SENIOR RESEARCH

Topic: The Effect of Renewable Energy Consumption on Economic Growth - Evidence from Thailand

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Abstract

This study explores how renewable energy consumption relates to economic growth and foreign direct investment (FDI) in Thailand between 1992 and 2023. As renewable energy has become a key part of Thailand's sustainability efforts, understanding its economic effects is increasingly important. Using an Autoregressive Distributed Lag (ARDL) model, this analysis looks at both short-run and long-run connections between the variables. Unit root tests and bounds testing suggest the presence of a stable long-term relationship. The results show that renewable energy consumption positively influences GDP and FDI in the short term, while its long-run effect appears statistically insignificant. The error correction term is negative and significant, indicating that the system adjusts back to equilibrium after short-term shocks. Overall, the findings highlight the important role renewable energy plays in Thailand's short-run economic performance and its potential to attract foreign investment, offering useful insights for policymakers aiming for sustainable growth.

Keyword: Renewable energy consumption, Economic growth, GDP, Foreign direct investment (FDI), Thailand, ARDL model, Sustainable development

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Chapter 1 : Introduction

1.1 Background and Significance

Over the past few decades, the shift towards renewable energy has developed significant international momentum because of fears of climate change, energy security and development that is environmentally friendly (International Energy Agency, 2022). Solar, wind power, and biomass sources of energy are being increasingly perceived as critical substitutes for fossil fuels and hold the capacity to disentangle economic growth from ecological deterioration (REN21, 2021). For that reason, analyzing the impact of renewable energy use on aggregate economic indicators is a significant field of study that has developed in recent times.

Thailand, being an emerging Southeast Asian economy, has made renewable energy a mainstay of its national development strategies (Ministry of Energy Thailand, 2020). Measures such as the Alternative Energy Development Plan (AEDP) and the Power Development Plan (PDP) demonstrate firm governmental commitment to increasing renewable energy capacity. In seeking to balance rapid economic growth with sustainability in the environment, the interaction among renewable energy use, gross domestic product (GDP), and foreign direct investment (FDI) becomes of particular interest. FDI is important in financing infrastructure, transferring technology and innovation that is important in accelerating Thailand's renewable energy industry (United Nations Conference on Trade and Development, 2023).

Despite the strategic priority accorded to renewable energy, empirical research on its macroeconomic effects in the Thai context remains scant and ambiguous. While some studies purport that renewable energy utilization has a positive growth promoting and investment attracting role (Sadorsky, 2009; Bhattacharya et al., 2016), others contend that the relationship is frail or is significant in the short run (Apergis and Payne, 2010). Hence, a closer study is called for in order to guide policy and decision makers. The current study attempts to cover the gap by examining the relationship among renewable energy use, growth in the economy, and FDI in Thailand between 1992 and 2023. Using the Autoregressive Distributed Lag (ARDL) model, the study captures both long-run and short-run relationships among the variables. The results will be beneficial to the general literature on energy economics and useful in framing policies that enhance growth and investment in a sustainable way.

1.2 Research Question

Research question 1: How does renewable energy consumption (REC) affect Thailand's Gross Domestic Product (GDP), and to what extent?

Research question 2: How does renewable energy consumption (REC) affect Thailand's ability to attract foreign direct investment (FDI), and to what extent?

1.3 Objective

Objective 1: To investigate the short-run and long-run impact of renewable energy consumption (REC) on Thailand's Gross Domestic Product (GDP).

Objective 2: To investigate the short-run and long-run effects of renewable energy consumption (REC) on Thailand's ability to attract foreign direct investment (FDI).

1.4 Contribution

This research investigates the impact of renewable energy consumption (REC) on Thailand's economic growth and its ability to attract foreign direct investment (FDI). The findings provide insight into how REC influences both GDP and FDI in the short run and long run, using data updated to 2023. This study contributes to the limited literature focused specifically on Thailand, addressing gaps in past research that either excluded FDI or used outdated datasets. The results can serve as a guideline for policymakers in designing energy and investment strategies that support sustainable development and economic performance.

1.5 Definition

1.5.1 Renewable Energy Consumption (REC)

Renewable energy use is defined here as the utilization of energy from naturally renewing sources like solar, wind power, hydro power, and biomass. In the research conducted here, REC statistics come from Thailand's Energy Policy and Planning Office (EPPO) and include biofuels in the forms of paddy husk and bagasses (EPPO, 2024). These energy sources count towards Thailand's end-use energy statistics and are deemed to be in the scope of renewable energy in the context of the research here.

1.5.2 Foreign Direct Investment (FDI)

Foreign direct investment is defined as cross-border investment where one country's resident or entity takes a lasting interest in, or a substantial level of influence over, a business firm situated in some other country. This research takes Thailand's FDI inflows to be one of a nation's most significant indicators of openness and attractiveness to external investors.

1.5.3 Autoregressive Distributed Lag (ARDL) Model

The ARDL model is an econometric method employed in the investigation of the short-run and long-run relationships among time series variables where some of the variables share different levels of integration (I(0) and I(1)). It is most beneficial in the case of studies with a limited sample size and is also competent in estimating short-run fluctuations and long-run equilibrium relationships concurrently.

Chapter 2: Literature Review

This chapter examines the interrelationships among renewable energy consumption, economic growth, which was indicated by Gross Domestic Product (GDP) and Foreign Direct Investment (FDI). It also considers the influence of inflation and other macroeconomic variables, discusses the methodological relevance of the Autoregressive Distributed Lag (ARDL) model, and identifies research gaps, especially concerning the Thai economy.

2.1 Renewable Energy Consumption and Economic Growth

The relationship between renewable energy consumption and economic growth has been widely explored, especially in the context of developing economies. Bhattacharya et al. (2016) conducted a panel study of 38 countries and found that renewable energy use had a long-run positive impact on GDP in more than half of the sample. This suggests that shifting to clean energy sources does not merely serve environmental goals, but can also promote economic output. In Thailand, Fazal et al. (2020) employed the ARDL bounds testing approach using data from 1990 to 2018 and confirmed a significant long-run equilibrium relationship between renewable energy consumption and GDP. Their findings underline the importance of energy policy in Thailand's economic strategy, as increasing the use of renewable energy has demonstrably contributed to the country's development. Further extending this view, Jia et al. (2023) examined 90 countries along the Belt and Road Initiative and identified a bidirectional causality between renewable energy use and GDP growth. This implies not only that energy supports economic growth, but also that growing economies are more likely to invest in sustainable energy infrastructure, forming a virtuous cycle.

2.2 Foreign Direct Investment and Economic Growth

Foreign direct investment (FDI) has long been recognized as a key contributor to economic development in emerging markets. It brings in not only capital but also technology transfer, managerial expertise, and job creation. Haque et al. (2022) analyzed data from 53 middle-income countries and found that FDI positively affects GDP growth, particularly when inflation remains moderate. Their study also revealed that strong economic performance itself tends to attract more FDI, highlighting a two-way relationship between investment and growth. Omri and Kahouli (2014) also confirmed this bidirectional causality across 65 countries, showing that both FDI and economic growth reinforce each other over time. In a regional study focused on Africa, Opeyemi (2020) emphasized that FDI has supported capital formation and industrial development, making it a central engine of productivity and economic expansion. These findings suggest that fostering a stable and open economic environment is crucial to maximizing the benefits of FDI.

2.3 The Nexus Between Renewable Energy, FDI, and Economic Growth

Recent research increasingly considers the interlinkages between renewable energy, foreign investment, and economic growth. Omri and Kahouli (2014) found feedback loops connecting all three variables in their panel study, though the strength of the link between renewable energy consumption and FDI was found to vary by income level. In higher-income countries, renewable energy infrastructure appears to influence foreign investors' location choices, while in lower-income economies, this relationship is weaker. Ozturk and Acaravci (2013) studied the Turkish economy and found that renewable energy consumption, trade openness, financial development, and GDP were cointegrated, emphasizing the broader macroeconomic relevance of energy policy. Another important angle in this literature is the environmental dimension. Sarkodie and Strezov (2019) examined 46 developing countries and concluded that while economic growth and FDI are associated with rising carbon emissions, increasing the share of renewable energy consumption can reduce this environmental burden. This insight highlights a potential trade-off and underscores the need for balanced policy-making that allows countries to benefit from investment and growth while still addressing sustainability.

2.4 Inflation, Macroeconomic Stability, and Growth Dynamics

Inflation is a critical macroeconomic variable that shapes both growth outcomes and investment flows. A stable and predictable inflation rate encourages investor confidence and promotes long-term planning, while high and volatile inflation tends to deter both domestic and foreign investment. In a study of the Western Balkans, Abdurrahmani and Tmava (2024) found that modest inflation levels had a positive short-run impact on GDP and FDI. Their data indicated that a one percent increase in inflation was associated with a 0.30 percent rise in FDI and a 0.17 percent rise in GDP. However, they cautioned that inflation beyond a manageable threshold could lead to the opposite effect. These findings reflect the nuanced nature of inflation's impact, particularly in transitional economies. The International Monetary Fund (2022) contributed to this discussion by showing that countries with higher shares of renewable energy in their energy mix tend to experience lower inflation volatility. This is largely because they are less exposed to fossil fuel price shocks. Supporting this, Sarkodie and Strezov (2019) emphasized that renewable energy adoption can help stabilize macroeconomic conditions by insulating economies from external price fluctuations. Together, these studies suggest that renewables not only support output growth but also contribute to a more stable investment climate by reducing inflationary pressures.

Table 1. Summary of Literature review.

No	Topic	Findings	Methodology	Author
1.	**Renewable Energy Consumption and Economic Growth**	Analyzed data from 38 countries and found that renewable energy consumption has a significant long-run positive effect on GDP in 57% of the cases studied.	Panel data regression using long-run cointegration analysis.	Bhattacharya et al. (2016)
		Focused on Thailand from 1990 to 2018 and confirmed a long-term equilibrium relationship between renewable energy consumption and GDP. The study suggests that investments in renewables contribute directly to economic development.	ARDL bounds testing approach using national time series data.	Fazal et al. (2020)
		Studied 90 countries along the Belt and Road Initiative and found a bidirectional causality between renewable energy consumption and GDP growth, implying a feedback relationship.	Granger causality tests within a multi-country panel data framework.	Jia et al. (2023)
2.	**Foreign Direct Investment (FDI) and Economic Growth**	Found that in middle-income countries, FDI has a significant positive impact on economic growth, especially when inflation is controlled. Strong GDP growth also leads to increased FDI inflows, indicating a circular relationship.	Panel data analysis across 53 middle-income countries.	Haque et al. (2022)
		Identified bidirectional causality between FDI and GDP across 65 countries of different income levels, confirming that growth attracts FDI and FDI boosts economic performance.	Panel cointegration and causality testing using dynamic models.	Omri & Kahouli (2014)
		Emphasized the importance of FDI in fostering capital formation and industrial development in Africa, pointing to its role in job creation and productivity growth.	Cross-country econometric regression focused on African economies.	Opeyemi (2020)
3.	**FDI Renewable Energy Growth Nexus**	In Turkey, renewable energy consumption, economic growth, financial development, and trade openness were found to be cointegrated, indicating strong long-run interdependence.	ARDL bounds testing with macroeconomic time series data.	Ozturk & Acaravci (2013)
		Found feedback relationships between GDP, FDI, and energy use. However, the causality between energy consumption and FDI was weaker in low-income countries.	Panel cointegration and causality testing across 65 countries.	Omri & Kahouli (2014)
		Found that while FDI and GDP growth raise carbon emissions, increased renewable energy use helps offset these effects, underscoring the environmental value of clean energy.	Environmental Kuznets Curve (EKC) analysis with panel data.	Sarkodie & Strezov (2019)

4.	**Inflation and Macroeconomic Stability**	Studied Western Balkan countries and found that a modest inflation rate had a positive short-term effect on GDP and FDI. However, unchecked inflation still posed risks in the long run.	Time series regression and short-run dynamic modeling.	Abdurrahmani & Tmava (2024)
		Reported that economies that rely more on renewable energy tend to experience less inflation volatility, particularly from fossil fuel price shocks. This promotes greater macroeconomic stability.	Macroeconomic modeling using inflation sensitivity simulations.	IMF (2022)
		Found that high inflation negatively impacts FDI inflows and growth. Emphasized that transitioning to renewables helps stabilize prices and reduce inflationary pressures.	Panel data analysis with inflation-growth interaction terms.	Sarkodie & Strezov (2019)

2.5 Research Gap

Many studies have looked at how renewable energy consumption affects economic growth, especially in developed countries. However, there is limited research focusing on Thailand, especially using updated data that covers recent changes in the energy sector. Earlier studies, such as Fazal et al. (2020), only included data up to 2018 and did not reflect new developments in renewable energy policy and investment in Thailand.

Most research also looks at how renewable energy impacts GDP, but few studies consider how it might affect foreign direct investment (FDI). FDI is important for economic development, and renewable energy could help attract investors by improving infrastructure and showing that the country supports sustainable growth. However, this area is still not well studied in the case of Thailand.

Therefore, this study fills two main gaps:

Research gap 1: It uses updated data from 1992 to 2023 to study Thailand.

Research gap 2: It examines both GDP and FDI as outcomes of renewable energy consumption.

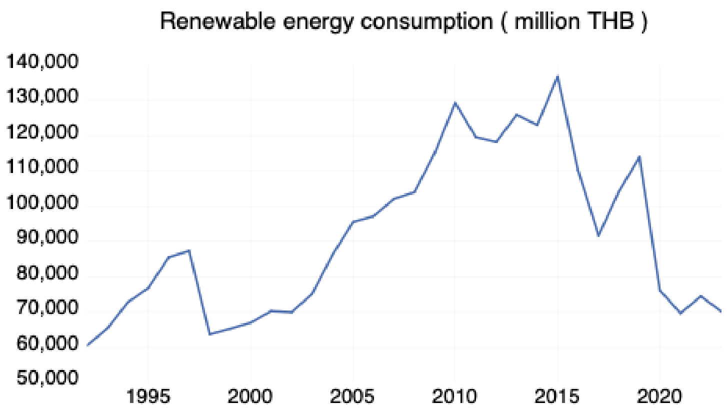
Chapter 3: Methedology

3.1 Data and Variables

This study investigates the impact of renewable energy consumption on economic growth and foreign direct investment (FDI) in Thailand using annual time series data from 1992 to 2023. The three main variables are renewable energy consumption (REC), gross domestic product (GDP), and foreign direct investment (FDI), with inflation rate and real interest rate included as control variables. All data were obtained from official and reliable sources, including the World Bank, Thailand's Energy Policy and Planning Office (EPPO), and the National Economic and Social Development Council (NESDC).

Renewable energy consumption (REC) is measured in million Thai Baht (THB) and represents national expenditure on renewable energy sources such as solar, wind, hydro, biomass, and biofuels including paddy husks and bagasse. These data were obtained from EPPO.

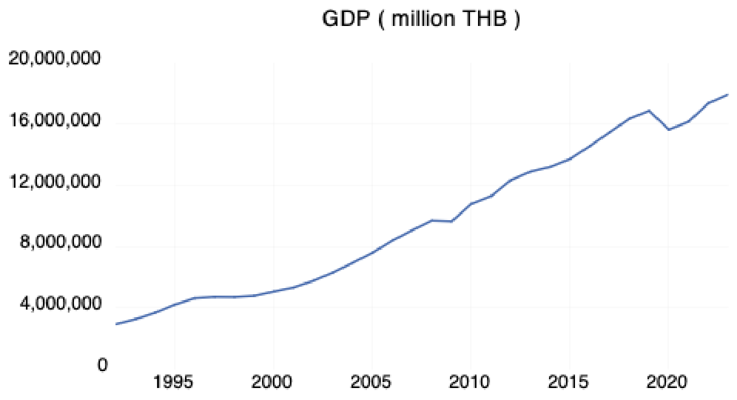
Figure 1. Renewable Energy Consumption (REC) in Thailand, 1992–2023 (in million THB)



Source: Energy Policy and Planning Office (EPPO, 2024)

Gross Domestic Product (GDP) is measured in million Thai Baht (THB) and was collected from the National Economic and Social Development Council (NESDC). It serves as a measure of Thailand's overall economic performance.

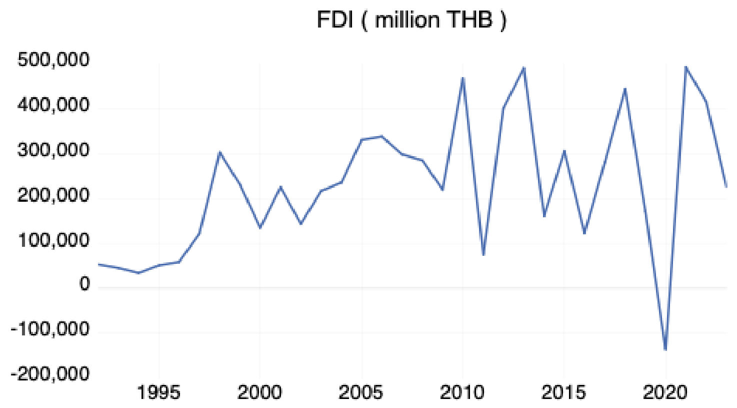
Figure 2. Gross Domestic Product (GDP) in Thailand, 1992–2023 (in million THB).



Source: National Economic and Social Development Council (NESDC, 2024)

Foreign direct investment (FDI) was originally recorded in million US dollars and was converted into million Thai Baht (THB) using average annual exchange rates for each year, sourced from the World Bank. This ensures consistency in currency units across all financial variables.

Figure 3. Foreign Direct Investment (FDI) Net Inflows in Thailand, 1992–2023 (million THB).



Source: World Bank (2024); exchange rates from World Bank (2024)

Inflation rate is included as a control variable and reflects the annual percentage change in consumer prices, obtained from the World Bank.

Real interest rate, also from the World Bank, is used as a control variable and represents the lending interest rate adjusted for inflation. It provides insight into borrowing conditions and the cost of capital.

All variables were used in their original form without logarithmic transformation. The timeframe from 1992 to 2023 was selected based on the availability of consistent data and major developments in Thailand's renewable energy policy.

3.2 Models and Methods

To investigate the impact of renewable energy consumption on Thailand's economic growth and foreign direct investment (FDI), this study employs the Autoregressive Distributed Lag (ARDL) bounds testing approach, as introduced by Pesaran, Shin and Smith (2001). This approach is well-suited for analyzing time series data with small sample sizes and mixed levels of integration, as it allows the estimation of both short-run and long-run relationships in a single reduced-form equation.

The ARDL methodology is particularly appropriate when the underlying variables are either stationary at level I(0) or become stationary after first differencing I(1), but not when integrated at second difference I(2) (Nkoro and Uko, 2016). This study follows a structured estimation process that includes unit root testing, automatic lag selection, bounds cointegration testing, and estimation of short- and long-run dynamics through the ARDL framework. The full estimation was performed using EViews software.

3.2.1 Unit Root Test

The first step in the analysis is to determine the stationarity of the time series variables. The Augmented Dickey-Fuller (ADF) test was employed to assess the order of integration for each variable. This is essential to ensure that none of the variables are I(2), which would invalidate the ARDL technique. The test was conducted by evaluating the null hypothesis that a variable has a unit root. Rejection of the null implies that the series is stationary either at level I(0) or after differencing I(1). This test was selected for its widespread application in economic time series analysis (Gujarati and Porter, 2009).

3.2.2 ARDL Model Estimation with Automatic Lag Selection

Following the unit root testing, the ARDL model is estimated to examine both short-run and long-run effects of renewable energy consumption and macroeconomic variables on the dependent variables. In this study, two models are estimated: one where GDP is the dependent variable, and another where FDI is the dependent variable. This allows for a comparative understanding of how renewable energy consumption may influence economic growth and investment flows differently.

3.2.2.1 GDP

To examine the impact of renewable energy consumption and macroeconomic factors on economic growth, this study specifies the following functional form:

The standard Form Model:

$$GDP_t = f(REC_t, RIR_t, IFR_t) \quad (1)$$

In this equation, real gross domestic product (GDP) is influenced by renewable energy consumption (REC), real interest rate (RIR), and inflation rate (IFR).

The theoretical relationship is transformed into a linear regression model, which serves as the base structure for estimation

OLS Linear Form:

$$GDP_t = \beta_0 + \beta_1 REC_t + \beta_2 RIR_t + \beta_3 IFR_t + \varepsilon_t \tag{2}$$

The ARDL model allows the estimation of both short-run and long-run relationships between the variables.

ARDL approach equation:

$$\Delta GDP_t = \alpha_0 + \sum_{i=1}^{p} \alpha_1^I \Delta GDP_{t-i} \sum_{j=0}^{q_1} \alpha_2^j \Delta REC_{t-j} + \sum_{k=0}^{q_2} \alpha_3^k \Delta RIR_{t-m} + \sum_{l=0}^{q_3} \alpha_4^l \Delta IFR_{t-l} + \phi_1 GDP_{t-1} + \phi_2 REC_{t-1} + \phi_3 RIR_{t-1} + \phi_4 IFR_{t-1} + \varepsilon_t \tag{3}$$

This model captures how changes in renewable energy consumption, and macroeconomic variables affect GDP in both the short run and the long run. Estimation is conducted using the ARDL bounds testing procedure to ensure model validity and to test for the presence of a long-run cointegration relationship.

3.2.2.2 Foreign Direct Investment

To examine the impact of renewable energy consumption and macroeconomic factors on economic growth, this study specifies the following functional form:

The standard Form Model:

$$FDI_t = f(REC_t, RIR_t, IFR_t) \tag{4}$$

In this equation, real foreign direct investment (FDI) is influenced by renewable energy consumption (REC), real interest rate (RIR), and inflation rate (IFR).

The theoretical relationship is transformed into a linear regression model, which serves as the base structure for estimation.

OLS Linear Form:

$$FDI_t = \psi_0 + \psi_1 REC_t + \psi_2 RIR_t + \psi_3 IFR_t + \mu_t \tag{5}$$

The ARDL model allows the estimation of both short-run and long-run relationships between the variables.

ARDL approach equation:

$$\Delta FDI_t = \beta_0 + \sum_{i=1}^{p} \beta_1^I \Delta FDI_{t-i} \sum_{j=0}^{q_1} \beta_2^j \Delta REC_{t-j} + \sum_{k=0}^{q_2} \beta_3^k \Delta RIR_{t-m} + \sum_{l=0}^{q_3} \beta_4^l \Delta IFR_{t-l} + \psi_1 FDI_{t-1} + \psi_2 REC_{t-1} + \psi_3 RIR_{t-1} + \psi_4 IFR_{t-1} + \varepsilon_t \quad (6)$$

This model captures how changes in renewable energy consumption, and macroeconomic variables affect FDI in both the short run and the long run. Estimation is conducted using the ARDL bounds testing procedure to ensure model validity and to test for the presence of a long-run cointegration relationship.

3.2.3 Bounds Test

To determine whether a stable long-run relationship exists between the variables, the bounds testing approach is applied. This method tests the null hypothesis of no cointegration among the variables using an F-statistic. The decision rule is based on critical values provided by Pesaran et al. (2001). If the computed F-statistic exceeds the upper bound, the null hypothesis is rejected, indicating that the variables are cointegrated.

This step is essential in justifying the estimation of long-run and short-run coefficients within the ARDL framework.

3.2.4 Estimating Long-run and Short-run Dynamics

If cointegration is confirmed, the model proceeds to estimate both long-run coefficients and short-run dynamics, including the Error Correction Term (ECT). The ECT measures the speed of adjustment back to equilibrium following a short-term shock. A negative and statistically significant ECT value confirms that deviations from long-run equilibrium are corrected over time, indicating model stability.

The short-run dynamics are captured through differenced variables, while the long-run coefficients reflect the equilibrium relationship among the original variables.

3.2.5 Model Diagnostics and Robustness

To ensure the reliability of the estimation results, a set of diagnostic tests is performed:

Breusch-Godfrey LM test for serial correlation

Breusch-Pagan-Godfrey test for heteroskedasticity

Jarque-Bera test for residual normality

CUSUM *and* ***CUSUMSQ tests*** to check model stability over time

To address any potential heteroskedasticity in the residuals, the model uses **White's heteroskedasticity-consistent standard errors**, which provide robust estimates of standard errors and improve inference reliability (White, 1980).

Chapter 4: Results and Discussion

4.1 Unit Root test results of Stationary of Variables

The stationarity of the variables was assessed using the Augmented Dickey-Fuller (ADF) test. The results, as shown in Table 2, indicate that FDI, RIR, and IFR are stationary at level I(0), while GDP and REC are stationary at first difference I(1). This mixed order of integration justifies the use of the ARDL bounds testing approach for further analysis.

Table 2. Result of unit root tests.

Variable	Level		1st Difference		Result
	Intercept	Trend and Intercept	Intercept	Trend and Intercept	
FDI	-3.9139*** (0.0055)	-4.7009*** (0.0038)	-4.8327*** (0.0006)	-4.9197*** (0.0034)	I(0)
GDP	0.6863 (0.9898)	-2.0707 (0.5411)	-4.7376*** (0.0007)	-4.7840*** (0.0031)	I(1)
REC	-1.6912 (0.4256)	-1.0992 (0.9130)	-5.2151*** (0.0002)	-5.5496*** (0.0005)	I(1)
RIR	-2.8427** (0.064)	-3.6312** (0.0433)	-8.0775*** (0.000)	-5.6853*** (0.0004)	I(0)
IFR	-3.7687*** (0.0077)	-4.5525*** (0.0053)	-8.5328*** (0.0000)	-8.3578*** (0.0000)	I(0)

Notes: ** denotes a 5% significance level, and *** denotes a 1% significance level.

4.2 ARDL Model Estimation

4.2.1 GDP

4.2.1.1 GDP Equation Bound test results

To examine whether a long-run relationship exists among the variables in the GDP model, the ARDL bounds testing approach was applied. Table 4.2 presents the F-statistic and compares it with the critical value bounds. The F-statistic of 17.37686 exceeds the upper bound critical values at the 1%, 5%, and 10% significance levels. Therefore, we reject the null hypothesis of no cointegration and conclude that a long-run relationship exists among GDP, renewable energy consumption, inflation rate, and real interest rate.

Table 3. GDP equation Bound test results.

Test statistic	k	Critical value bounds					
		10%		5%		1%	
F-statistic		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
17.37686	3	2.676	3.586	3.272	4.306	4.614	5.966

The test confirms a statistically significant long-run relationship for the GDP equation at all common levels of significance.

4.2.1.2 GDP Equation Diagnostic test results

To ensure the validity and robustness of the ARDL model, diagnostic tests were conducted. Table 4. presents the results of tests for serial correlation, normality of residuals, and heteroskedasticity.

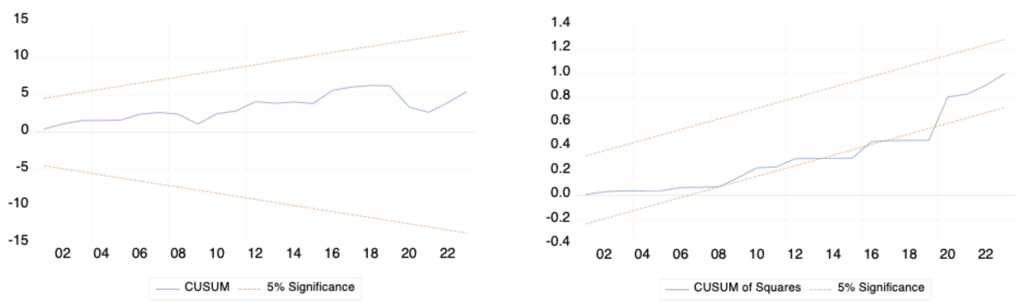
The results indicate that there is no evidence of serial correlation or non-normality in the residuals, as both p-values are above the 0.05 threshold. However, the p-value for the heteroskedasticity test is below 0.01, suggesting the presence of heteroskedasticity. This supports the use of heteroskedasticity-consistent standard errors, as employed in the White-ARDL framework.

Table 4. Results of GDP Equation Diagnostic tests.

Test category	**Diagnostic test**	**Statistic**	**P-value**
Serial Correlation Test	Breusch-Godfrey LM	1.2248	0.314
Normality Test	Jarque-Bera	2.2243	0.3289
Heteroskedasticity Test	Breusch-Pagan-Godfrey	8.708	0.0001

In addition, the model's structural stability was assessed using the CUSUM and CUSUM of Squares tests. As illustrated in Figure 4, the CUSUM plot remains within the 5% significance bounds, indicating parameter stability. Although the CUSUM of Squares plot slightly exceeds the confidence bounds toward the end of the sample, such a pattern is not uncommon when heteroskedasticity is present. Given that corrective measures have been applied through robust standard errors, the model is still considered acceptably stable for inference.

Figure 4. Plot of the cumulative sum of recursive residuals (a) and the cumulative sum of squares of recursive residuals (b) with 95% confidence intervals.



4.2.1.3 GDP Equation Short-Run, Long-Run, and ECM Results (White-Adjusted)

Given the confirmed cointegration from the bounds test, the ARDL model was further estimated to capture both the short-run and long-run dynamics of the GDP equation. As heteroskedasticity was present, White's heteroskedasticity-consistent standard errors were used to improve the robustness of statistical inference.

Table 5. Short-run Coefficient Estimates from the ARDL Model Using White Heteroskedasticity-Consistent Standard Errors.

Variable	Coefficient	Robust Std. Error	t-Statistic	P-value
ΔGDP(-1)	0.9887	0.0224	44.1348	0.0000***
ΔREC	16.1729	9.1429	1.7689	0.0902*
ΔREC(-1)	-24.5414	13.3779	-1.8345	0.0796*
ΔREC(-2)	12.3907	7.2879	1.7002	0.1026
ΔIFR	471,276	332,753.70	1.4176	0.1697
ΔRIR	-7,826,470	2,174,663	-3.5999	0.0015***
Constant	402,342.70	307,397.00	1.3089	0.2035
R-Squared	0.9962	Adjusted R^2		0.9952

Notes: * Denotes a 10% significance level, ** denotes a 5% significance level, and *** denotes a 1% significance level.

The R-squared value of 0.9962 indicates that approximately 99.62% of the variation in GDP is explained by the model's independent variables in the short run. This suggests a very strong model fit, although high R-squared values in time series models should be interpreted with caution due to potential overfitting.

In the short run, changes in renewable energy consumption (ΔREC) show a marginally significant positive effect on GDP. Specifically, the coefficient of 16.1729 for ΔREC implies that a 1 million THB increase in renewable energy consumption is associated with an approximate short-run increase of 16.17 million THB in GDP, holding other factors constant.

Real interest rate (ΔRIR) is statistically significant and negatively associated with GDP, indicating a contractionary impact. This suggests that an increase in real interest rates leads to a reduction in GDP, likely due to reduced borrowing and investment activity. Inflation (ΔIFR) is statistically insignificant but still theoretically relevant. The positive but statistically insignificant coefficient implies that inflation may have a mild expansionary effect on GDP in the short run, but the evidence is not strong enough to confirm this relationship within the sample.

Table 6. Long-run Coefficient Estimates from the ARDL Model Using White Heteroskedasticity-Consistent Standard Errors.

Variable	Coefficient	Robust Std. Error	t-Statistic	P-value
REC	356.1753	506.3041	0.7035	0.4888
IFR	417,726,810.75	929,000,000.00	0.4497	0.6572
RIR	-693,053,949.24	1,240,000,000.00	-0.5597	0.5811
Constant	35,628,475.45	72,949,173.00	0.4804	0.6299

In the long run, as shown in Table 6, none of the variables are statistically significant at conventional levels. Despite the direction of the coefficients suggesting expected economic relationships, the large standard errors and high p-values indicate that there is insufficient statistical evidence to confirm any long-run effects of these variables on GDP within the sample period.

Table 7. ECM estimation results for the GDP ARDL model.

Variable	Coefficient	Std. Error	t-Statistic	P-value
CointEq(-1)	-0.0113	0.0011	-10.0999	0.0000***

Notes: ** denotes a 5% significance level, and *** denotes a 1% significance level.

The negative and highly significant coefficient of the error correction term (−0.0113) implies that approximately 1.13% of the previous period's deviation from long-run equilibrium is corrected in the current period. Although the speed of adjustment is relatively slow, the strong significance confirms the existence of a stable long-run relationship among the variables in the GDP model.

4.2.2 FDI

4.2.2.1 FDI Equation Bound test results

To assess the existence of a long-run relationship in the FDI model, the ARDL bounds testing approach was applied. Table 8. displays the F-statistic and its comparison with the critical value bounds. The computed F-statistic of 13.04135 is significantly higher than the upper bound critical values at the 1%, 5%, and 10% significance levels. This leads to the rejection of the null hypothesis of no cointegration.

Table 8. FDI Equation Bound test results.

Test statistic	k	Critical value bounds					
		10%		5%		1%	
F-statistic		I(0)	I(1)	I(0)	I(1)	I(0)	I(1)
13.04135	3	2.676	3.586	3.272	4.306	4.614	5.966

The result confirms the presence of a statistically significant long-run relationship among foreign direct investment, renewable energy consumption, inflation rate, and real interest rate in the FDI model.

4.2.1.2 FDI Equation Short-Run, Long-Run, and ECM Results

Table 9. FDI Sort-run coefficients estimation results of the ARDL model.

Variable	Coefficient	Std. Error	t-Statistic	P-value
FDI(-1)	0.07396	0.12529	0.59026	0.5616
ΔREC	4.19798	1.31972	3.18097	0.0047***
ΔREC(-1)	-11.3311	1.76531	-6.41876	0.0000***
ΔREC(-2)	8.42352	1.40693	5.98716	0.0000***
ΔIFR	-408,827.90	1,074,395.00	-0.38052	0.7076
ΔIFR(-1)	259,561.50	1,623,279.00	1.5999	0.1255
ΔIFR(-2)	138,886.40	1,051,273.00	1.32113	0.2014
ΔRIR	-5,064,487.00	1,426,471.00	-3.55036	0.0020***
ΔRIR(-1)	1,882,909.00	1,333,714.00	1.41178	0.1734
Constant	128,959.50	115,088.20	1.12053	0.2758

Notes: * Denotes a 10% significance level, ** denotes a 5% significance level, and *** denotes a 1% significance level.

Table 9. presents the short-run coefficient estimates from the ARDL model for the FDI equation. Renewable energy consumption (ΔREC) and its lagged values are all highly significant at the 1% level, indicating strong short-run dynamics. A 1 million THB increase in renewable energy consumption is associated with a short-term rise of approximately 4.20 million THB in FDI, holding other factors constant. However, the significant and alternating signs of the lagged REC terms suggest complex short-run adjustment behavior.

Real interest rate (ΔRIR) is also statistically significant and negatively related to FDI, suggesting that higher borrowing costs may reduce foreign investment inflows in the short run. Inflation (ΔIFR) and its lags, however, are statistically insignificant.

Table 10. FDI Long-run coefficients estimation results of the ARDL model.

Variable	Coefficient	Std. Error	t-Statistic	P-value
REC	1.3935	0.9957	1.3995	0.177
IFR	3,861,207	1,264,915	3.0525	0.0063***
RIR	-3,435,663	949,252.90	-3.6193	0.0017***
Constant	139,258.30	119,374.00	1.1656	0.2571

Notes: * Denotes a 10% significance level, ** denotes a 5% significance level, and *** denotes a 1% significance level.

In the long run, inflation (IFR) and real interest rate (RIR) are statistically significant at the 1% level. The positive coefficient for IFR suggests that moderate inflation may attract foreign investment, potentially through increased nominal returns or growth expectations. Conversely, the negative coefficient for RIR confirms that higher real interest rates deter FDI inflows, likely due to increased capital costs. Renewable energy consumption (REC), although positively signed, is statistically insignificant in the long run.

Table 11. ECM estimation results for the FDI ARDL model.

Variable	Coefficient	Std. Error	t-Statistic	P-value
CointEq(-1)	-0.926045	0.104688	-8.845795	0.0000***

Notes: ** denotes a 5% significance level, and *** denotes a 1% significance level.

The error correction term (ECT) is negative and highly significant, with a coefficient of -0.9260. This indicates that approximately 92.6% of the deviation from long-run equilibrium is corrected in the current period, suggesting a rapid speed of adjustment toward equilibrium following short-term shocks. The strong statistical significance confirms the stability and long-run validity of the estimated ARDL model.

4.2.2.3 FDI Equation Diagnostic test results

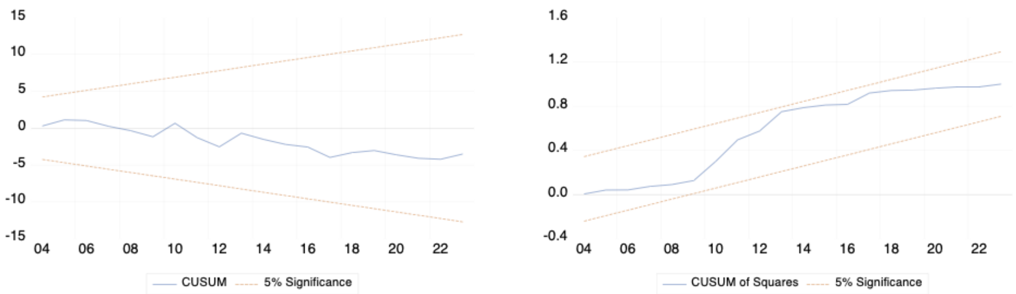
To assess the robustness of the FDI equation, a series of diagnostic tests were performed. As shown in Table 12, the Breusch-Godfrey LM test for serial correlation yielded a p-value of 0.0576, which is slightly above the 5% significance level, suggesting no evidence of autocorrelation. The Jarque-Bera test produced a p-value of 0.4869, indicating that the residuals are normally distributed. Additionally, the Breusch-Pagan-Godfrey test for heteroskedasticity returned a p-value of 0.5477, providing no evidence of heteroskedasticity.

Table 12. Results of FDI Equation diagnostic tests.

Test category	Diagnostic test	Statistic	P-value
Serial Correlation Test	Breusch-Godfrey LM	3.3595	0.0576
Normality Test	Jarque-Bera	1.4395	0.4869
Heteroskedasticity Test	Breusch-Pagan-Godfrey	0.8940	0.5477

The CUSUM and CUSUM of Squares plots further confirm the structural stability of the model over the sample period. As both plots remain well within the 5% significance bounds, they provide strong evidence that the FDI equation is stable over time.

Figure 5. Plot of the cumulative sum of recursive residuals (a) and the cumulative sum of squares of recursive residuals (b) with 95% confidence intervals.



Chapter 5: Conclusion

5.1 Summary of Findings

This study aimed to investigate the relationship between renewable energy consumption, economic growth, and foreign direct investment (FDI) in Thailand from 1992 to 2023 using the Autoregressive Distributed Lag (ARDL) approach. Two separate models were estimated, one with GDP and another with FDI as the dependent variable, to capture both short-run dynamics and long-run equilibrium relationships.

The bound test results confirmed the presence of cointegration in both models, indicating that renewable energy consumption, inflation, and real interest rate are jointly associated with long-term movements in GDP and FDI. In the GDP model, short-run estimates revealed that renewable energy consumption has a marginally significant and positive effect, while real interest rates showed a significant negative relationship. Although the long-run coefficients were statistically insignificant, the error correction term was negative and strongly significant, confirming the existence of a stable long-run equilibrium.

For the FDI model, renewable energy consumption exhibited a strong and statistically significant short-run impact. The long-run estimation found inflation and real interest rate to be significant, suggesting that moderate inflation may promote investment while high real interest rates deter it. The adjustment speed toward long-run equilibrium was rapid, as evidenced by the error correction mechanism.

Diagnostic tests for both models confirmed the absence of serial correlation, normality of residuals, and model stability over time. White's heteroskedasticity-consistent standard errors were applied in the GDP model to address heteroskedasticity, while the FDI model showed no evidence of such issues and was estimated using the standard ARDL framework.

In conclusion, renewable energy consumption plays an important role in influencing Thailand’s economic performance, particularly in the short run. Policymakers are encouraged to sustain support for renewable energy initiatives while managing interest rates and inflation to maintain macroeconomic stability and foster investment. Although long-run effects of renewable energy were not statistically confirmed, the overall findings underscore its relevance in shaping short-term economic outcomes and attracting foreign capital.

5.2 Limitations

Although this study offers useful findings, it is not without limitations. First, the ARDL method, while suitable for small samples and variables with mixed orders of integration, may not effectively capture nonlinear interactions or structural changes that might have occurred during the 1992 to 2023 period. Second, the reliance on secondary data introduces the risk of measurement errors or inconsistencies due to data revisions. Lastly, the absence of significant long-run coefficients may stem from model simplification or omitted variable bias, as other important economic factors could not be included in the scope of this analysis.

5.3 Recommendations

To improve future studies, researchers may consider applying nonlinear models or introducing structural break analysis to better reflect the evolving relationship between renewable energy and macroeconomic indicators. Including additional explanatory variables, such as fiscal incentives, energy market fluctuations, or environmental compliance policies, could provide deeper insights. Moreover, conducting disaggregated studies at the regional or industry level within Thailand may help tailor policy responses more effectively. Finally, using updated datasets and alternative models, such as panel ARDL or nonlinear ARDL frameworks. Expanding the set of explanatory variables, including government incentives, energy prices, or environmental regulations, could enhance the robustness of the findings. Moreover, sector-specific or regional-level analyses within Thailand may provide more granular insights for targeted policymaking. Finally, continuous data updates and the use of alternative estimation techniques such as NARDL or panel ARDL models could further validate and extend the conclusions of this study.

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