carried out by testing the presence or absence of unit roots. The time series approach requires the data to be stationary (does not contain unit roots), which means that there are no drastic changes in the data.

The Augmented Dickey-Fuller (ADF) test, a type of unit root test, serves as a quick check to confirm whether a time series is stationary or non-stationary. The ADF test assumes that the null hypothesis indicates non-stationarity or the presence of a unit root, while the alternative hypothesis suggests stationarity or the absence of a unit root (Dickey and Fuller, 1979). Rejecting the null hypothesis implies stationarity, indicated by a test statistic lower than the critical value and a *p*-value below 0.05, signaling a lack of time-dependent structure in the series. The ADF test extends the Dickey-Fuller test equation by incorporating a higher-order autoregressive process into the model.

$$y_{it} = c + \beta_{it} + \delta y_{it-1} + \sum_{L=1}^{P_i} \theta_{iL} \Delta y_{it-L} + \varepsilon_{it}$$

Also, the Phillips and Perron (1988) (PP) test is a unit root test widely used in time series analysis to assess whether a time series is integrated with order 1. It extends the Dickey-Fuller test by considering the null hypothesis $\rho = 1$ in the equation $\Delta y_{it} = (\rho - 1) = (\rho - 1) y_{it-1} + u_{it}$, where Δy_{it} is the first difference parameter. Similar to the ADF test, the PP test addresses the potential issue of higher-order autocorrelation in the data-generating process, which could render y_{it-1} endogenous and invalidate the Dickey-Fuller *t*-test. While the augmented Dickey-Fuller test handles this by introducing lags of Δy_{it} as regressors, the PP test employs a non-parametric correction to the *t*-test statistic. This test demonstrates robustness in the presence of unspecified autocorrelation and heteroscedasticity in the disturbance process in data.

3.2.2. Optimum lag test

The optimum lag test is one of the stages in the VAR or VECM model approach to determine the length of the data lag in looking at the period of attachment of endogenous variables to changes in variables. The most commonly used approach in testing the optimum lag is using information criteria such as the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), and Hannan-Quinn Information Criterion (HQIC) (Craine, 1971).

3.2.3. Cointegration test

Cointegration testing is usually used to see the long-term balance between research variables. If the variables have cointegration in this test, then the variables studied will have a stable relationship in the long term. Cointegration relationships use Johansen Cointegration Vectors to indicate that the test variables have a fixed long-term relationship, even though they may have different short-term fluctuations (Johansen, 1988).

3.2.4. VAR/VECM test

The VAR/VECM method predicts and analyses the relationship between variables in macroeconomic models. This involves estimating a Vector Autoregressive (VAR) model, which captures dynamic interactions between variables, and a Vector Error Correction Model (VECM), which takes into account long-term equilibrium relationships between variables (Winarno et al., 2021). The VAR or VECM method has been applied in various studies to analyze various economic phenomena.

3.2.5. Impulse response function

The Impulse Response Function test is useful in identifying cause-and-effect relationships and the impact of shocks or changes in certain variables in the context of a VAR or VECM model (Winarno et al., 2021). It can be used to analyze the dynamics of carbon emissions and how changes in variables such as economic growth, energy consumption, or environmental policy can affect carbon emissions over a certain period of time.

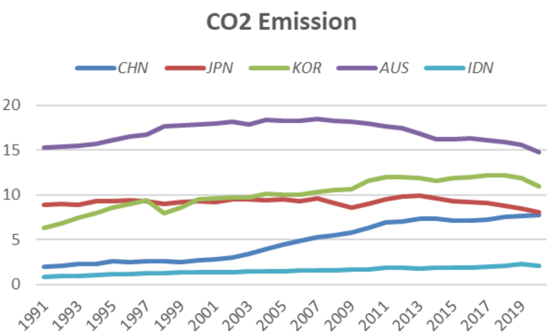
3.2.6. Granger causality test

The Granger causality test aims to understand short-term trends in the reciprocity of vector variables in VAR or VECM. In this test, the t-statistical test value is seen using the Ordinary Least Square (OLS) method. Thus, short-term causality in VAR or VECM testing can be understood through the Granger causality test (Chikalipah and Okafor, 2019).

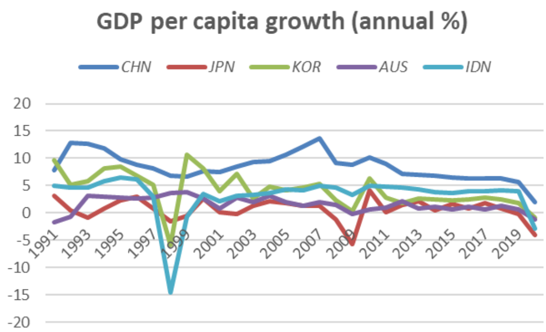
4. Findings

This research seeks to uncover the symbiotic relationship between investment partnerships and their essential role in guiding economic prosperity and environmental responsibility in the EAP-5 region. The following shows the development of each variable:

Figure 3 shows that carbon emissions in the EAP-5 region have increased every year, but in Australia, the growth of carbon emissions has decreased since 2019. Regarding GDPPC growth, trade, and foreign capital receipts show fluctuating trends every year, but since 2020, these countries have experienced a decline. Meanwhile, domestic credit growth in the private sector increases every year in the EAP-5 region. Energy use shows a stagnant trend, but only China has experienced an increase in consumption since 2000. However, in terms of renewable energy use, Indonesia and China have experienced a decline in total energy use.



(a)



(b)

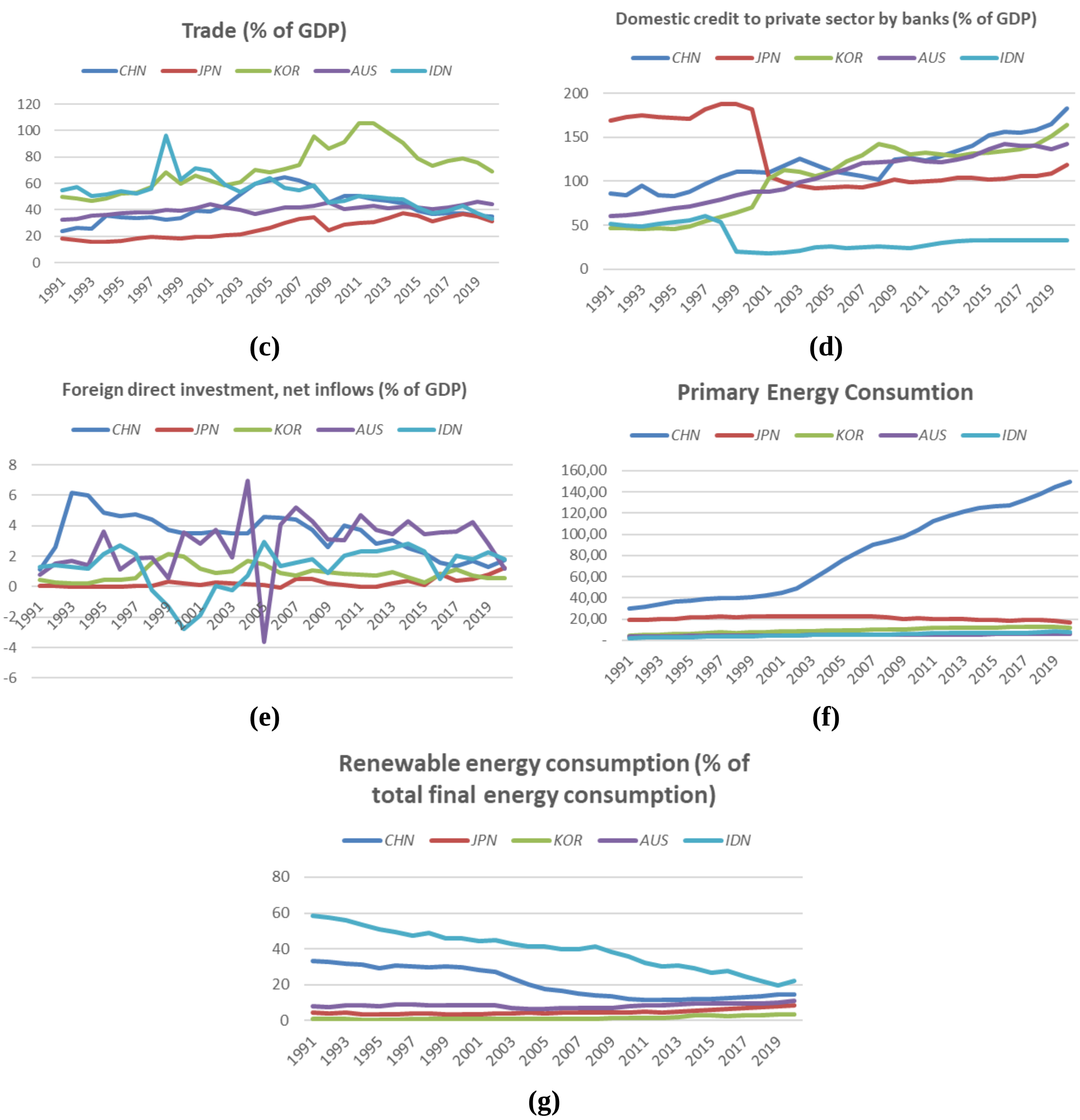


Figure 3. Growth trends of macro pillars in the period 1991–2020 of EAP-5. **(a)** CO_2 emission; **(b)** GDP per capita growth (annual %); **(c)** trade (% of GDP); **(d)** domestic credit to private sector by banks (% of GDP); **(e)** foreign direct investment, net inflows (% of GDP); **(f)** primary energy consumption; **(g)** renewable energy consumption (% of total final energy consumption).

Source: WorldBank Data (2020).

4.1. Unit root results

To identify the stochastic trend component of the test variable, this study uses four unit root panel tests: Levin, Lin and Chu, Im, Peseran and Shin, ADF, and PP, by testing variable stationarity at a probability value of 0.05%.

Table 2. Unit root results.

Tests	**Levin, Lin and Chu**		**Im, Peseran, and Shin**		**ADF-Fisher Chi-square**		**PP Fisher Chi-Square**	
Variable	**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**
D(CO_2)	−2.48075	0.0066	−4.03387	0.000	38.8120	0.000	56.9620	0.000
D(GDPPC)	−5.79292	0.000	−9.23386	0.000	85.9085	0.000	125,554	0.000

Table 2. (*Continued*).

Tests	Levin, Lin and Chu		Im, Peseran, and Shin		ADF-Fisher Chi-square		PP Fisher Chi-Square	
Variable	**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**	**Statistics**	**Prob.**
D(TR)	−4.05271	0.000	−6.60483	0.000	59.8076	0.000	99.5812	0.000
D(FDI)	−9.83423	0.000	−10.4211	0.000	96.3497	0.000	87.0868	0.000
D(DC)	−5.36001	0.000	−4.70390	0.000	40.4712	0.000	51.2980	0.000
D(EC)	−1.97893	0.024	−4.07111	0.000	36.0455	0.000	58.4411	0.000
D(RE)	−2.00475	0.022	−3.16121	0.001	29.9587	0.001	70.5653	0.000

Source: Author.

Based on **Table 2**, it can be concluded that all variables are not stationary at the level but at the first difference level. Therefore, overall, it uses the Vector Autoregressive (VAR) methodology.

4.2. Cointegration test

Based on the results of the cointegration carried out in **Table 3** and **Figure 4**, it can be seen that all variables have a probability level of <0.05 (below the 0.05 significant level), which means that the test variables have cause-and-effect cointegration in the long term. The test can use the VECM method.

Table 3. This is a table cointegration results.

Hypothesized		Trace	0.05	
No. of CE(s)	**Eigenvalues**	**Statistics**	**Critical value**	**Prob.**
None	0.616340	411.5116	125.6154	0.0000
At most 1	0.552237	282.1817	95.75366	0.0000
At most 2	0.380169	173.7103	69.81889	0.0000
At most 3	0.290954	109.1388	47.85613	0.0000
At most 4	0.228974	62.72112	29.79707	0.0000
At most 5	0.158128	27.61670	15.49471	0.0005
At most 6	0.031920	4.379487	3.841466	0.0364

Source: Author.

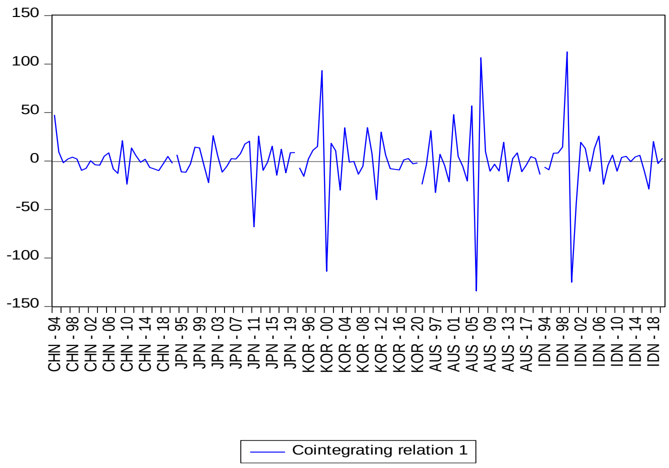


Figure 4. Cointegration test graph.

Source: Author.

4.3. VECM test

In unit root data panel testing, all variables are stationary at the first difference level, which means the test uses the Vector Error Correction Model (VECM) method. This VECM test shows that the dependent variable significantly affects the independent variable if the *t*-statistic value > *t*-table. In research with a data sample of 150 data and 07 variables, the *t*-table value was obtained at 1.976692 at the 0.05 significant level.

Based on the results of the long-term VECM test in **Table 4**, it can be seen that the GDPPC and FDI variables influence the level of carbon emissions in Asia Pacific-5. This follows research by Niyonzima et al. (2022), which states that CO_2 emissions and GDPPC have a negative relationship, which means that the higher the GDPPC, the more CO_2 emissions can be reduced. Meanwhile, FDI, in accordance with research by Essandoh (2020), states that foreign investment has a negative relationship in the long term with CO_2 emissions (Essandoh et al., 2020). This can happen because a country with a high GDPPC and foreign investment will suppress the growth of carbon emissions from various sectors. Meanwhile, the variables DC, TR, EC, and RE together do not have a long-term influence on the development of CO_2 emissions.

Table 4. VECM test results.

No	Variable	Coefficient	*T*-statistics	Information
1	D(CO_2(−1))	1.000000	-	-
2	D(GDPPC(−1))	−7.049190	[−9.81989]	Significant influence
3	D(FDI(−1))	13.38355	[8.81558]	Significant influence
4	D(DC(−1))	−0.147733	[−0.93915]	No effect
5	D(TR(−1))	0.525941	[1.72425]	No effect
6	D(EC(−1))	0.120846	[0.20748]	No effect
7	D(RE(−1))	0.041160	[0.03101]	No effect

Source: Author.

4.4. Impulse response test

Based on the IRF in **Table 5**, at the beginning of the period, the independent variable did not experience a response to CO_2 emissions. The response fluctuates from variable to variable to CO_2 carbon emissions. The variance decomposition results are shown in **Table 6** for further reference.

Table 5. Impulse response test results.

Period	D(CO_2)	D(GDPPC)	D(FDI)	D(DC)	D(TR)	D(EC)	D(RE)
1	0.356510	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.219811	0.017927	0.030432	−0.029773	0.009559	0.000897	0.001544
3	0.246367	−0.016315	0.024205	−0.007202	0.013086	0.006004	−0.005001
4	0.255348	0.008999	0.022069	−0.018412	0.009868	0.004961	−0.001744
5	0.245907	0.001294	0.018451	−0.013769	0.009861	0.004628	−0.002613
6	0.250436	−0.000609	0.026332	−0.015662	0.010350	0.004202	−0.001688
7	0.247474	0.002007	0.019927	−0.015025	0.010953	0.005142	−0.003137

Table 5. (*Continued*).

Period	D(CO_2)	D(GDPPC)	D(FDI)	D(DC)	D(TR)	D(EC)	D(RE)
8	0.250568	0.001566	0.022787	−0.014934	0.009767	0.004477	−0.001822
9	0.247845	0.000842	0.022215	−0.015356	0.010653	0.004654	−0.002579
10	0.249554	0.001405	0.022187	−0.014929	0.010325	0.004732	−0.002288

Source: Author.

4.5. Variance decomposition test

Table 6 shows the variance decomposition results.

Table 6. Variance decomposition results.

Period	SE	D(CO_2)	D(GDPPC)	D(FDI)	D(DC)	D(TR)	D(EC)	D(RE)
1	0.356510	100,0000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
2	0.421479	98.74556	0.180919	0.521317	0.498976	0.051434	0.000453	0.001342
3	0.489365	98.59499	0.245360	0.631365	0.391800	0.109656	0.015387	0.011441
4	0.552912	98.56181	0.218689	0.653887	0.417803	0.117750	0.020103	0.009957
5	0.605673	98.62231	0.182705	0.637733	0.399866	0.124634	0.022591	0.010158
6	0.656220	98.57867	0.155728	0.704291	0.397600	0.131048	0.023345	0.009315
7	0.701891	98.59867	0.136939	0.696219	0.393362	0.138899	0.025773	0.010141
8	0.745855	98.60378	0.121712	0.709901	0.388446	0.140157	0.026428	0.009577
9	0.786511	98.60346	0.109569	0.718185	0.387447	0.144386	0.027267	0.009688
10	0.825668	98.60790	0.099713	0.723885	0.384262	0.146655	0.028026	0.009558

Source: Author.

4.6. Granger causality

Based on the statistical analysis conducted in **Table 7**, it is evident that there are varied causal relationships between CO_2 emissions and different macroeconomic factors. Firstly, Gross Domestic Product per Capita (GDPPC) exhibits a significant two-way causality with CO_2 emissions, as indicated by the probability values of $0.0104 \leq 0.05$ for GDPPC influencing CO_2 emissions and $0.0247 \leq 0.05$ for CO_2 emissions influencing GDPPC. This can be attributed to higher levels of industrialization, increased energy consumption, and greater use of fossil fuels associated with economic growth and development. Conversely, the significant influence of CO_2 emissions on GDPPC suggests that changes in CO_2 emissions levels can impact economic activity and productivity. This could be due to factors such as environmental regulations, the cost of mitigating emissions, or shifts in consumer preferences towards eco-friendly products, all of which can affect economic output and GDP per capita. However, we can observe that Trade Openness (TR) does not significantly affect CO_2 (p-value $0.4653 \geq 0.05$), while CO_2 does not affect TR (p-value $0.9624 \geq 0.05$). Also, Foreign Direct Investment (FDI) does not significantly influence CO_2 (p-value $0.8877 \geq 0.05$), while CO_2 does not significantly influence FDI (p-value $0.8498 \geq 0.05$). Similarly, Domestic Credit (DC) does not significantly influence CO_2 (p-value $0.5642 \geq 0.05$), while CO_2 does not significantly influence DC (p-value $0.0985 \geq 0.05$). These variables do not significantly influence CO_2 emissions, nor do CO_2 emissions significantly influence them, suggesting no two-way causality among them.

Conversely, Energy Consumption (EC) does not significantly influence CO_2 emissions (p-value 0.5642 ≥ 0.05), but CO_2 emissions significantly influence EC (p-value 0.0397 ≤ 0.05), indicating a one-way causality from CO_2 emissions to energy consumption. This finding highlights the complex relationship between CO_2 emissions and energy consumption. While energy consumption patterns may not directly impact CO_2 emissions in this context, CO_2 emissions significantly influence energy consumption behaviors. It suggests that factors such as industrial processes, transportation systems, and energy production methods contribute to CO_2 emissions and also play a crucial role in shaping overall energy consumption patterns. Similarly, Renewable Energy (RE) significantly influences CO_2 emissions (p-value 0.0393 ≤ 0.05), while CO_2 emissions do not significantly influence RE (p-value 0.0797 ≥ 0.05), suggesting a one-way causality from renewable energy to CO_2 emissions. This indicates that changes in renewable energy consumption have a notable impact on CO_2 emissions levels, meaning that an increase in the use of renewable energy sources correlates with a decrease in CO_2 emissions. However, the absence of a significant influence of CO_2 emissions on renewable energy consumption implies that changes in CO_2 emissions do not necessarily drive alterations in the utilization of renewable energy sources. This finding underscores the importance of renewable energy adoption as a means to mitigate CO_2 emissions and promote environmental sustainability.

Table 7. Granger causality results.

Null Hypothesis	Obs	F-statistics	Prob.
GDPPC does not Granger Cause CO_2	145	6.73462	0.0104
CO_2 does not Granger Cause GDPPC		5.15121	0.0247
TR does not Granger Cause CO_2	145	0.53592	0.4653
CO_2 does not Granger Cause TR		0.00223	0.9624
FDI does not Granger Cause CO_2	145	0.02002	0.8877
CO_2 does not Granger Cause FDI		0.03601	0.8498
DC does not Granger Cause CO_2	145	0.33401	0.5642
CO_2 does not Granger Cause DC		2.76517	0.0985
EC does not Granger Cause CO_2	145	2.01036	0.1584
CO_2 does not Granger Cause EC		4.31032	0.0397
RE does not Granger Cause CO_2	145	4.32559	0.0393
CO_2 does not Granger Cause RE		3.11535	0.0797

Source: Author.

5. Conclusion

This research analyzes the influence of economic growth, macro pillars, and energy consumption on the development of CO_2 emissions in EAP-5 for 30 years (1991–2020). The empirical results in this research show a cointegration of long-term and short-term trends in the dependent and independent variables. Based on the tests carried out, it was found that economic growth and foreign direct investment variables significantly affect the development of CO_2 carbon emissions in the long-term relationship. A higher country's GDPPC will reduce CO_2 emissions, while high investment will increase CO_2 emissions in EAP-5. Meanwhile, domestic credit, trade, energy consumption, and renewable energy variables do not influence the development of CO_2 carbon emissions in the long term in EAP-5. In looking at the short-term causality relationship, the Granger test shows that the GDPPC variable experiences two-way causality towards carbon emissions, and the consumption energy and renewable energy variables experience one-way causality towards carbon emissions. In contrast, the trade, foreign direct investment, and domestic credit to private sector variables do not experience causality two-way against CO_2 emissions.

The results of this research have several policy implications for the EAP-5 in suppressing the development of CO_2 carbon emissions. The significant two-way causality between GDPPC and CO_2 emissions underscores the interconnected nature of economic development and environmental sustainability. It highlights the need for policies and strategies that promote economic growth while simultaneously addressing the environmental challenges posed by CO_2 emissions, aiming for a balance between economic prosperity and ecological responsibility. Increasing GDPPC in the EAP-5 region can create opportunities for diversification in economic sectors, especially in the services sector, information technology, and sustainable industry, so that it can help reduce carbon emissions. Also, addressing CO_2 emissions may lead to changes in energy consumption practices, such as implementing energy-efficient technologies or transitioning to cleaner energy sources. Therefore, strategies aimed at reducing CO_2 emissions can indirectly influence energy consumption behaviors, contributing to efforts to mitigate climate change and promote sustainability. In addition, policies to encourage economic growth must be accompanied by a focus on the renewable energy transition. Our finding suggests that policies aimed at increasing the share of renewable energy in the energy mix can effectively contribute to reducing greenhouse gas emissions without significant feedback effects from CO_2 emissions influencing renewable energy consumption. Therefore, fostering the transition towards renewable energy sources represents a promising strategy for addressing climate change and achieving sustainable development goals. Thus, the government must encourage investment in the clean energy sector, such as renewable energy (solar, wind, hydro, and environmentally friendly technology), as shown by previous studies of Nguyen et al. (2023a) and Zhang et al. (2023).

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