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Renewable energy dynamics in Southeast Asia: Analyzing the impact of CO2 emissions, geopolitical risk, tourism, and GDP through FMOLS and CCR estimation approach

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Abstract

This study examines the impact of CO_2 emissions, geopolitical risk, economic growth, and tourism on renewable energy consumption (as a proxy for clean energy) in five Southeast Asian countries from 1995 to 2023. The research aims to identify key drivers and barriers to clean energy adoption in the region. The study employs the Fully Modified Ordinary Least Squares (FMOLS) regression technique to analyze the long-term relationships between the variables. Additionally, Canonical Cointegrating Regression (CCR) estimation is used as a robustness check to validate the findings. The results reveal that CO_2 emissions negatively affect clean energy consumption in Indonesia, Malaysia, and the Philippines but improve renewable energy adoption in Thailand. Economic growth has a significant negative impact on clean energy in Indonesia, Thailand, and Vietnam, whereas it serves as a driver in Malaysia. Geopolitical risk exerts a strong adverse effect on renewable energy consumption only in the Philippines and Vietnam. Finally, tourism is negatively associated with clean energy solely in Malaysia. The results show that economic and geopolitical considerations have varying effects on the adoption of renewable energy throughout Southeast Asia, indicating that each country needs a different approach to policy. In support of clean energy adoption, policymakers must devise personalized strategies that cater to the distinct challenges of every country. In this regard, it could involve adopting carbon pricing in those countries with high-emitting characteristics, fostering stable geopolitics to hedge against risks to investments, and synchronizing tourist development with sustainable goals. Research also calls for regional coordination so that one may consolidate efforts with the possibility of aggregating resources by which Southeast Asian countries can navigate commonalities during a transition to renewable energy.

Keywords: CO_2 emissions, economic growth, FMOLS regression, geopolitical risk, renewable energy consumption, tourism.

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1. Introduction

The energy challenge in Southeast Asia is complex and intertwined with environmental, economic, and geopolitical implications. Among these, the transition to clean or renewable energy has truly become one of the main driving forces for sustainable development as countries try to strike a delicate balance between pursuing economic growth and the reduction of carbon emissions to counter climate change. The role of renewable energy is very important for Southeast Asia, considering its vulnerability to climate-related risks and dependence on fossil fuel sources for energy production. Understanding the multidimensional drivers of renewable energy adoption within this context is crucial for informing effective policy formulation and strategy in line with both global sustainability goals and regional development priorities.

This study explores the effects of four key variables: CO_2 emissions, geopolitical risk (GPR), tourism, and GDP on the consumption and development of renewable energy in five Southeast Asian countries: Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. All these countries face different challenges and opportunities with regard to a transition toward clean energy because of their specific economic structure, resources, and conditions, dependent on external factors, such as geopolitical stability. Their share of CO_2 emitted through the consumption of fossil fuel is great enough to constitute environmental degradation and raises questions about the use of cleaner sources of energy. Simultaneously, their economic growth, having its industrialization and tourism sectors-is influential in determining their energy demand and potential for renewable energy uptake.

Geopolitical risk further complicates the energy landscape, adding to the impact on energy security, foreign investments, and the implementation of energy policies. Tourism is another significant driver of the economy, but it enhances the demand for energy systems, especially in highly touristic destinations, which makes the relationship between energy demand and environmental sustainability even more complex. This paper, therefore, attempts to analyze how these factors interact and influence renewable energy consumption in Southeast Asia, with a view to providing a nuanced understanding of the regional dynamics shaping the future of clean energy adoption. It also hopes to add valuable inputs for policymakers and stakeholders working toward a sustainable energy future in Southeast Asia.

The novelty of this study is threefold. Firstly, to the best of our knowledge, this study is the first attempt to analyze factors affecting clean energy in these five countries of the Southeast Asia region. Secondly, this study introduced tourism, CO_2 emissions, geopolitical risk, and economic growth as possible determinants to study their impact on renewable energy. Thirdly, this study used the FMOLS (fully modified ordinary least squares) regression technique to explore the relationship between variables. Canonical cointegration regression (CCR) estimation is used as a robust estimator.

The structure of this paper is organized as follows: Section 2 reviews the relevant literature. Sections 3 and 4 describe the data and methodology used in this study. Section 5 presents the empirical results. Section 6 provides a comprehensive discussion. Finally, Section 7 concludes and examines the policy implications derived from the findings.

2. Literature Review

In the wake of growing environmental challenges, in particular those associated with CO_2, the transition towards clean energy has achieved global priority status. Solar and wind power along with hydroelectricity, are rightly regarded as essential elements in the paradigm of sustainable development and climate change mitigation. However, influencing factors on the adoption and consumption of clean energy are greatly differing between different regions and economic settings, and may be studied at great detail. Among these, the interaction of economic growth (GDP), geopolitical risk (GPR), tourism, and CO_2 emissions holds particular interest in its multiway impact on energy policies and practices.

This, in turn, as a by-product of burning fossil fuel, further deteriorates the environment and acts as a catalyst to accelerate clean energy. Similarly, GDP growth can be either a hindrance or a driver to renewable energy adoption, depending on policy frameworks and investment priorities. Tourism is yet another layer to this dynamic, adding that it is one of those sectors contributing to economic growth as well as environmental strain. Geopolitical risks, in turn, affect energy security and the stability of renewable energy investments, adding a further layer of complexity.

This literature review seeks to explore the existing body of knowledge on the effects of CO_2 emissions, GDP, GPR, and tourism on renewable energy consumption. By synthesizing theoretical and empirical findings, this review aims to provide a comprehensive understanding of the drivers and barriers to clean energy adoption, offering insights to inform future research and policy development in the context of global energy transitions.

Akay et al. [1] investigated the causal links among renewable energy, CO_2 emissions, and economic growth in a group of Middle East and North African countries. Their findings revealed a bidirectional causality between economic growth and renewable energy, a unidirectional causality from CO_2 emissions to renewable energy, and another one-way causality from economic growth to CO_2 emissions within these countries.

Omri et al. [2] analyzed the factors influencing renewable energy consumption across a panel of 64 countries, encompassing high-, middle-, and low-income nations, during the period from 1990 to 2011. Their findings revealed that CO_2 emissions per capita significantly affect renewable energy consumption per capita, independent of a country's GDP level.

Lu [3] explored the relationship between CO_2 emissions, renewable energy consumption, and economic growth across 24 Asian countries. The study found that these three variables are cointegrated over the long term. Based on country-specific coefficients, CO_2 emissions were shown to have a negative impact on renewable energy consumption in six countries, a positive impact in another six, and no significant effect in the remaining countries. Additionally, economic growth was positively associated with renewable energy consumption in seven countries, negatively in two, and insignificantly in the

others. The causality analysis revealed bidirectional causality between renewable energy and both CO_2 emissions and economic growth, alongside a unidirectional causality from economic growth to CO_2 emissions.

Alola and Alola [4] analyzed how agricultural land use and tourism influence renewable energy consumption in the Mediterranean coastal countries. The results showed that an increase in agricultural land use leads to an increase in renewable energy consumption because farms are increasingly using solar and wind energy for irrigation and processing. Tourism causes huge seasonal increases in energy demand, especially in coastal areas, which has driven investment in renewable energy infrastructure. However, large-scale renewable energy projects are constrained by land scarcity, making a trade-off between agriculture and energy generation. Economic development and supportive government policy positively moderate the adoption of renewable energy, while high population density amplifies the demand for energy but complicates infrastructure expansion.

Chen [5] examined the drivers and barriers to renewable energy consumption in China, using provincial panel data. The results indicated that economic growth is positively related to renewable energy consumption because it raises the demand for energy and allows for investment in renewable energy infrastructure. Technological innovation significantly enhances the efficiency of renewable energy and its adoption. While strong enablers do exist in government policies, such as subsidies and renewable energy targets, amplifying the demand is achieved by industrialization and urbanization. Challenges, however, in terms of balance, are posed toward reducing fossil fuel dependence. Renewable resource availability and infrastructure remain uneven among provinces.

Isik et al. [6] explored the linear and nonlinear interrelationships between tourism demand, renewable energy consumption, and economic growth. The empirical results indicate that there is a bidirectional linear relationship between tourism demand and economic growth, as increased tourism fuels economic activities and vice versa. Similarly, renewable energy consumption has a positive linear impact on economic growth, entrenching its role in sustainable development. Non-linear dynamics suggest that excessive tourism demand strains renewable energy resources and consequently reduces efficiency, while a moderate level of renewable energy consumption optimizes tourism-related energy needs.

Ben Jebli et al. [7] examined the dynamic relationships between renewable energy consumption, tourism, CO_2 emissions, economic growth, foreign direct investment (FDI), and trade. The authors identified some significant unidirectional and bidirectional causal relationships among variables. The unilateral causality supports the fact that renewable energy consumption reduced CO_2-related emissions, FDI increased the demand for renewable energy, trade resulted in higher economic growth, and tourism increased the CO_2 emissions whenever sustainable energy resources were not consumed. From the bidirectional ones, there exists a positive reinforcement of economic growth-renewable energy consumption, tourism-economic growth, and trade-FDI.

Bayar et al. [8] identified a one-way causality from CO_2 emissions to renewable energy in Lithuania and Slovenia, while observing a bidirectional relationship between renewable energy and CO_2 emissions in Romania and Slovakia. However, they found no causal links between the two variables in the remaining seven EU transition economies studied during the period 1995–2015.

Cai and Wu [9] analyzed the dynamic relationship that exists between GPR and renewable energy consumption by using time-varying analysis. The outcome has shown that, at different periods and given various times and geopolitical contexts, GPR affects positive and negative renewable energy consumption. While it is geopolitical tensions that increase renewable energy consumption, given the concern of countries on energy security and diversification, this relation is weakened at stable periods. Second, the effect of GDP on renewable energy consumption is positive, reflecting a function of economic capacity to invest in clean energy infrastructure. Oil prices have a mixed effect: while high prices provide an incentive to adopt renewable energy, they could implicate energy affordability problems in some regions.

Godawska and Wyrobek [10] investigated the effect of environmental policy stringency on renewable energy production in the Visegrad Group countries (the Czech Republic, Hungary, Poland, and Slovakia). It finds that stricter environmental policies positively influence renewable energy production, emphasizing the role of robust regulatory frameworks in fostering clean energy. The study also shows that a higher level of GDP magnifies the positive effect of EPS on renewable energy, and CO2 emissions are inversely related to renewable energy, implying that the higher the emissions, the lesser the production of renewable energy.

Sweidan [11] analyzed a sample of 10 net oil-importing countries to examine whether geopolitical risk (GPR) motivates nations to reduce their dependence on fossil fuels and increase their reliance on alternative energy sources. His findings support the idea that heightened geopolitical tensions have a positive effect on the adoption of clean energy technologies.

Cheikh and Zaied [12] provided evidence on renewable energy's determinants from 1990 to 2018 for a sample of 34 countries. They found that CO_2 emissions and income growth negatively impact the diffusion of clean energy solutions. But there is a significant positive impact of trade openness and geopolitical risk on the share of clean energy.

Chu et al. [13] found that the shadow economy significantly constrains renewable energy deployment, although this effect is stronger in middle-income countries. Strict environmental policy is conducive to renewable energy adoption in both groups, but high-income countries have a greater responsiveness due to stronger enforcement. The geopolitical risk helps renewable energy in the group of high-income countries because energy security issues take a leading role and impede it in middle-income countries, since instability discourages investments. The study revealed a positive relationship between CO_2 emissions and renewable energy in high-income countries and a negative relationship in middle-income countries.

Dong et al. [14] observed that, for BRICS nations, increased geopolitical tensions could positively impact the renewable energy sector and stimulate green investment initiatives. Similarly, Hille [15], employing an instrumental variable approach, found comparable results for 37 European countries. Hille [15] emphasized that geopolitical conflicts in oil-producing regions act as a catalyst, accelerating Europe's transition to cleaner energy solutions.

Athari [16] investigated the impact of global economic policy uncertainty on renewable energy demand within OECD countries, along with its interaction with environmental policy stringency and other determinants over the period 1990-2018. The results indicated that higher EPU decreases renewable energy demand since such uncertainty discourages investment in green energy projects. On the other hand, strong environmental policy mitigates the negative impact of uncertainty with a stable regulatory environment. Again, CO_2 emissions and economic development are found to be positively contributing to renewable energy demand, indicating that with increasing environmental degradation and economic growth, demand for renewable energy is increasing. FDI supports the adoption of renewable energy, but with higher natural resource rents, it adversely affects the same, presumably because of dependence on conventional energy resources.

Belloumi and Aljazea [17] examined the effects of economic growth and financial development on renewable energy consumption in 13 major oil-exporting countries between 1990 and 2020. According to the result, long-run renewable energy use is positively associated with both economic growth and financial development, hence inferring that the more countries are economically grow and developing their financial sectors, the more they use renewable energy. However, economic growth results in negative impacts on renewable energy in the short run, perhaps due to increased demand that depends on conventional energy sources.

Cheikh and Zaied [18] investigated the impact that geopolitical uncertainty has on the adoption and diffusion of clean energy technologies for a panel of countries across the period 1995-2020. The findings indicate that geopolitical uncertainty significantly enhances the process of the diffusion of clean energies, since countries try to reduce their dependence on volatile fossil fuel markets and enhance energy security. This effect is more pronounced in high-income countries with sound institutional frameworks and established policy initiatives for clean energy.

Erdogan et al. [19] explored how GPR might have an impact on German, French, Italian, Polish, and Austrian clean energy generation with daily data spanning 2010-2021. In these countries, especially in reducing dependency on imports of Russian fossil fuel, increasing geopolitical risk has considerably raised the level of clean energy generation. The stronger this effect will be, the greater the levels of geopolitical tension become-representative of strategic change towards energy security and diversification.

3. Data

This analysis examines the effect of geopolitical risk, CO_2 emissions, tourism, and GDP on clean energy in five Southeast Asian countries (Indonesia, Malaysia, Philippines, Thailand and Vietnam). The selection of these countries for this study is based on their strategic and diversified importance in Southeast Asia, representing dynamic economies with high energy demands and varied levels of renewable energy uptake. These countries are among the major contributors of CO_2 emissions in the world due to their high dependence on fossil fuels, industrialization, and urbanization; hence, this places them at a critical position with regard to transitioning in clean energy for the region. They also have high economic growth and strong tourism industries, factors that shape energy use patterns. In addition, unique geopolitical risks in these countries influence the investment in and adoption of renewable energy.

The temporal scope of our data is from 1995 to 2023, thus enabling a full and extensive review. The logged variables are tourism (TOUR) and economic growth (GDP). More information about the data and the sources used may be found in the informative Table 1 shown below.

Table 1.
Description and definition of variables.

Variables	Symbols	Remark/comment	Data sources
Clean Energy	REN	Renewable Energy Consumption (% of total final energy consumption)	WDI, Our World in Data
Geopolitical Risks	GPR	Index	https://www.matteoiacoviello.com/gpr.htm
Tourism	TOUR	Total number of arrivals in the host country	WDI, World Tourism Organisation
Economic Growth	GDP	GDP per capita (Constant 2015 US$)	WDI
Environment degradation	CO_2	CO_2 emissions (metric tons per capita)	WDI, Our World in Data

3.1. Descriptive statistics

Table 2 presents the descriptive statistics of the variables and permits to assets the differences in renewable energy consumption (REN), CO_2 emissions, GPR, LTOUR and LGDP countries of the study.

Table 2.
Descriptive statistics.

	Variables	REN	CO_2	GPR	LTOUR	LGDP
Indonesia	Mean	35.46	1.77	0.05	15.68	7.87
	Median	38.20	1.64	0.04	15.52	7.84
	Max	50.70	2.64	0.11	16.59	8.34
	Min	18.59	1.11	0.02	14.26	7.48

	Std. Dev.	10.45	0.43	0.03	0.49	0.29
Malaysia	Mean	4.28	6.78	0.04	16.38	8.99
	Median	4.20	6.96	0.03	16.68	8.98
	Max	7.89	8.37	0.14	17.13	9.34
	Min	2.00	4.64	0.01	11.81	8.66
	Std. Dev.	1.72	1.11	0.03	1.04	0.22
Philippines	Mean	31.26	0.97	0.04	14.86	7.78
	Median	32.40	0.88	0.04	14.86	7.26
	Max	37.80	1.35	0.11	15.93	8.23
	Min	21.66	0.74	0.01	12.01	7.43
	Std. Dev.	3.67	0.19	0.03	0.73	0.26
Thailand	Mean	21.37	3.38	0.04	16.42	8.47
	Median	21.60	3.36	0.03	16.44	8.48
	Max	24.40	4.04	0.07	17.50	8.77
	Min	15.62	2.60	0.01	13.62	8.10
	Std. Dev.	2.10	0.49	0.01	0.78	0.22
Vietnam	Mean	40.67	1.67	0.05	15.16	7.56
	Median	37.90	1.44	0.04	15.14	7.46
	Max	64.90	3.70	0.22	16.71	8.23
	Min	18.90	0.42	0.01	11.96	6.83
	Std. Dev.	14.02	0.98	0.04	0.95	0.42

The data reveals significant disparities between countries across key variables. Vietnam has the highest mean for REN, indicating significant reliance on renewable energy, but Malaysia shows a considerably lower mean than other countries, suggesting limited renewable energy use. For CO_2 emissions, Malaysia has the highest mean, reflecting greater industrial activity or fossil fuel dependency. However, the Philippines has the lowest CO_2 mean, suggesting lower emissions or a less industrialized economy. Geopolitical risk (GPR) is generally low across all countries, with similar means ranging from 0.04 to 0.05. Thailand has the highest mean for LTOUR, aligning with its reputation as a global tourism hub. In contrast, the Philippines has the lowest mean, suggesting comparatively lower tourism activity. Malaysia has the highest mean LGDP, reflecting its relatively advanced economy. However, Thailand follows closely, while Indonesia, the Philippines, and Vietnam have lower LGDP means, indicating smaller economies or less wealth on average.

3.2. Unit Root Test

Table 3 shows the result of the unit root test with Augmented Dickey-Fuller (ADF) unit root test. This is a statistical test to check whether the status of the unit-root of our series indicates non-stationarity or not, because stationarity is crucial in conducting the analysis using models.

The above result of the ADF unit root suggests that all the variables for their respective countries are not stationary at l(0) but are stationary after the first difference, that is, l(I).

Table 3.
Augmented Dickey-Fuller test.

	REN		**CO_2**		**GPR**		**LTOUR**		**LGDP**	
	I(0)	**I(1)**	**I(0)**	**I(1)**	**I(0)**	**I(1)**	**I(0)**	**I(1)**	**I(0)**	**I(1)**
Indonesia	-0.13 0.94	-6.25 0.00***	0.96 0.99	-5.59 0.00***	-2.40 0.15	-6.08 0.00***	-1.83 0.36	-6.55 0.00***	0.66 0.99	-4.16 0.00***
Malaysia	-1.02 0.93	-4.19 0.01***	-3.06 0.14	-5.4 0.00***	-2.39 0.37	-5.74 0.00***	2.15 1.00	-6.57 0.00***	-3.18 0.11	-5.83 0.00***
Philippines	-0.36 0.90	-4.56 0.00***	0.34 0.98	-3.69 0.04**	-2.55 0.30	-3.81 0.03**	-2.16 0.23	-4.54 0.00***	0.62 0.99	-3.79 0.01***
Thailand	-0.17 0.99	-4.18 0.00***	-1.53 0.51	-3.63 0.01**	-2.31 0.41	-7.97 0.00***	-1.93 0.32	-6.62 0.00***	-0.34 0.91	-4.24 0.00***
Vietnam	-3.42 0.07*	-5.01 0.00***	1.26 0.99	-7.54 0.00***	-2.86 0.06*	-6.63 0.00***	-2.92 0.06*	-6.11 0.00***	-1.69 0.73	-4.45 0.00***

Note: *** & ** indicate 1% & 5% significance level respectively, L denotes log.

3.3. Co-Integration Test

Alongside the unit root test, the cointegration test plays a vital role in dynamic and causality analyses by identifying long-term relationships between variables. This study utilizes the Johansen cointegration test, renowned for its reliability in detecting cointegration.

The results for each country in Table 4 provide critical insights into the degree and structure of interdependence among the examined variables. For Indonesia, Malaysia, and Vietnam, the presence of one cointegrating relationship suggests a stable long-term equilibrium among the studied variables, despite short-term fluctuations. But for the Philippines, the

detection of three cointegrating relationships indicates a complex interplay among the variables, reflecting robust long-term connections. For Thailand, evidence of two cointegrating equations highlights moderate but meaningful linkages among variables over the long term.

Table 4.
Results of Johansen co-integration test.

	Hypothesized No. of CE(s)	Fisher Stat.* (From trace test)	Prob.	Fisher Stat.* (From max-eigen test)	Prob.
Indonesia	None	96.6057	0.0001*	54.2504	0.0001*
	At most 1	42.3553	0.1490	19.0679	0.4093
	At most 2	23.2873	0.2322	15.5298	0.2535
	At most 3	7.7575	0.4917	5.3143	0.7018
	At most 4	2.4433	0.1180	2.4433	0.1180
Malaysia	None	93.2228	0.0002*	46.9236	0.0008*
	At most 1	46.2993	0.0695	26.8049	0.0627
	At most 2	19.4944	0.4578	14.3093	0.3402
	At most 3	5.1851	0.7889	4.0797	0.8508
	At most 4	1.1054	0.2931	1.1054	0.2931
Philippines	None	108.6192	0.0000*	39.7392	0.0089*
	At most 1	68.8801	0.0002*	36.6258	0.0026*
	At most 2	32.2543	0.0256	23.1894	0.0253
	At most 3	9.0648	0.3594	9.0648	0.2808
	At most 4	0.0000	0.9991	0.0000	0.9991
Thailand	None	123.4250	0.0000*	72.5351	0.0000*
	At most 1	50.8899	0.0252*	26.5727	0.0669
	At most 2	24.3173	0.1874	16.4337	0.2005
	At most 3	7.8836	0.4779	6.7422	0.5201
	At most 4	1.1414	0.2854	1.1414	0.2854
Vietnam	None	108.9126	0.0000*	61.8188	0.0000*
	At most 1	47.0938	0.0589	28.0438	0.0437*
	At most 2	19.0499	0.4893	11.0963	0.6377
	At most 3	7.9537	0.4704	7.1197	0.4751
	At most 4	0.8340	0.3611	0.8340	0.3611

Note: * indicate significant at 5% level

4. Methodology

After determining a substantial long-run relationship between the variables, we employ the estimation procedure of Fully Modified Ordinary Least Squares. FMOLS is developed by Pedroni [20] to retrieve the unbiased estimators. This technique is a residual-based test that provides efficient results in the case of cointegrated variables. According to Hamit-Haggar [21] it is especially noted for small sample sizes while being able to handle the effects of endogeneity and serial correlation. Moreover, we applied the Canonical Cointegrating Regression (CCR) as a robustness check to confirm the findings obtained through FMOLS [22, 23].

To explore the relationship between the dependent and independent variables, the functional specification for our model is stated as:

$$REN = f(CO2, GPR, LTOUR, LGDP) \quad (1)$$

Basically, Eq. (1) is then remodelled as:

$$REN_t = \alpha_0 + \alpha_1 CO2_t + \alpha_2 GPR_t + \alpha_3 LTOUR_t + \alpha_4 LGDP_t + \varepsilon_t \quad (2)$$

Where: REN is renewable energy consumption, CO_2 is CO_2 emissions, GPR is geopolitical risk index, LTOUR represents log of tourism, LGDP is the log of gross domestic product and ε stands for the error term all at time 't' time period. α_1, α_2, $\alpha_3$and $\alpha_4$are the estimated slope coefficients of the regressors, α_0 is the intercept.

5. Results

5.1. FMOLS Estimation Results

Table 5. presents the results obtained from FMOLS estimator for our five countries.

Table 5.
FMOLS estimates.

Variable	Indonesia	Malaysia	Philippines	Thailand	Vietnam
CO_2	-11.486***	-2.425***	-13.502***	11.928***	3.854
	(3.775)	(0.774)	(3.399)	(3.089)	(2.608)
GPR	-9.581	5.142	-25.326*	16.193	-47.943**
	(17.963)	(9.498)	(12.457)	(22.934)	(20.406)

LGDP	-19.653***	16.023***	-3.443	-25.234***	-37.285***
	(5.919)	(3.995)	(2.492)	(6.363)	(5.748)
LTOUR	0.215	-1.026***	0.331	0.434	-0.338
	(0.287)	(0.238)	(0.450)	(0.494)	(0.728)
_Constant	207.395***	-106.711***	67.276***	187.055***	323.770***
	(41.657)	(31.857)	(15.595)	(46.725)	(35.537)
Adj. R^2	0.972	0.422	0.647	0.261	0.953

Note: ***, **, and * imply the significance at 1%, 5%, and 10% level, respectively. Standard errors are presented in the parenthesis.

In Indonesia, CO_2 emissions and GDP significantly reduce renewable energy adoption, likely reflecting dependency on traditional energy sources. Geopolitical risk and tourism have no significant influence.

In Malaysia, CO_2 emissions negatively impact renewable energy, while GDP positively supports it, indicating economic growth fosters renewable investment. However, tourism shows a significant negative effect, possibly due to energy demands from conventional sources.

For the Philippines, CO_2 emissions significantly hinder renewable energy adoption, while geopolitical risk has a weakly negative effect. Neither GDP nor tourism show a significant influence.

In Thailand, higher CO2 emissions are associated with increased renewable energy use, possibly as a response to environmental concerns, while GDP significantly reduces it, reflecting reliance on fossil fuels. Geopolitical risk and tourism are not significant.

In Vietnam, geopolitical risk and GDP both significantly reduce renewable energy adoption, indicating economic and political stability challenges. CO_2 emissions and tourism have no significant impact.

5.2. Robustness check: Canonical Cointegrating Regression (CCR)

Canonical Cointegrating Regression (CCR) provides a robustness check for the results from FMOLS since it is a reliable alternative method of estimation of long-run relationships in cointegrated systems, while considering problems such as endogeneity and serial correlation. The transformation carried out by CCR frees the variables from the correlations between the error term and regressors, hence providing consistent estimates in a non-biased way. It is efficient, especially when dealing with small samples, since it offers more stability in the estimation process.

Results obtained from the CCR estimator are presented in Table 6.

Table 6.
CCR estimates.

Variable	Indonesia	Malaysia	Philippines	Thailand	Vietnam
CO_2	-11.687**	-2.472***	-13.365***	12.836***	4.614
	(4.375)	(0.836)	(3.501)	(3.905)	(2.981)
GPR	-10.626	5.308	-24.567*	15.564	-57.901**
	(22.308)	(12.007)	(12.921)	(24.358)	(27.414)
LGDP	-19.371**	16.289***	-3.777	-27.247***	-38.134***
	(6.977)	(4.266)	(2.512)	(8.129)	(6.835)
LTOUR	0.126	-1.074***	0.303	0.221	-0.337
	(0.891)	(0.276)	(0.572)	(0.684)	(1.323)
_Constant	207.000***	-107.960***	70.094***	204.536***	329.444***
	(48.133)	(34.278)	(14.753)	(62.750)	(36.780)
Adj. R^2	0.972	0.403	0.645	0.247	0.950

Note: ***, **, and * imply the significance at 1%, 5%, and 10% level, respectively. Standard errors are presented in the parenthesis.

The results show that the CCR model results are consistent with the previous estimation method i.e., FMOLS only the value of coefficient varies slightly. Also, for Indonesia, the significance level of CO_2 and LGDP changed from 1% in FMOLS to 5% in CCR.

6. Discussion

6.1. Case of Indonesia

Table 5 shows that CO_2 is negatively and significantly associated with renewable energy. This might be attributed to the high dependence of the country on fossil fuels, especially coal, which is the dominant energy source in its mix. Indonesia is one of the largest exporters of coal in the world, and the national energy policy has traditionally favored the development of fossil fuels due to their affordability and abundance. High dependence on coal contributes to higher CO_2 emissions and may inhibit investment in renewable energy infrastructure. This may further be related to insufficient economic incentives, regulatory frameworks, and technical capacity for scaling up renewable energy projects.

Also, it is shown that LGDP has a significant negative effect on clean energy. The above would thus suggest a relationship where, with the improvement in the economy, the country's reliance on conventional energy sources becomes very high and the development of renewable energy installations very low. This perhaps can be justified by the fact that most energy-related industries, such as mining, manufacturing, and the production of agricultural products, in Indonesia still rely on fossil fuels. Besides, economic growth can lead to an increase in energy demand, which is met through established and

cost-effective fossil fuel infrastructure rather than renewable alternatives due to their higher initial investment costs and policy barriers. In addition, subsidies for fossil fuels, which are common in Indonesia, could make renewables less competitive, thus discouraging their adoption despite economic progress.

For the tourism (LTOUR) and the geopolitical risk (GPR), both haven't a significant effect on clean energy. These two insignificances can be explained by the peculiarities of these factors in the Indonesian context. For instance, even though tourism is one of the major tourist destinations in the world, its tourism sector is still not closely linked with the development of renewable energy. Most of the tourism-related activities, especially in remote areas, still depend on conventional sources of energy due to a lack of infrastructure and high costs associated with integrating renewable energy into the sector. This could be a reason for the missing link between tourism and its impact on renewable energy adoption.

In Indonesia, geopolitical risk traditionally shows relative political stability, and its energy policy is more linked to domestic economic and regulatory issues than to geopolitics. Therefore, geopolitical risk to renewable energy investment is low since the decisions involved in energy investment are more domestic, internal ones: subsidies, market structures, and regulatory frameworks. Evidence has therefore shown that while tourism and geopolitical risks do play a vital role in other contexts, they have yet to be major variables that influence Indonesia's renewable energy landscape.

6.2. Case of Malaysia

Table 5 reports that CO_2 emissions negatively affect clean energy. The negative relation of CO_2 emissions with clean energy adoption can thus be explained by the context of Malaysia in relation to heavy dependence on fossil fuel, especially natural gas and oil, for energy needs. While Malaysia has increased awareness on environmental issues, fossil fuel-based power generation dominates in the energy sector due to an established infrastructure base, lower comparative costs, and rich domestic fossil fuel reserves. While CO_2 emissions increase, it is a reflection of the continued use of these conventional energy sources and takes away from the push for renewable energy. Moreover, the economic and political foci on ensuring energy security and cost-effective generation of power may also eclipse the necessity of switching over to cleaner sources of energy and make the road to renewable energy sources more difficult to travel.

Economic growth (LGDP) appears to be the driver of clean energy. Our findings are supported by the results of Belloumi and Aljazea [17]. This positive relationship suggests that with the growth of the economy, there is increased potential and capacity to invest in renewable energy technologies. Economic growth in Malaysia, especially in sectors such as manufacturing and services, has created a rising demand for energy and, consequently, a growing need for sustainable and diversified energy sources. Greater GDP would, in turn, give Malaysia more resources to invest in clean energy infrastructure, research and development, and phasing out fossil fuels. Indeed, economic growth usually comes with higher levels of awareness about environmental problems, thus making the environment more propitious for green investments and policies. It speaks to the growing importance of rendering economic growth sustainable with the country inching toward attaining its renewable energy targets under the 11th Malaysia Plan and other sustainability frameworks.

Tourism (LTOUR) has an adverse effect on renewable energy consumption. This can be justified by the nature of the tourism industry as being energy-intensive. Malaysia as a tourist destination, the industry in places, such as resort islands or urban centers, relies heavily on conventional sources to meet its spiralling energy demand. Generally, the hotel industry and transportation, as well as recreational facilities in tourism areas, rely on fossil fuels due to the high front-end costs associated with renewable integration and inadequate infrastructure in heavy tourism areas. Accompanied by the growth in tourism is increased energy demand, but more often than not, this demand is accommodated not by renewables but by conventional sources, since these would be more expensive to implement in the short-term, high-demand sectors like tourism. Besides, tourism as a form of economic development often diverts attention from investing in long-term sustainable energy infrastructure.

As in the Indonesian context, GPR has no significant effect on clean energy. This could be because of the politically stable environment and energy policies internally driven by priorities such as energy security and economic growth. In fact, the development of renewable energy is more driven by internal factors—including government incentives and market dynamics—rather than external geopolitical events.

6.3. Case of Philippines

CO_2 emissions are negatively and significantly associated with renewable energy which reflects the dominance of fossil fuels in meeting energy demands despite the rich renewable energy resources of the country, such as geothermal, wind, and solar. High project costs, outdated infrastructure, and regulatory challenges are some of the stumbling blocks to transitioning to clean energy.

Negative and significant coefficient of GPR can be attributed to the country's vulnerability to both domestic and regional political uncertainties. Geopolitical risks, such as territorial disputes in the South China Sea or internal conflicts, make the atmosphere unstable for foreign and local investment in long-term renewable energy projects. More important, these risks even change government priorities to focus more on direct security and economic problems. Our results are consistent with those of Chu et al. [13] for Middle-Income Countries.

For the economic growth (LGDP) and the tourism (LTOUR), both they haven't a significant effect on clean energy. The insignificant effect of economic growth may suggest that the economic growth of the country is not in line with investment in renewable energy, since economic growth usually favours conventional energy sources to meet the growing demand. Similarly, the insignificant effect of tourism implies that energy utilization in this industry is still heavily dependent on conventional energy sources, with little effort toward sustainable practices or renewable energy infrastructure.

6.4. Case of Thailand

As shown in Table 5, CO_2 appears to be the driver of clean energy. This positive relationship indicates that increasing emissions are driving the move towards renewable energy in response to environmental concerns and international commitments. The Thai government has set ambitious renewable energy targets under its Power Development Plan and is actively working on reducing greenhouse gas emissions. This increase in CO_2 emission means dependence on fossil fuel, and probably encouraged government policy and investment to move towards renewable energy sources for the sustainability objective and compliance with international climate agreements. This relation could help underscore how environmental challenges serve as a driver for the adoption of renewable energies within the country.

Regarding the GDP, it negatively and significantly affects renewable energy. This reflects the structure of the Thai economy, which is essentially very energy-resource demanding, having broad-based development such as agriculture, manufacturing sectors, and tourism-nearing industries dominated mainly by taking fossil fuel energy. Though Thailand, particularly through the policy called the Alternative Energy Development Plan, has been trying to promote renewable energy, the transformation has been quite gradual given the cost advantage and infrastructure domination of conventional sources of energy such as natural gas and coal, on which a large fraction of the current energy mix has been based. Most economic growth is hinged on the increase of industrial output and infrastructure, which would favor short-term energy solutions over the generally higher investments needed to pursue renewable energy projects.

No significant effect detected for either tourism or geopolitical risk. This can be attributed to the country's stable political environment and the relatively low emphasis on sustainable energy within the tourism sector.

6.5. Case of Vietnam

LGDP has a negative significant impact on clean energy. This result reflects the rapid industrialization of the country, with much dependence placed on fossil fuels to meet the growing energy demands in sectors such as manufacturing and construction. While renewable energy projects are ongoing, high costs and infrastructure challenges associated with the transition to clean energy amid strong economic growth ensure that conventional sources of energy, such as coal and natural gas, continue to lead the way. This result suggests that, while the economy of Vietnam is expanding, the focus remains on short-term energy solutions, limiting the adoption of sustainable energy alternatives.

Regarding geopolitical risk, the negative and significant coefficient of GPR indicates that geopolitical tensions may distract governments and take away resources needed for long-term renewable energy development in order to respond to security concerns. In addition, foreign investors would be very reluctant to commit to large-scale renewable energy projects in a politically volatile environment, which translates to slower progress in the country's clean energy adoption despite its renewable potential.

CO_2 emissions and tourism do not affect clean energy in Vietnam. The lack of impact from CO_2 emissions and tourism on clean energy suggests that the country's renewable energy transition is more influenced by factors such as government policies and economic priorities rather than environmental concerns or tourism growth.

7. Conclusion and Policy Implications

This study explored the relationship between clean energy and its determinants in five Southeast Asian countries (Indonesia, Malaysia, the Philippines, Thailand, and Vietnam) from 1995 to 2023. We utilized four different determinants, including CO_2 emissions, geopolitical risk, economic growth, and tourism, to analyze their impact on renewable energy consumption (as a proxy for clean energy). The FMOLS (Fully Modified Ordinary Least Squares) regression technique is used to explore the relationship, while the Canonical Cointegrating Regression (CCR) estimation is used as a robust analysis.

The results show that the effects of these variables are not unanimous for all countries. CO_2 emissions negatively affect clean energy in Indonesia, Malaysia, and the Philippines, but they improve renewable energy in Thailand, and they have no significant effect in Vietnam. Economic growth has a significant negative effect on clean energy in Indonesia, Thailand, and Vietnam, but it appears to be the driver of clean energy in Malaysia, and its effect is muted for the Philippines. Our results concerning CO_2 emissions and GDP are similar to those of Lu [3]. Geopolitical risk seems to have a very large negative impact on renewable energy consumption in the Philippines and Vietnam, which indicates that instability and uncertainty can deter investment and slow the transition to clean energy, but its effect is not notable in other countries. Finally, tourism has an adverse relationship with clean energy in Malaysia, but it has no effect in other countries.

Southeast Asian governments must adopt stronger policies to accelerate their energy transition. Indonesia, Malaysia, and the Philippines should enforce stricter carbon regulations, diversify their energy mix, and ease structural constraints to reduce fossil fuel dependency. Thailand should prioritize funding for renewable infrastructure, simplify clean energy project approvals, and promote public-private partnerships. Vietnam must integrate climate goals into energy policies by implementing carbon taxes, emission limits, and renewable energy subsidies.

To align economic growth with sustainability, Indonesia, Thailand, and Vietnam should harmonize their development plans with renewable energy expansion, while Malaysia should embed clean energy strategies within its broader economic growth initiatives. The Philippines should impose renewable energy quotas, offer tax incentives, and integrate sustainability metrics into economic planning.

For investment stability, the Philippines and Vietnam need to enhance regulatory transparency and investor protections. Indonesia, Malaysia, and Thailand should maintain domestic clean energy policies to ensure long-term momentum despite geopolitical uncertainties.

Finally, Malaysia should integrate renewable energy into its tourism sector, while all five countries should promote green tourism, renewable-powered infrastructure, and eco-tourism incentives to align tourism growth with clean energy goals.

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