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Is Renewable Energy or Fossil Fuels Preferred in the Development of Asian Countries?

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Abstract

The goal of all countries is to reduce dependence on fossil fuels and promote renewable energy consumption. Renewable energy sources occur naturally and have unlimited production potential, making them ideal for industrial, residential and transportation use. Unlike renewable energy, fossil fuel reserves are limited, depletable and cause environmental pollution. The aim of this study is to investigate the impact of gross domestic product, foreign direct investment, financial development and other proposed variables on renewable energy consumption in 26 Asian countries. We used panel data and estimated regressions using the Driscoll-Kraay method for the period 2000-2020. The panel regression results show that gross domestic product has a significantly negative relationship on renewable energy consumption; likewise, both gross capital formation and financial development are found to negatively affect renewable energy consumption. The findings show that economic and financial development in Asian countries has not yet promoted renewable energy consumption. It shows that in the current economic and financial situations of countries, the trend towards using more fossil fuels as a share of total energy resources continues.

Keywords: Renewable Energy, Fossil Fuels, Growth, Asian Countries.
JEL Classification: Q43, N75, O13.

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1. Introduction

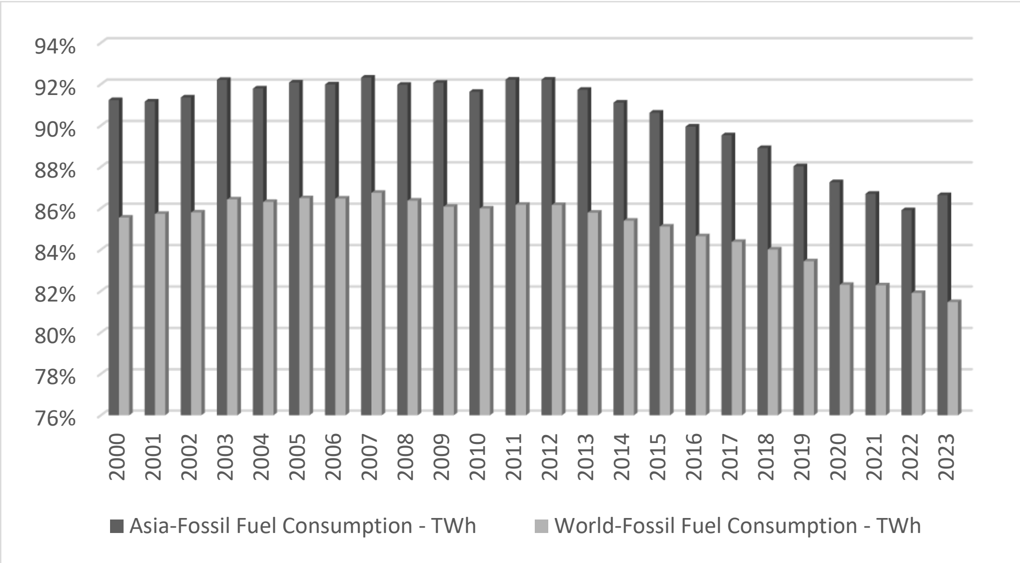
The Asia-Pacific region occupies a central position in the global efforts to decarbonize the energy sector and achieve net-zero emissions. The region's strategic significance stems not only from its rapid economic growth and industrial expansion, but also from its disproportionately high share of global energy-related emissions. Between 2000 and 2023, energy-based carbon emissions in Asia-Pacific increased by approximately 151%, driven predominantly by rising GDP, population growth, and the acceleration of industrialization (BloombergNEF, 2024). As of 2022, excluding China, developing markets and emerging economies in Asia have become the fastest-growing contributors to global emissions. In these economies, carbon emissions grew by 4.2%, reaching a total of 206 million metric tons of CO_2. Notably, more than half of this increase is linked to coal combustion for electricity generation (Khan, Razak, and Premaratne, 2025). This reliance on fossil fuels has intensified environmental vulnerability across the region.

Southeast Asia, in particular, illustrates this challenge. In 2020, the share of renewable energy in the region's primary energy supply was only 18.8%, reflecting a continued dependence on fossil fuels (ASEAN Centre for Energy, 2020). This level of reliance is inconsistent with the emission reduction pathways outlined in the Paris Agreement, highlighting the urgency for an accelerated energy transition. According to projections by the International Renewable Energy Agency (IRENA) and the ASEAN Centre for Energy (ACE), Southeast Asia must invest approximately USD 210 billion annually in renewable energy by 2050 in order to align with the global 1.5 °C scenario and reach net-zero emissions targets (IRENA and ACE, 2022). In South Asia, approximately 64% of electricity generation still relies on non-renewable energy sources, reinforcing the region's carbon-intensive energy profile and amplifying its environmental vulnerability (Khan, Razak, and Premaratne, 2025). This dependence presents a significant barrier to achieving long-term sustainability and emissions reduction goals. In Southeast Asia, all countries have ratified the United Nations Framework Convention on Climate Change (UNFCCC), and many have initiated efforts to explore carbon pricing instruments such as carbon taxes and emissions trading systems (ETS). Countries including Vietnam, Singapore, Thailand, Indonesia, and the Philippines have made notable progress in this regard. However, despite these national-level initiatives, there is currently no comprehensive regional mechanism or unified climate change policy aimed at collectively reducing emissions across Southeast Asia (Nguyen et al., 2023).

In the last few years, fossil fuel consumption has increased dramatically due to advancements in quality of life, the expansion of industrialization, and the quick growth of the global population. Fossil fuels have been essential to advancing social advancement and economic activity (Farhad et al., 2008; Cosmi et al., 2003). But using fossil fuels produces CO_2 emissions. In this situation, addressing the depletion of fossil fuels and lowering air pollution needs the use of green energy sources.

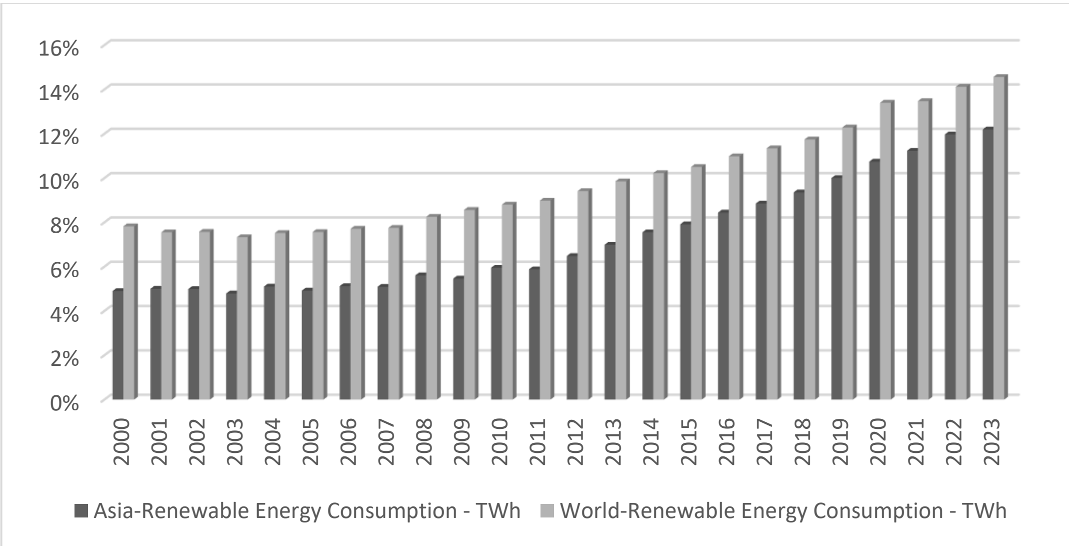
Figures 1 and 2 show, share of primary energy consumption from fossil fuels and renewable energy in the world and 26 Asian countries (Our World in Data 2025a; Our World in Data, 2025b).

Figure 1. Proportion of fossil fuel-based primary energy consumption



As Figure 1 shows, the share of primary energy consumption from coal, gas and oil is much higher in 26 Asian countries than globally.

Figure 2. Share of primary energy consumption from renewable energy



As seen in Figure 2, the share of primary energy consumption derived from renewable energy is much higher globally than in 26 Asian countries.

In 26 Asian countries, the transition from fossil to renewable energy is important for a sustainable environment. One of the primary goals of most countries is to increase infrastructure investments in clean energy sources and make the switch from brown to green energy sources (Bull, 2001). Nowadays, most countries are formulating renewable energy policies aimed at diminishing reliance on fossil fuels and strengthening domestic renewable energy generation. Essentially, research and development initiatives centered on renewable energy sources constitute a key priority for all nations. Renewable energy sources occur naturally and have unlimited production potential, making them suitable for industrial, residential, and transportation purposes. In contrast, fossil fuel reserves are finite and depletable (Popp, 2011). Thus, it is essential to create plans that motivate the use of clean energy sources and to put in place very successful environmental regulations.

In developed countries, the implementation of carbon pricing mechanisms has largely stemmed from their leadership responsibilities under the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC). Within this context, the European Union has adopted a comprehensive and integrated policy framework to meet its collective emission reduction targets. In contrast, the efforts of developed countries in the Asia-Pacific region remain relatively limited. Nevertheless, several countries in the region have introduced national-level carbon pricing mechanisms. While Japan and Singapore have adopted carbon tax systems, Kazakhstan, New Zealand, the Republic of Korea, and the People's Republic of China (PRC) have launched emissions trading systems (ETS). Notably, China's national ETS, initiated in 2021, is now the largest carbon market in the world in terms of scale and coverage. Beyond these efforts, Indonesia has adopted a hybrid cap-trade-and-tax scheme, marking its entry into carbon pricing. Vietnam has made significant progress toward integrating carbon pricing into its domestic legal framework. Meanwhile, Pakistan, the Philippines, Taiwan, and Thailand are currently assessing the feasibility of implementing domestic ETS systems. India took a major step by launching its national carbon trading platform in 2022, laying the foundation for a structured carbon market (Duggal, 2023).

Despite the relatively limited initiatives of developed economies in the region, carbon mitigation efforts are gaining momentum in several developing Southeast Asian countries. In particular, countries such as China and India have made substantial investments in renewable energy infrastructure and energy efficiency practices to meet growing energy demand in a sustainable manner and to reduce their environmental footprint (Kamau, 2024). These investments are critical to enabling the region's alignment with the climate targets outlined in the Paris Agreement. Moreover, many Asian countries actively support renewable energy deployment through a range of financial instruments, including feed-in tariffs, subsidies, and tax incentives.

In theory, the relationships between ecological protection, including renewable energy, and economic growth (recently referred to as green growth) have been examined under the title of sustainable development, which is a more general term in economic and social terms (Khan et al., 2025). In this context, according to the endogenous growth theory, sustainable growth can be achieved with appropriate public policies and technological investments in renewable energy. Growth is also expected to increase the orientation towards renewable energy sources. However, this may take a long time because the transition to a cleaner ecological economy may initially negatively affect production factors and reduce the potential for long-term endogenous growth by reducing the income that can be obtained from investments (Aghion, 2014). However, within the scope of Directed Technical Change theory, since developing countries have a comparative advantage over developed countries in dirty technologies, they will specialize in the production of dirty goods, clean technologies need to be made cheap and accessible for lower-income countries (Acemoğlu, 2013). The Environmental Kuznets Curve (EKC) Hypothesis is also seen as one of the basic hypotheses for the orientation towards renewable energy. According to the hypothesis, it is argued that the transition to a clean economy occurs only after a certain stage of growth. Expenditures on renewable energy sources are expected to increase or reach the required level after this stage (Grossman & Krueger, 1995).

This study examines the impact of economic variables on renewable energy consumption in Asian countries based on data from the period 2000–2020, and analyzes the relationship between energy use and economic development within a comprehensive framework. The originality of the research lies in its focus on how macroeconomic indicators such as economic growth, foreign direct investment, financial development, gross capital formation, and inflation influence renewable energy consumption at a regional level. The aim of this study is to examine whether, as economies grow, they tend to rely more on fossil fuel consumption or shift toward renewable energy use in line with the goals of the Paris Agreement for a cleaner environment and sustainable growth, by testing this relationship within the framework of other macroeconomic variables. The central hypothesis tested in the study is that "Fossil energy consumption is more influential than renewable energy consumption in the development of Asian countries." Accordingly, the study is expected to provide original and empirically grounded contributions to the economics literature.

The format of this document is as follows: Section 2 provides a review of earlier studies. Section 3 provides an explanation of the data and methods used in the study. Section 4 presents and discusses the study's empirical findings, while Section 5 summarizes and discusses them.

2. Literature Review

2.1. Renewable Energy Utilization and Financial Development

Aboagye and Kwakwa (2023) investigated the interplay between tourism expansion, clean energy utilization and trade openness in shaping financial development within select African nations. Their empirical findings suggest that, over the long term, trade liberalization, tourism sector growth, and increased reliance on green energy sources collectively foster financial development. Similarly, Sun et al. (2023) employed an econometric modeling approach to examine the effects of financial development on green energy consumption across 103 countries between 1991 and 2014, encompassing 28 advanced economies and 75 emerging markets. The findings demonstrated that overall financial development has a significant positive effect on green energy consumption in developed economies but was not significant in emerging economies. Dimnwobi et al., (2022) utilized an econometric modeling approach to investigate the linkages between financial development and clean energy utilization in Nigeria, Africa's largest economy. Their findings underscore the substantial positive influence of financial development on the country's green energy sector. Similarly, Shahbaz et al., (2021) explored the impact of financial development on clean energy utilization across 34 developing nations, revealing that financial expansion and economic growth play a pivotal role in fostering clean energy adoption. However, the study found that energy prices do not notably influence green energy utilization. The empirical evidence also suggests a long-term association between financial development and clean energy adoption, while economic growth exhibits an inverse relationship with green energy deployment.

In a broader context, Khan et al. (2020) examined the interaction between green energy diversification, carbon emissions, and financial development across 192 countries. Their findings indicate that financial development positively contributes to clean energy utilization, whereas increased green energy adoption is associated with a noteworthy decline in carbon dioxide emissions. Mukhtarov et al., (2020) extended this analysis by assessing the interconnections among financial development, green energy consumption, economic expansion, and energy pricing in Azerbaijan. Their results highlight that domestic credit, as a percentage of GDP, and economic growth exert a statistically significant and positive impact on clean energy adoption, while consumer price index (CPI) based energy prices negatively influence green energy utilization.

Focusing on India, Eren et al., (2019) examined how financial development impacts the country's clean energy sector. Their findings suggest that both financial expansion and economic growth have a long-term and statistically significant role in promoting green energy utilization.

Contrasting these findings, Nawaz and Rahman (2023) explored the dynamic relationship between financial development, institutional frameworks, foreign investment, and human capital's direct and indirect effects on green energy usage in Sub-Saharan Africa. Their study suggests that in the early stages of economic expansion, per capita GDP tends to reduce clean energy utilization; however, beyond a certain threshold, economic growth begins to facilitate green energy adoption. Additionally, their research highlights a negative correlation between financial development and clean energy consumption in the region.

Saygin and Iskenderoglu (2022) employed panel data from 20 emerging economies to assess the interplay between financial development and green energy deployment. Their empirical findings indicate that, when financial development is measured using both stock market and banking indicators, its impact on clean energy utilization remains marginal. Nevertheless, an increase in financial development, particularly when assessed through stock market capitalization, appears to contribute positively to green energy adoption.

In another study, Lin and Okoye (2023) investigated the role of financial development and governance in shaping clean energy production and greenhouse gas (GHG) emissions across 35 high-income countries (HICs). Their results suggest that financial development and governance structures have only a limited explanatory power concerning clean energy output and emissions reduction.

2.2. Foreign Direct Investment and Renewable Energy Consumption

Kutan et al. (2018) analyzed the influence of foreign direct investment (FDI) inflows and stock market expansion on the progression of green energy utilization across Brazil, China, India, and South Africa. Their findings suggest that both FDI inflows and stock market growth play a pivotal role in promoting the adoption of clean energy. Similarly, Samour et al., (2022) determined that economic growth, foreign direct investment, and financial development significantly contribute to the expansion of green energy use in the United Arab Emirates. In a related study, Nor & Mohamud (2024) examined the long-term dynamics between FDI, GDP, trade openness, and renewable energy utilization in Somalia, reporting a positive association among these variables. Shah et al. (2022) also found empirical support for the notion that increased FDI inflows bolster clean energy consumption in China.

Further exploring the relationship between FDI and clean energy, Akpanke et al. (2023) conducted an analysis across 15 West African nations. Their results indicated that while GDP does not exert an important impact on green energy usage in either the short or long term, FDI and public sector credit have a positive impact over extended periods. Additionally, their findings suggest that while inflation and broad money supply negatively affect clean energy consumption in the long run, they exert a positive influence in the short term.

Conversely, Yadav et al. (2024) investigated the interplay between financial development and green energy consumption in BRICS economies (Brazil, Russia, India, China, and South Africa). Their analysis revealed that economic expansion facilitates greater green energy adoption, with additional positive correlations observed between clean energy consumption and both the consumer price index and domestic credit. However, in contrast to previous findings, this study identified an inverse relationship between FDI and green energy utilization. Islam et al. (2023) arrived at a similar conclusion, noting that while financial development fosters increased clean energy consumption, FDI appears to have a negative correlation with green energy adoption in BRICS nations.

Supporting this perspective, Maarof et al. (2023) found no evidence to suggest that foreign direct investment increase green energy consumption in South Africa. Expanding the scope further, Khan et al. (2021) assessed the impact of economic growth, technological advancements, and FDI on clean energy utilization in 69 countries participating in the Belt and Road Initiative (BRI). Their study concluded that these factors negatively affect green energy consumption, while financial development plays a crucial role in fostering its expansion. Additionally, the research highlighted that economic growth, FDI, and technological innovation contribute to increased overall energy consumption and carbon emissions among BRI nations. Moreover, findings from the Granger non-causality test revealed bidirectional causality among clean energy utilization, technological innovation, financial development, and FDI.

3. DATA AND METHODOLOGY

3.1. Dataset and Explanatory Variables

This research aims to investigate the causal relationships among renewable energy consumption, gross domestic product (GDP), foreign direct investment (FDI), financial development, and additional key macroeconomic indicators. The analysis is based on a dataset covering 26 Asian countries over the period 2000–2020, with country selection and data availability determined using the World Bank database. The regression model incorporates the following variables: renewable energy consumption (REN), gross domestic product (GDP), foreign direct investment (FDI), financial development index (FIND), gross fixed capital formation (GFCF), and inflation rate (lnINF). These data were sourced from the World Development Indicators (refer to Table 1 for further details).

The empirical framework is structured to elucidate the interconnections among renewable energy consumption, economic growth, foreign direct investment, financial sector development, capital formation, and inflationary trends, as formally specified in the following model:

$$REN_{it} = f(GDP_{it}, FDI_{it}, FIND_{it}, GFCF_{it}, INF_{it}) \quad (1)$$

We converted the proposed variables into natural logarithms:

$$REN_{it} = \beta_0 + \beta_1 \, lnGDP_{it} + \beta_2 FDI_{it} + \beta_3 FIND_{it} + \beta_4 \, lnGFCF_{it} + \beta_5 \, lnINF_{it} + \varepsilon_{it} \quad (2)$$

The model's constant term is denoted by $\beta0$; the coefficient values of each explanatory indicator are represented by $\beta1$ to $\beta5$; the error white noise term is denoted by ε_t, and t is the time series variable's time period.

Table 1. Summary of Variables

Variables	Description	Measurement	Source
GDP	Gross Domestic Product	Current value US$	World Bank-World Development Indicators
REN	Renewable Energy	% of total final energy	
FDI	Foreign Direct Investment	Net inflows, % of GDP	
FIND	Financial Development Index	Index	
GFCF	Gross Fixed Capital Formation	Current US$	
INF	Inflation Rate	Consumer prices, annual %	

Countries	China, Indonesia, Malaysia, Turkey, Russia, Japan, Pakistan, Bangladesh, Iran, Qatar, Jordan, Republic of Korea, Philippines, Thailand, Lebanon, Mongolia, Kazakhstan, Azerbaijan, Kyrgyzstan, Georgia, Israel, Vietnam, Armenia, Nepal, Singapore

3.2. Methodology

The empirical analysis follows a structured approach to identify the determinants of renewable energy consumption in Asian countries. First, the Hausman specification test is conducted to determine the appropriate estimation technique. Second, groupwise heteroscedasticity and autocorrelation tests are performed sequentially to assess potential econometric issues. Third, the model and its variables are examined for cross-sectional dependence. Fourth, the Cross-sectionally Augmented Dickey-Fuller (CADF) panel unit root test, a second-generation approach that accounts for cross-sectional dependence, is employed to establish the integration properties of the variables. Fifth, the Driscoll-Kraay estimator is applied to obtain robust standard errors, addressing issues of heteroscedasticity and autocorrelation in the presence of cross-sectional dependence. To examine the presence of a long-run relationship among the variables, the Westerlund ECM Panel Cointegration test is utilized.

3.2.1. Hausman Specification Test

Hausman's (1978) specification test is commonly used to choose between fixed effects and random effects models. It relies on the concept that, under the null hypothesis where unobservable unit effects and regressors are uncorrelated, the coefficient estimates derived from fixed effects estimation should not differ systematically from those obtained through random effects estimation (Manuel & Vance, 2010) In other words, the primary distinction between random and fixed effects is whether or not the unit effects exhibit a correlation with the independent variables. If they are not correlated, it is concluded that the random effects model is efficient, and the random effects model is preferred. Consequently, the null hypothesis is rejected if the Hausman test results are significant, suggesting that the fixed effects model is reliable and ought to be applied in the investigations. In contrast, random effects estimators should be used if the test statistics are not significant since the null hypothesis cannot be rejected.

3.2.2. Heteroscedasticity in Panel Data

One of the assumptions of linear regression models is that the error terms of the main population regression have constant variance, known as homoscedasticity. This assumption implies that the variance of the error term u_i remains constant regardless of changes in the independent variables, with σ^2 being a constant value. The heteroscedasticity issue arises when this assumption is violated. The Modified Wald test is employed to identify the issue of heteroscedasticity in panel data models. The null hypothesis of the Wald test states that the variance of the error terms remains constant.

$H_0: \sigma_i^2 = \sigma^2$

$H_1: \sigma_i^2 \neq \sigma^2$

Modified Wald statistics:

$$W = \sum_{i=1}^{N} \frac{(\hat{\sigma}_i^2 - \sigma^2)^2}{V_i} \tag{3}$$

Here, $\hat{\sigma}_i^2$ is the estimator of the variance of the error term of the cross-section unit, which is calculated by the equation given below:

$$\hat{\sigma}_i^2 = \frac{1}{T_i} \sum_{t=1}^{T_i} v_{it}^2 \tag{4}$$

$$V_i = \frac{(T_i - 1)}{T_i} \sum_{t=1}^{T_i} (v_{it}^2 - \hat{\sigma}_i^2)^2 \tag{5}$$

The Wald test statistic follows an asymptotic χ^2 distribution with N degrees of freedom (Tatoğlu, 2012)

3.2.3. Autocorrelation in Panel Data

An assumption of the linear regression model is the absence of serial correlation among the population error terms, meaning that the error term values are uncorrelated across consecutive periods. In panel data models, the correlation of the error term of one observation with the error term of another observation causes the autocorrelation problem, and inefficient regression parameter estimation results are obtained. In this case, the Local Best Invariant (LBI) test developed by Baltagi-Wu (1999) and the Durbin-Watson test of Bhargava, Franzini, and Narendranathan (1982) are used to detect the autocorrelation problem in panel data. The null hypothesis in these tests evaluates the the alternative hypothesis assumes the presence of autocorrelation (Bhargava et al., 1982; Baltagi & Wu, 1999) absence of autocorrelation among error terms, while

$H_0: \rho = 0$

$H_1: \rho \neq 0 \; or \; \rho > 0, \rho < 0$

3.2.4. Cross-Sectional Dependence Test

Geographically, economically, and culturally, the nations in the sample are nearly identical. As a result, there is a chance that the data will show cross-sectional dependence, which could lead to ineffective outcomes. To avoid this issue, CD test by Pesaran (2004) was employed that can be used in T < N and T > N circumstances, and mathematically, Pesaran (2004) CD test statistic is estimated as follows (Pesaran, 2004):

$$CD = \sqrt{\frac{2}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \sqrt{T_{ij}} \, \hat{\rho}_{ij} \right) \tag{6}$$

Where N denotes the number of observations and ρ indicates the correlation. It shows that, under the null hypothesis of no cross-sectional dependency, CD has a normal distribution with N (0, 1) since $N \rightarrow \infty$ and T are both sufficiently large. The CD statistics mean for cross-sections and fixed time values is zero. This feature enables the test to be applied to panel data models that have dynamic, non-stationary, heterogeneous, and homogenous features (De Hoyos, Rafael & Sarafidis, 2006).

3.2.5. Test of Homogeneity

To determine if the slope coefficients of the variables are homogeneous or heterogeneous, the Pesaran and Yamagata (2008) homogeneity test was utilized. The following is an expression for the panel data model with FE and heterogeneous slopes:

$$y_{it} = \alpha_i + \beta_i' x_{it} + \varepsilon_{it}, \quad i = 1, \dots, N, \quad t = 1, \dots T, \tag{7}$$

where x_{it} is a $k \times 1$ vector of a strictly exogenous regressor, β_i is s a k×1 vector of unknown slope coefficients, and α_i is limited on a compact set, such that $\|\beta_i\| < K$.

$$y_i = \alpha_i \tau_T + X_i \beta_i + \varepsilon_{it}, i = 1, \dots, N, \tag{8}$$

where $y_i = (y_{i1}, \dots, y_{iT})', \tau_T$ is a $T \times 1$ vector of ones, $X_i = (x_{i1}, \dots, x_{iT})'$, and $\varepsilon_i = (\varepsilon_{i1}, \dots, \varepsilon_{iT})'$.

The null hypothesis of interest is:

H_0: $\beta_i = \beta$ for all i (slope coefficients exhibit homogeneity)

Against the alternatives:

H_1:For a non-zero percentage of pairwise slopes for $i \neq j$, $\beta i \neq \beta j$ for every i (slope coefficients do not show homogeneity).

3.2.6. Panel Unit Root Tests

There are two test generations in the panel unit root testing framework. While the second generation allows cross-sectional dependence, the first generation presumes that the cross-sectional units are independent of one another.

Since we found a connection between the different sections in the first tests, we then perform a second-generation test called the Cross-sectional Augmented Dickey-Fuller (CADF) unit root test, which was enhanced by Pesaran. The second generation of panel unit root tests aims to overcome the cross-sectional dependence problem of the first generation. The null hypothesis in this case is based on the assumption that the data has a unit root. The second-generation tests assume that the panels are distinct and that there is no autoregressive (AR) structure across the series.

In the context of econometric analysis, Pesaran (2007) introduces a modification to standard Dickey-Fuller (DF) or Augmented Dickey-Fuller (ADF) regressions to address the issue of cross-dependence. Cross-dependence arises when the observations in a panel dataset are not independent, and this can affect the validity of traditional regression techniques.

A simple dynamic linear heterogeneous panel data model is defined for a panel of T time periods and N cross-sectional units, where T and N can be more than either (Pesaran, 2007):

$$y_{it} = (1 - \varphi_i)\mu_i + \varphi_i y_{i,t-1} + u_{it} \qquad i = 1, \dots, N \; and \; t = 1, \dots, T \tag{9}$$

$$u_{it} = y_i f_t + \varepsilon_{it} \tag{10}$$

In the y_{it}, the observation for the ith cross-section unit at time, f_t is the unobserved common effect, whereas ε_{it} is the individual-specific error. Equations (9 and 10) may be rewritten as:

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i f_t + \varepsilon_{it} \qquad (9)$$

Where $\alpha_i = (1 - \varphi_i)\mu_i,\ \beta_i = -(1 - \varphi_i)\ and\ \Delta y_{it} = y_{it} - y_{i,t-1}$

The unit roots H_0 and H_1 are formulated in the following way:

$H_0: \beta_i = 0$ for all i

$H_1: \beta_i < 0, i = 1,2, \dots, N, i = N_1 + 1, N_1 + 2, \dots, N$

Regression analysis is enhanced with additional data using a statistical CIPS (cross-sectionally augmented IPS) approach. It contains the initial differences of each series in the panel as well as the cross-sectional averages of the lagged levels. This adjustment enhances the accuracy of the regression results when dealing with panel data characterized by cross-sectional interdependencies among observations.

$$CIPS\ (N,T) = t - bar = N^{-1} \sum_{i=1}^{N} t_i\ (N,T) \qquad (10)$$

For the *i*th cross-section unit, the cross-sectionally augmented Dickey-Fuller statistic is represented by $t_i(N,T)$, provided the t-ratio of the coefficient of $y_{i,t-1}$ in the CADF regression (Pesaran, 2007; Tugcu, 2018; Pesaran et al., 2008; Im et al, 2003).

3.2.7. Driscoll-Kraay Standard Error Correction Model Estimation

Hoechle (2007) recommends opting for the Driscoll-Kraay estimation method if the estimated model exhibits issues such as cross-sectional dependence, heteroscedasticity, and autocorrelation. This method generates robust parameters that account for these challenges. In the Driscoll and Kraay (1998) method, the adjusted standard errors provide consistent results regardless of the cross-sectional size. Moreover, it is emphasized that the estimator developed by Driscoll and Kraay should be used in the detection of changing variance, spatial dependence, and serial dependence in the fixed effects panel model (Hoechle, 2007; Driscoll and Kraay,1998).

3.2.8. Cointegration Test in Panel Data

Westerlund (2007) ECM (Error Correction Model) Panel Cointegration Test was executed, which was proposed by Westerlund (2007), for analyzing the long-term relationship between the variables in the panel dataset. Westerlund's (2007) cointegration methodology has an advantage over the others by specifically addressing cross-sectional dependence. Four panel cointegration tests based on error-correction were developed by Westerlund (2007). Of these tests, two are known as panel statistics (Pa, Pt) and the other two as group mean statistics (Ga, Gt). Two tests are formulated to test the alternative hypothesis that the entire panel is cointegrated, whereas the remaining two tests evaluate the H_1 hypothesis that at least one unit within the panel exhibits cointegration. The error correction model, where all variables in levels are integrated into order 1, is as follows (Westerlund, 2007):

$$\Delta y_{it} = \delta_i' d_t + a_i\left(y_{i,t-1} - \beta_i' x_{i,t-1}\right) + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \quad (11)$$

To allow for the estimation of the error correction parameter, a_i, equation (11) can be rewritten as:

$$\Delta y_{it} = \delta_i' d_t + a_i y_{i,t-1} + \lambda_i' x_{i,t-1} + \sum_{j=1}^{p_i} \alpha_{ij} \Delta y_{i,t-j} + \sum_{j=-q_i}^{p_i} \gamma_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \quad (12)$$

where $\lambda_i' = -\alpha_i \beta_i'$, the parameter α_i represents the rate at which the system adjusts back to the long-term equilibrium relationship. The computation then includes the standard error of the error correction coefficient and the error correction coefficient for the complete panel model.

$$\hat{\alpha} = \left(\sum_{i=1}^{N} \sum_{t=2}^{T} \tilde{y}_{it-1}^2\right)^{-1} \sum_{i=1}^{N} \sum_{t=2}^{T} \frac{1}{\hat{\alpha}_i(1)} \tilde{y}_{it-1} \Delta \tilde{y}_{it} \quad (13)$$

$$E(\hat{\alpha}) = \left(\left(\hat{S}_N^2\right)^{-1} \sum_{i=1}^{N} \sum_{t=2}^{T} \tilde{y}_{it-1}^2\right)^{-1/2} \quad (14)$$

Panel statistics, assume that α_i is equal for all i, and can be given as follows:

$$P_\tau = \frac{\hat{\alpha}}{SE(\hat{\alpha})} \quad (15)$$

The null hypothesis and alternative hypothesis of panel cointegration statistics are defined as follows:

H_0: $\alpha_i = 0$ for all i , no cointegration for all cross-sectional units

H_1: $\alpha_i = \alpha < 0$ for all i, there is cointegration for all cross-sectional units

The rejection of null implies that error correction is in place for both individual panel members and the panel as a whole.

4. Empirical Findings

This chapter presents and discusses empirical findings from a theoretical standpoint.

4.1. Hausman Specification Test Result

The Hausman test is applied to determine which of the fixed effects and random effects panel data models is preferred. The Hausman test statistics probability value is 0.0000, presented in Table 2. Accordingly, the null hypothesis that the random effects model is appropriate is strongly rejected at all significance levels. Consequently, it is decided that the fixed effects model is the appropriate model.

Table 2. Hausman Test Result

chi2(5)	(b-B)'[(V_b-V_B)^(-1)](b-B)
	45.97
Prob>chi2	0.0000

Note: H_0: difference in coefficients not systematic

4.2. The Results of Heteroscedasticity and Autocorrelation Tests

In order for the results to be reliable, the model must be tested for deviations from the basic assumptions (heteroscedasticity and autocorrelation). This study utilized the modified Wald test to assess groupwise heteroscedasticity, following the method suggested by Baum in 2001. According to the findings in Table 3, the null hypothesis of no heteroscedasticity problem (homoskedasticity) is strongly rejected at all significance levels. Rejection of the null hypothesis implies that the variance of error terms in the model is not constant (heteroskedasticity) and that there is a problem of varying variance.

Table 3. Result of Heteroscedasticity Test

H_0: sigma(i)^2 = sigma^2 for all i	
chi2 (26)	8717.38
Prob>chi2	0.0000

Note: Modified Wald Test for Group Heteroscedasticity in Fixed Effect Regression Model

Bhargava, Franzini, and Narendranathan (1982) used the Durbin-Watson test to evaluate autocorrelation, as did Baltagi and Wu (1999) with the LBI test. The findings are shown in Table 4. Bhargava et al. and the Baltagi-Wu LBI Test yielded test statistic values of 0.1733577 and 0.39803207. Because the estimated test statistic values are fewer than two, the null hypothesis of no autocorrelation is strongly rejected at all significance levels. As a result, the fixed effects model suffers from autocorrelation, and the error terms follow a sequential pattern.

Table 4. Results of the Autocorrelation Test in Fixed Effects Model

H_0: sigma(i)^2 = sigma^2 for all i	
F test that all u_i=0: F(25,489)	14.03
Prob > F	0.0000
Modified Bhargava et al. Durbin-Watson	0.1733577
Baltagi-Wu LBI	0.39803207

4.3. Cross Section Dependence Test Results

In this study, Pesaran (2004) CD test was applied to test for cross-section dependency. According to the cross-sectional dependence test results presented in Table 5, the null hypothesis stating that there is no cross-sectional dependence in the model is strongly rejected at the 1% significance level since the probability values in all series are below 0.01. Therefore, by rejecting the null hypothesis, it can be concluded that both the variables and the model have cross-sectional dependence. This implies that shocks occurring in a particular country will affect other countries over time.

Table 5. Results of Cross-Section Dependence Test for Variables

	Pesaran CD_{LM3}	Probability Value	Decision
REN	3.694348	0.0002	Reject
GDP	74.73743	0.0000	Reject
FDI	9.448000	0.0000	Reject
INF	23.37480	0.0000	Reject
GFCF	68.61773	0.0000	Reject
FIND	26.02420	0.0000	Reject
Model	9.695529	0.0000	Reject
	Pesaran Scaled LM		
Model	99.18158	0.0000	Reject

4.4. Results of the Homogeneity Test

According to the findings of the homogeneity test in Table 6, the null hypothesis (H_0) that the slope coefficients are homogenous is rejected. As a consequence, it is concluded that the constant term and slope coefficients are not homogenous among selected Asian countries.

Table 6. Homogeneity Test Results

Test	Test Stat.	Prob. Val.
Delta_tilda	11.452	0.000
Delta_tilda_adj	14.026	0.000

4.5. Panel Unit Root Test Results

The presence of cross-sectional dependence in panel data is crucial for choosing the appropriate unit root tests. First generation unit root tests are employed in the absence of cross-sectional dependency. However, second-generation unit root tests are required if cross-sectional dependency is present. Given that the series being analyzed exhibits cross-sectional dependence, second-generation unit root tests that account for this dependence should be employed to assess the stationarity of the series.

Table 7 presents the results of the unit root test for the fixed effects model. The empirical results indicate significant cross-sectional dependence among the cross-sections. As a result, the second-generation panel data method is used to obtain more robust and reliable outcomes. The panel unit root tests are implemented with intercept and trend. The outcomes of these tests depict whether the data is stationary or not. The lag length in each analysis is considered the Akaike Information Criterion (AIC). The CIPS statistics indicate that the series are non-stationary at the level. Therefore, the empirical findings prompt us to conduct panel unit root tests on the first differences of the series. According to the empirical findings, there is a trend effect in GDP and GFCF variables at the level. The test statistics and associated p-values show that all series become stationary at the first difference at a 1% significance level.

Table 7. CADF-Unit Root Test Results for Fixed Effects Model[3]

Variable	At Level			1st Difference		
	Lag	int. or trd.	CIPS stat.	Lag	int. or trd.	CIPS statistics
REN	3	0	-1.453	3	0	-3.097*
GDP	4	1	-2.500	4	1	-2.869*
FDI	4	0	-1.164	4	0	-3.378*
GFCF	2	1	-2.515	2	1	-2.515 *
FIND	3	0	-1.902	2	0	-4.009*

Note: The Akaike Information Criterion has been used to determine statistical values. The * symbol indicates a fixed variable with a statistical value significant at %1.

4.6. Panel Cointegration Test Results

Cointegration techniques are used to determine the presence of long-term linkages among integrated variables. Essentially, panel cointegration approaches are used to study the long-term connection between non-stationary series in panel data analysis. Table 8 shows the results of the Westerlund (2007) bootstrap panel-ECM cointegration test. After analyzing the data, it is clear that the null hypothesis H_0, which asserts the absence of a cointegration connection between variables with intercept and trend, is rejected. In this scenario, the variables employed in the study model have a substantial long-run association, indicating that they will tend to converge toward a long-run equilibrium. These findings imply that in the long run, renewable energy consumption will be affected by any changes in gross domestic product, foreign direct investment, financial development index, gross fixed capital formation, and inflation rate.

Table 8. Results of Westerlund Bootstrap Panel-ECM Cointegration Test

	Statistics	asym p-val	bootstrap p-val
g_tau	2.687	0.996	0.976
g_alpha	1.912	0.972	0.002

[3] The Akaike Information Criterion has been used to determine statistical values.

The * symbol indicates a fixed variable with a statistical value significant at %1.

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p_tau	-1.107	0.134	0.001
p_alpha	-2.397	0.008	0.045

Note: 1000 iterations are used to get bootstrap probability values. Premise and lag levels are set to 1.

4.7. Driscoll-Kray Standard Error Correction Model Estimation Results

After identifying the cointegration relationship between variables, the coefficients must be estimated. Since the model contained autocorrelation, heteroscedasticity and cross-sectional dependence, the Driscoll-Kraay method, which is resistant to all these conditions, was applied. Table 9 displays the results from the fixed effects model using the Driscoll-Kraay (1998) Standard Errors estimation method. The regression examines the relationship between renewable energy consumption, gross domestic product *(GDP),* renewable energy *(REN)*, foreign direct investment (*FDI*), financial development index (FIND), gross fixed capital formation *(GFCF)* and inflation rate *(lnINF)* for 26 Asian countries. The relevant model could be developed as follows in light of the Driscoll-Kraay test results:

$$lnRENt = 99.01 - 0.06\ lnGDPt - 2.23\ lnFDIt - 5.13\ lnFINDt - 7.49\ lnGFCFt + 0.01\ lnINFt + \varepsilon_t$$

Table 9. Results of the Driscoll-Kraay Standard Error Regression Test

Method: Fixed Effects Regression Model							
Dependent Variable: REN		**Coefficient**	**D.K. Std. Error**	**t value**	**P>|t|**	**[95% Conf. Interval]**	
Independent Variables	**GDP**	-0.0645811	0.0273503	-2.36	0.026	-0.12091	-0.00825
	FDI	-2.2265390	2.3535780	-0.95	0.353	-7.07382	2.620745
	INF	0.0058461	0.0148635	0.39	0.697	-0.02476	0.036458
	GFCF	-7.4997690	2.0570540	-3.65	0.001	-11.7363	-3.26318
	FIND	-5.1309460	2.7538470	-1.86	0.074	-10.8026	0.540707
	_cons	99.017650	7.9734280	12.42	0.000	82.59607	115.4392
F(5.25)=30.79, Prob> F=0.0000				R^2=0.2818			

According to these results, it is seen that there is an inverse relationship between GDP and renewable energy, that is, growth does not lead to a result in favour of renewable energy. The same situation is observed in the relations between gross fixed capital formation and financial development and renewable energy. No statistically significant relationship was found between inflation and foreign direct investment or renewable energy use.

5. Discussion

The panel regression results reveal a significant negative relationship between gross domestic product (GDP) and renewable energy utilization. Similarly, both gross capital formation and financial development are found to exert an adverse effect on renewable energy consumption. These findings suggest that economic expansion does not necessarily foster the adoption of renewable energy in Asian countries. This outcome diverges from previous empirical studies, such as those by Usman et al. (2022), Rahman and Sultana (2022) and Ali et al. (2025) , which document a positive association between economic growth and renewable energy consumption.

Furthermore, gross capital formation appears to impede the uptake of renewable energy, potentially due to the perceived financial risks associated with investments in clean energy infrastructure. Lenders may hesitate to provide funding due to uncertainties regarding the long-term viability and profitability of renewable energy projects. In addition, studies by Salisu et al., (2017), Sek, (2017) and Raheem et al. (2020) have explored the relationship between oil prices and inflation, suggesting that fluctuations in oil prices influence consumer prices indirectly via import costs and production expenses. In the present study, inflation is incorporated as a proxy for oil prices, yet its estimated effect is statistically insignificant, warranting further investigation and a more detailed exploration of its role in the energy transition.

Contrary to the findings of previous research (Aboagye and Kwakwa, 2023; Sun et al., 2023; Dimnwobi et al., 2022; Shahbaz et al., 2021; Khan et al., 2020; Mukhtarov et al.,2020; Eren et al., 2019) this study identifies an inverse relationship between financial development and renewable energy consumption across the selected countries. The estimated coefficient suggests that financial sector advancement does not contribute to an increase in renewable energy adoption; rather, it may inhibit its growth. This result may stem from inefficiencies in the financial system, particularly concerning the availability and accessibility of green financing mechanisms. Additionally, the underdeveloped banking infrastructure in many Asian economies may limit the financial sector's ability to support renewable energy investments, thereby constraining their expansion. These findings align with the conclusions of prior studies (Nawaz and Rahman, 2023; Saygin and Iskenderoglu, 2022) reinforcing the argument that economic and financial development in Asian countries does not necessarily accelerate the transition to renewable energy. Instead, as economies grow, their reliance on fossil fuels may increase, reducing the share of renewable energy in the overall energy mix.

However, it should not be forgotten that this result may be reversed after a certain stage if these countries continue to develop, since the Environmental Kuznets Curve (EKC) Hypothesis put forward by Grossman & Krueger (1995) suggests that the relationship between environmental factors and growth is likely to be in the form of an inverted U. However, within the framework of Acemoğlu's (2013) dirty technology idea, the advantage of these countries in producing dirty goods may also be the encouraging factor for this result.

6. Conclusion and Implications

This study examines the key factors influencing renewable energy utilization across Asian economies, with a particular focus on the interplay between renewable energy consumption, gross domestic product (GDP), foreign direct investment (FDI), financial development (FIND), gross fixed capital formation (GFCF), and inflation (INF). The dataset, spanning the period from 2000 to 2020, has been sourced from the World Development Indicators (WDI) database.

To determine the appropriate econometric model for panel data estimation, the study initially applies the Hausman (1978) test, which compares the fixed effects and random effects models. The test results confirm the superiority of the fixed effects model for this analysis. Following this, the modified Wald test is conducted to diagnose the presence of groupwise heteroskedasticity within the fixed effects regression model. The findings reveal substantial heteroskedasticity, indicating that the variance of error terms is not constant across observations, which could influence the robustness of standard estimation techniques.

Additionally, to assess potential autocorrelation within the fixed effects framework, the Bhargava et al. Durbin-Watson (1988) and Baltagi-Wu LBI (1999) tests are employed. The results of both tests reject the null hypothesis of no autocorrelation, confirming the presence of serial correlation among the error terms. This suggests that residuals from one period are systematically related to those of preceding periods, which can distort parameter estimates if not properly addressed. Subsequently, the Pesaran (2004) CD test is utilized to evaluate cross-sectional dependence across countries. The rejection of the null hypothesis implies that economic shocks or policy changes in one country have spillover effects on other nations, underscoring the interconnectedness of Asian economies in terms of renewable energy adoption. In addition, the result of the Homogeneity test, which was conducted to investigate whether the model was homogeneous, revealed that the model had a heterogeneous structure, that is, the structure or composition was not uniform.

Given the detected cross-sectional dependence, the study employs the Cross-sectionally Augmented Dickey-Fuller (CADF) unit root test, developed by Pesaran (2007), to analyze the stationarity properties of the data. The results indicate that all variables are non-stationary at levels but attain stationarity at their first differences, implying integration of the same order, I(1). This satisfies the prerequisite for cointegration testing, ensuring the validity of long-run equilibrium relationships among the variables. the Westerlund (2007) ECM Panel Cointegration test outcomes confirm a robust long-run association, indicating that these economic variables move together over time in influencing renewable energy usage.

After the cointegration analysis, the fixed effects model is estimated using the Driscoll-Kraay (1998) robust standard error method, which accounts for heteroskedasticity, autocorrelation, and cross-sectional dependence. The estimation results reveal that GDP, GFCF, and FIND exert a statistically significant negative impact on renewable energy consumption (REN), whereas INF and FDI do not exhibit a significant relationship with REN.

Based on the empirical findings, several policy recommendations can be proposed to enhance renewable energy adoption in Asian economies. First, policies governing foreign direct investment should be structured to align with sustainability goals, ensuring that FDI inflows contribute to the expansion of renewable energy projects rather than reinforcing fossil fuel dependency. Regulatory frameworks should incentivize green investments and foster the growth of domestic renewable energy industries.

Second, targeted financial incentives; such as feed-in tariffs, tax credits, and direct subsidies—can significantly enhance the affordability and competitiveness of renewable energy, thereby promoting its wider adoption. Moreover, strategic investments in research and development (R&D) and modern energy infrastructure will facilitate the seamless integration of renewable energy sources into national grids, enhancing energy security and sustainability.

Finally, the financial sector must be restructured to create a more robust and efficient investment climate for renewable energy projects. Strengthening financial institutions and expanding access to green financing mechanisms will be critical in mobilizing capital toward clean energy initiatives. Establishing specialized financial instruments, such as green bonds and sustainability-linked loans, can further enhance investment in renewable energy. Over time, a well-functioning financial system will play a pivotal role in accelerating the transition to a cleaner and more sustainable energy future for Asian economies.

Çatışma Beyanı (Competing Interests)

Çalışmanın yazarları, herhangi bir çıkar çatışması olmadığını beyan etmektedirler.

The authors declare that they have no competing interests.

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It is declared that scientific and ethical principles have been followed while carrying out and writing this study and that all the sources used have been properly cited.

Araştırmacıların Katkı Oranı (Authors' contributions)

Yazarlar çalışmaya eşit oranlarda katkı sağlamışlardır.

The authors contributed equally to the study.

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