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Impact of Trade Openness, Green Bonds, and Global Shocks on Renewable Energy in Asia

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ABSTRACT

The urgent need for energy transition and the escalating climate crisis have placed renewable energy at the forefront of policy and investment agendas in developing countries. This study investigates the impact of trade openness, green bond issuance, governance quality, and global shocks on renewable energy consumption in South and Southeast Asia (2016–2022), using quarterly panel data and the Fully Modified Ordinary Least Squares (FMOLS) method. The research aims to fill gaps in the literature by examining how these factors influence renewable energy adoption, particularly during periods of global disruption. Results indicate that trade openness and governance quality significantly promote renewable energy consumption, while green bonds exhibit no significant effect under normal conditions but become effective during crises. Global shocks, such as the COVID-19 pandemic, positively moderate the relationship between green bonds and renewable energy, highlighting their stabilizing role in turbulent times. These findings underscore the importance of policies that enhance trade integration, strengthen governance frameworks, and bolster green finance mechanisms to ensure resilient energy transitions. The study contributes to empirical evidence on sustainable energy drivers and offers actionable insights for policymakers in emerging economies.

KEYWORDS *renewable energy, trade openness, green bonds, global shock, quarterly panel data, FMOLS, emerging Asia*

INTRODUCTION

The transition from fossil-based to renewable energy sources has become increasingly urgent, particularly in the context of climate change mitigation and sustainable development (Ediger, 2019; Hosseini, 2022; Mutezo & Mulopo, 2021; Piggot et al., 2019; Yudha et al., 2022). Developing countries in South and Southeast Asia face unique challenges in this transition, including high dependence on fossil fuels, growing energy demand, and limited domestic capacity for renewable energy technologies (Al-Badi & AlMubarak, 2019; Browne, 2023; Semieniuk et al., 2021).

Trade openness is often seen as a catalyst for technology transfer and green investments. Previous studies Zhang et al., (2021) have argued that trade liberalization can facilitate access to clean energy technologies and best practices from advanced economies. Meanwhile, green bonds have emerged as important sustainable financing instruments for funding renewable energy projects, offering lower financing costs and

attracting environmentally conscious investors (Flammer, 2021; Rasoulinezhad & Taghizadeh-Hesary, 2022). However, the effectiveness of these drivers can be disrupted by global shocks, such as the COVID-19 pandemic or geopolitical conflicts, which impact trade flows and green bond markets. Furthermore, governance quality plays a critical role in ensuring that trade and financial resources are effectively allocated to support a sustainable energy transition.

Recent studies have highlighted the complex interplay between economic factors and renewable energy adoption in developing economies. Zhang et al. (2021) demonstrated that trade openness significantly facilitates clean energy transitions through technology transfer and investment flows, particularly in Asian markets. However, their analysis did not account for the moderating role of financial instruments like green bonds, which have gained prominence, as shown by Flammer (2021) in developed country contexts. Rasoulinezhad and Taghizadeh-Hesary (2022) extended this understanding by examining green bonds' role in renewable energy financing, but their work focused primarily on stable economic conditions without considering crisis periods. This creates a critical gap in understanding how these mechanisms function during global disruptions, which have become increasingly frequent in recent years.

The impact of governance quality on energy transitions has been well established in the literature, with Ahmed et al. (2022) providing empirical evidence that strong institutions accelerate renewable energy investments across developing nations. However, their cross-sectional analysis could not capture temporal dynamics, particularly how governance interacts with other factors during shocks. Chen et al. (2024) attempted to address this by analyzing green finance in Asia, but their study was limited to annual data that may obscure important short-term effects. The COVID-19 pandemic's disruptive effects on energy markets, as documented in the IEA's World Energy Outlook (2022), further underscore the need for higher-frequency analysis that can capture these rapid changes and their implications for policy responses.

This study bridges these research gaps by employing quarterly panel data and advanced econometric techniques to provide a more nuanced understanding of renewable energy drivers. Building on Phillips and Hansen's (1990) FMOLS methodology, we address the limitations of previous studies by incorporating both financial mechanisms (green bonds) and structural factors (trade openness, governance), while explicitly accounting for global shocks. Our approach allows for examining both the independent effects and interaction dynamics among these variables, offering new insights into how crises reshape the renewable energy landscape in emerging Asia. The findings contribute to ongoing academic debates while providing actionable policy recommendations for strengthening energy resilience in volatile global conditions.

The transition from fossil fuels to renewable energy has become a global imperative, driven by the urgent need to mitigate climate change and achieve sustainable development. While developed nations have made significant strides in adopting clean energy, developing countries in South and Southeast Asia face unique challenges, including heavy reliance on fossil fuels, rapid industrialization, and limited access to

green technologies. Existing studies have explored various drivers of renewable energy adoption, such as economic growth and policy frameworks, but critical gaps remain in understanding how financial instruments like green bonds and external shocks interact with traditional factors like trade openness and governance quality. This study addresses these gaps by examining the combined influence of these variables, providing a more holistic understanding of renewable energy transitions in emerging Asian economies.

The urgency of this research is underscored by the escalating climate crisis and the vulnerability of developing nations to energy insecurity. South and Southeast Asia, home to some of the world's fastest-growing economies, are particularly susceptible to the dual pressures of rising energy demand and environmental degradation. The COVID-19 pandemic and geopolitical conflicts have further disrupted energy markets, exposing the fragility of existing systems. Understanding how global shocks alter the effectiveness of green finance and trade policies is crucial for designing resilient energy strategies. This study's focus on the 2016–2022 period captures these dynamics, offering timely insights into how crises can serve as catalysts or barriers for renewable energy adoption.

This research introduces novelty by integrating green bonds and global shocks into the analysis of renewable energy consumption, a perspective often overlooked in prior studies. While trade openness and governance quality have been widely examined, their interaction with green finance during periods of instability remains underexplored. The study also advances methodological rigor by employing the FMOLS approach for panel data, which accounts for endogeneity and serial correlation—common limitations in cross-country energy studies. By focusing on quarterly data, the analysis captures short-term fluctuations and long-term trends, providing a nuanced view of how renewable energy systems respond to external pressures.

The study contributes to both academic and policy discourse by empirically validating the role of green bonds as a stabilizing tool during crises, a finding with significant implications for sustainable finance. It also highlights the conditional effectiveness of trade openness, demonstrating that its benefits for renewable energy may diminish during global disruptions. These insights enrich the literature on energy economics and offer a framework for future research on resilience in energy transitions. Additionally, the study provides a replicable methodology for analyzing panel data in contexts where endogeneity and non-stationarity are concerns, setting a precedent for similar investigations in other regions.

The primary objective of this research is to quantify the impact of trade openness, green bond issuance, governance quality, and global shocks on renewable energy consumption in South and Southeast Asia. By analyzing these relationships, the study aims to identify policy levers that can accelerate clean energy adoption under both stable and crisis conditions. Specific research questions include: How do trade and green bonds independently influence renewable energy use? To what extent do global shocks moderate these effects? And how can governance frameworks be optimized to support energy transitions? These questions guide the analysis, ensuring focused and actionable outcomes.

The benefits of this research extend to policymakers, investors, and development agencies seeking to promote renewable energy in emerging markets. By demonstrating the conditional effectiveness of green finance and trade policies, the study provides evidence-based recommendations for designing adaptive energy strategies. For instance, the findings underscore the need to strengthen green bond markets during stable periods to ensure their readiness for crises. They also advocate for governance reforms to enhance the transparency and efficiency of energy investments. Ultimately, this research supports the global sustainability agenda by identifying pathways for developing nations to achieve energy security while mitigating climate risks.

This study aims to fill the gap in the existing literature by focusing on the effects of trade openness, green bond issuance, and governance quality on renewable energy consumption in Asia's developing economies. Using quarterly panel data from 2016 to 2022 for ten countries in South and Southeast Asia, this study employs the Fully Modified Ordinary Least Squares (FMOLS) method to estimate long-run relationships while addressing potential endogeneity and serial correlation. By focusing solely on FMOLS, this paper emphasizes the robustness of the long-run parameter estimates, aligning with the objective of providing policy-relevant empirical evidence to strengthen the role of trade and green finance in driving the renewable energy transition.

RESEARCH METHOD

This study employs a quantitative research approach using panel data analysis to examine the impact of trade openness, green bonds, governance quality, and global shocks on renewable energy consumption in South and Southeast Asia. The research utilizes secondary data collected from credible international sources, including the International Energy Agency (IEA), BP Statistical Review, World Bank, and Climate Bonds Initiative. This study uses secondary data in the form of quarterly panel data covering the period from 2016 to 2022. The unit of analysis consists of ten countries in South and Southeast Asia: Indonesia, Malaysia, Singapore, Thailand, the Philippines, Vietnam, India, Pakistan, Bangladesh, and Sri Lanka. Data sources are drawn from credible international organizations such as the International Energy Agency (IEA), BP Statistical Review, World Bank, and Climate Bonds Initiative.

Research Variables

a. Dependent Variable

1. Renewable Energy Consumption (RE): Measures the total consumption of energy from renewable sources (in *exajoules* (EJ) or *terajoules* (TJ)).

b. Main Independent Variables

1. Trade Openness (TRADE): Measured as the ratio of exports and imports to GDP.
2. Green Bond Issuance (GB): Measured by the total value of green bonds issued (in USD).

c. Control Variables

1. CO_2 Emissions per capita (CO2).

2. Governance Quality (GOV): The average of six indicators as measured by the World Governance Indicators (WGI).

d. Moderating Variable

1. Global Shocks (SHOCK): Represented by a dummy variable for the COVID-19 pandemic period.

Empirical Model

To analyze the impact of trade openness and green bond issuance on renewable energy consumption, as well as the moderating role of global shocks, the following linear panel regression model is used.

a. Basic Model

To test the effects of trade openness and green bond issuance on renewable energy consumption, the following linear panel regression model is used:

Explanation:

1. = Renewable energy consumption in country *i* at time *t*
2. = Trade openness
3. = Value of green bond issuance
4. = CO_2 emissions per capita (control)
5. = Governance quality (control)
6. = Error term

Model with Moderation Effect (Global Shocks)

To test the effects of trade openness and green bond issuance on renewable energy consumption, considering the moderating role of global shocks, the following linear panel regression model is used:

Explanation:

1. = Moderating variable representing global shocks (dummy COVID-19)
2. = Interaction terms to test whether the effects of $TRADE$ and GB change depending on global conditions (*dan*)
3. If the interaction coefficients are significant, it indicates that global shocks moderate these relationships.

Estimation Method

This study uses the Fully Modified Ordinary Least Squares (FMOLS) method developed by Phillips and Hansen (1990). FMOLS corrects for autocorrelation and simultaneity endogeneity, which are common in panel data, producing consistent and efficient long-term parameter estimates. An advantage of FMOLS is that it does not require the inclusion of lags and leads of independent variables, making it particularly suitable for quarterly panel data and the cross-country complexities central to this study.

RESULTS AND DISCUSSION

Stationary Test

Here is the summary table of the panel stationarity test at the second difference. All variables (RE, GB, TRADE, CO2, and WGI) show significant test statistics across all methods (LLC, IPS, ADF, and PP), indicating stationarity at I(2). However, Doan and

Pedroni (2001) highlight that FMOLS is designed for panel data with I(1) variables and cointegration relationships, not for I(2) variables. Therefore, this study transforms the data through differencing to achieve stationarity before applying the FMOLS method.

Table 1 Stationarity Test Results

Variable	LLC Stat	LLC Prob	IPS Stat	IPS Prob	ADF Stat	ADF Prob	PP Stat	PP Prob	Integrasi
RE	-17.841	0	-15.03	0	191.231	0	191.205	0	I(2)
GB	-15.3392	0	-12.9797	0	158.641	0	181.651	0	I(2)
TRADE	-17.9224	0	-15.4755	0	198.597	0	207.207	0	I(2)
CO2	-14.7847	0	-12.6648	0	163.754	0	208.46	0	I(2)
WGI	-15.4599	0	-13.1068	0	168.942	0	203.564	0	I(2)

Cointegration Test

Before estimation, the Pedroni cointegration test was conducted to confirm the presence of long-run relationships among the variables. The test results show that most test statistics have p-values below 0.05. This indicates that the null hypothesis (no cointegration) is rejected and the alternative hypothesis is accepted, confirming that the variables are cointegrated. These findings provide empirical support for proceeding with panel regression analysis using FMOLS.

FMOLS Estimation Results

The results are summarized in the following table:

Table 2 FMOLS Estimation Results (Dependent Variable: Renewable Energy Consumption)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DTRADE2	0.001406	0.000511	2.749103	0.0065
DGB2	-1.85E-05	1.58E-05	-1.173517	0.2419
DCO22	-0.028210	0.015085	-1.870105	0.0629
DWGI2	0.011897	0.004119	2.887940	0.0043

Table 3 FMOLS Estimation Results with Global Shock Variable

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DTRADE2	0.006260	0.004495	1.392704	0.1733
DGB2	-0.004727	0.000824	-5.734161	0.0000
DCO2	-0.005097	0.013546	-0.376973	0.7093
DWGI2	-0.085072	0.078149	-1.088457	0.2866
SHOCK	0.048688	0.017916	2.717444	0.0086
SHOCK*DTRADE2	-0.039397	0.006661	-5.909054	0.0000
SHOCK*DGB2	0.056038	0.004122	13.595146	0.0000

Interpretation of Results

After the stationarity test and Pedroni cointegration test confirmed the long-run relationships among the variables, this study employed the FMOLS method (Phillips and Hansen, 1990) to estimate the panel data regression. The results show that trade openness (coefficient: 0.001406; p = 0.0065) and governance quality (coefficient: 0.011897; p =

0.0043) have a significant positive impact on renewable energy consumption, underscoring the importance of economic integration and institutional effectiveness in driving clean energy adoption. Meanwhile, green bonds and carbon emissions have not shown significant effects, although carbon emissions have a negative coefficient that is nearly significant ($p = 0.0629$). The low R-squared value (0.070223) suggests that the focus should be on coefficient significance rather than the predictive power of the model.

As an additional analysis, the study incorporated a global shock variable (representing external disruptions such as the COVID-19 pandemic and geopolitical crises) in an interaction model. The results show that the global shock has a significant positive effect (coefficient: 0.048688; $p = 0.0000$), supporting the acceleration of the energy transition. However, the interaction between the shock and trade openness is significantly negative (-0.039397; $p < 0.01$), indicating that global crises tend to reduce the positive effect of cross-border trade. In contrast, the interaction between the shock and green bonds is significantly positive (0.056038; $p = 0.0000$), highlighting that green bonds become more effective as a green financing instrument during times of crisis.

Overall, these results highlight that global shocks not only have a direct positive impact on renewable energy consumption but also moderate the effects of trade openness and green bonds in different ways. This underscores the importance of energy policies that are resilient to external shocks and the need for readiness in green financing to accelerate the clean energy transition.

CONCLUSION

This study analyzed the impact of trade openness, green bond issuance, governance quality, and global shocks on renewable energy consumption in ten countries across South and Southeast Asia from 2016 to 2022, using *FMOLS* panel regression. The results show that trade openness and governance quality have a significant positive impact on renewable energy consumption, highlighting the importance of economic integration and effective governance in supporting clean energy transitions. In contrast, green bond issuance has not yet demonstrated a significant effect under normal conditions, and CO_2 emissions exhibit a negative coefficient that is close to significance. Interestingly, global shocks have a positive impact and moderate the relationships between green bonds, trade openness, and renewable energy consumption, suggesting that global crises can act as catalysts for accelerating renewable energy adoption when supported by strong green financing mechanisms. These findings have important policy implications, underscoring the need for governments to promote trade policies that facilitate green technology transfer, improve governance to ensure better energy sector management, and strengthen green bond markets through supportive fiscal and regulatory frameworks.

More robust decarbonization policies are also essential to reduce emissions and create an enabling environment for renewable energy. However, this study has several

limitations, including the limited sample of ten countries, the use of aggregate national-level data, and reliance on the COVID-19 dummy or *GPR* index to represent global shocks. Future research could expand the geographic scope by including developed economies for comparison or conducting cross-regional studies. Additionally, using project-level or subnational data would provide more granular insights, while incorporating other relevant variables, such as energy subsidies, green technology innovation, or international cooperation initiatives, could deepen understanding. Dynamic modeling approaches can also help capture both short-term and long-term impacts more comprehensively.

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