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Original Research Article

Forecasting Renewable Energy Transition Using Error Correction Model: Addressing Environmental and Sustainable Development

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Abstract
In the context of global warming, the transition from fossil fuels to renewable energy is crucial for reducing carbon emissions and achieving sustainable development goals. From 1990 to 2022, this study examines new energy consumption in Indonesia and examines its relationship with GDP, foreign direct investment (FDI), urbanization, carbon emissions (CO_2), the exchange rate, and subsidies received. An ECM was used to determine the short- and long-term impacts. In the short term, economic growth has a positive and significant effect on energy consumption; however, in the long term, the negative effect becomes more pronounced. Direct investment (FDI) has no significant effect on renewable energy consumption, creating a negative long-term trend. Urbanization has significant positive and negative dampening effects on new energy consumption in the long term, but no significant short-term effects. Energy consumption and carbon emissions have a significant negative effect. To solve construction and environmental challenges in Indonesia, it is necessary to increase the capacity of renewable energy sources.

Keywords: Carbon emissions; FDI; GDP; renewable energy; tax revenue; urbanization

1. Introduction
Climate change is a critical global issue driven primarily by fossil fuel consumption and rapid economic growth, resulting in rising temperatures and environmental degradation (Chen et al., 2022). It impacts biodiversity, habitats, and extreme weather patterns, while also posing health risks (Yadav et al., 2024a). The development of renewable energy significantly reduces carbon dioxide (CO_2) emissions, which are the main causes of climate change. One of the key elements in efforts to preserve the environment and combat climate change is the use of renewable energy. The use of renewable energy is a key element in preserving the environment and combating climate change (Anthony and Patra, 2022; Aziz et al., 2024). Renewable energy sources, such as solar, wind, biomass, hydro, and geothermal, play a crucial role in mitigating climate change by reducing carbon emissions (Aziz et al., 2024a). Advancements in renewable technologies, including efficient solar panels, aerodynamic wind turbines, and improved battery storage systems, are making clean energy more accessible and effective (Bouzaid et al., 2024;

Zhiznin et al., 2019). These innovations are essential for addressing climate change and ensuring sustainability for future generations (Ziat et al., 2018).

Economic growth leads to higher energy demand and transportation use, resulting in increased pollution and carbon emissions. Inflation also plays a crucial role in environmental quality across Asia, requiring region-specific climate policies (Ahmad et al., 2021). Although fossil fuels have historically fueled economic progress, concerns about climate change, air pollution, and resource scarcity are accelerating the global transition toward energy efficiency and renewable sources (Kartal et al., 2024; Shittu et al., 2021). The widening gap between energy supply and demand has heightened the risk of energy insecurity (Yin and Qamruzzaman, 2024), pushing many countries to adopt sustainable energy strategies to address environmental challenges (Azam et al., 2021). Indonesia's energy consumption projections for the next 10 years are based on population and economic growth data, with the last 10 years showing the dominance of the transportation sector until there was a shift to the industrial sector in 2022 due to increasing demand for coal, such that the industrial sector became the largest, with a share of 45%, followed by transportation at 37%, households at 13%, commercial at 4.2%, and other sectors at 1% (DEN & S.J. 2023a). This is because new and renewable energy (NRE) in Indonesia faces barriers related to financing that require a special approach in terms of funding, technology, and raw materials, and is influenced by government policies in energy budget allocation. In addition, dependence on conventional energy, such as coal and petroleum, as well as existing infrastructure, makes the transition to NRE difficult, requiring long-term policies and commitments to reduce dependence on fossil energy (SolarKita, 2023).

According to the website of the National Development Planning Agency (BAPPENAS), through the Indonesia Green Growth Program, Indonesia is committed to reducing emissions by 29% through self-reliance and by to 41% with international assistance by 2030, as stated in the Nationally Determined Contribution (NDC). Of the total emission reduction target, 11% comes from the energy sector. In addition, the government has stipulated that 23% of energy in Indonesia must come from new and renewable energy sources by 2025. According to National Energy Council (DEN) (2023b), in 2022, Indonesia's total primary energy supply reached 246 million TOE (tonnes of oil equivalent), with the dominance of fossil energy sources, namely coal (42 %), petroleum (31 %), and natural gas (14 %), while new and renewable energy (NRE) still contributed relatively little at 12.3%. The utilization of renewable energy in 2023 has experienced significant progress, with biodiesel production reaching 13.2 million KL (up 11% compared to the previous year), biodiesel exports of 0.18 million KL, domestic consumption of 12.3 million KL, mixing biodiesel in Biogasoil by 34.9%, utilization of biomass in the industrial sector reaching 7.9 million metric tons, communal biogas in the household sector of 110 million m3, and the use of solar water heaters that produce 261 thousand TOE of hot and direct geothermal water in the industrial sector reaching 6.2 TWh (Ministry of Energy and Mineral Resources, 2023). Figure 1 shows a diagram of the use of renewable and fossil energy in Indonesia (Hannah Ritchie, 2024).

As shown in Figure 1, renewable energy consumption in Indonesia remains low, with only 65 TWh used in 2023 compared to 284 TWh from fossil fuels, highlighting the challenges in the clean energy transition. Government intervention is crucial for promoting energy efficiency, particularly in developing countries, where energy costs are a significant expense (Dilanchiev et al., 2023). Sustainable economic growth and the adoption of clean energy are aligned, as industries using renewable energy produce fewer environmental externalities (Hao et al., 2021). The Environmental Kuznets Curve (EKC) states that patterns of environmental degradation vary across industrialized and developing countries (Tsandra et al., 2023). Studies on GDP and renewable energy use have mixed results, while long-term economic growth positively affects renewable energy adoption in OECD countries (Alam and Murad, 2020). Research on Indonesia, Shafira Annisa et al. (2024), indicates a negative relationship. Meanwhile, in Pakistan, GDP has a long-term positive effect on renewable energy utilization, but no effect in the short term (Aziz et al., 2024b).

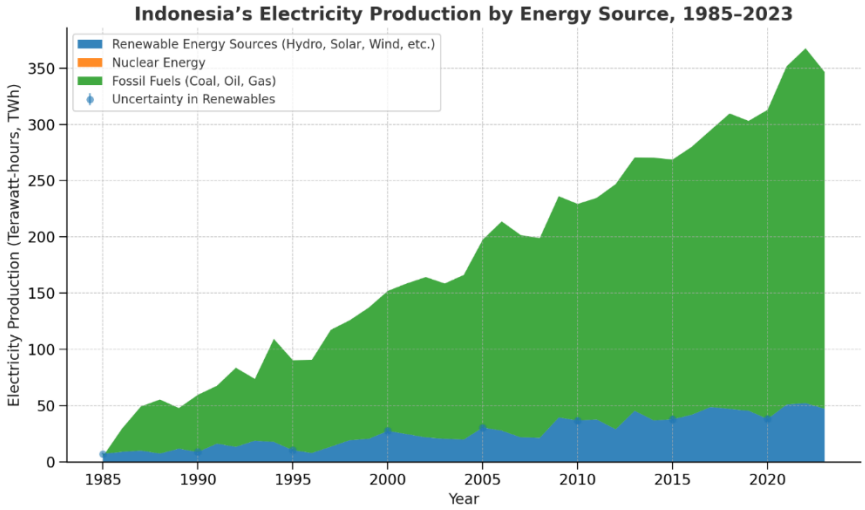

Figure 1. Renewable energy consumption in Indonesia

Sources: Our world in data, 2024; energy institute – statistical review of world energy,2024

Research on urbanization and renewable energy consumption in ASEAN reveals various impacts. While Shafira Annisa et al. (2024a) found an insignificant short-term impact, they found a significant negative long-term influence. Vo et al. (2024) show that urbanization harms the use of renewable energy in the short term but has a positive impact in the long term, except in Malaysia. The Philippines has successfully balanced both factors over time. Nathaniel and Khan (2020) suggest that urbanization and economic growth drive renewable energy consumption. Regarding financial influences, Tiwari et al. (2022) found no correlation between stock market development and renewable energy use in Asia but observed that trade and economic growth reduce energy consumption through technological advancements. Meanwhile, FDI supports renewable energy in low-income Asian countries but harms BRICS nations, possibly due to resource reallocation or technological progress that lowers energy demand (Yadav et al., 2024b).

This study examines the factors influencing current energy consumption in Indonesia, with special emphasis on GDP, FDI, urbanization, CO_2 emissions, water consumption, and temperature. GDP reflects economic growth and its impact on energy demand, but FDI plays an important role in financing and developing new energy technologies. Urbanization increases energy consumption, which requires more efficient energy solutions, while CO_2 emissions increase energy demand. CO_2 emissions increase energy demand. Investment demand in this sector is influenced by production and export volumes. To provide a comprehensive understanding of the recent energy transition and energy consumption efficiency in Indonesia, this study uses ECM to discuss the dynamic and long-run nature of the relationship.

2. Methods

2.1. Data Collection Method

The objects of this study are renewable energy consumption (REC), gross domestic product (GDP), foreign direct investment (FDI), carbon emissions (CO_2), urbanization (UPG), the Rupiah–US dollar exchange rate (IDR), and tax revenue (TR). The type of data used is secondary data, which was obtained indirectly from several official sources, such as the World Development Indicators (WDI), One Data Indonesia, and other relevant publications. These secondary data consist of information collected and published by authorized institutions in the form of documentation, annual reports, and previous research findings. The dataset is a time series with a span of 1990 to 2022, which is compiled continuously in a certain period and includes the variables mentioned previously: REC, GDP, FDI, CO_2, UPG, IDR, and TR.

2.2. Data Analysis Method

The analysis uses the ECM as an econometric tool to examine the relationship between long and short periods resulting from cointegration between the research variables. Furthermore, descriptive analysis is used to analyze data trends and patterns. To estimate the ECM, this study conducted several statistical tests, particularly the stationarity test (unit root test), to ensure the absence of unit roots in the data. This test verifies the equilibrium relationship between the variables.

After ECM estimation, a series of classical assumption tests were performed, including normality, autocorrelation, and heteroscedasticity tests, to ensure the validity and reliability of the model (Basuki & Prawoto, 2016). Econometric Long-run model and Short-run model following equation 1 and 2

$$REC = a_0 + a_1 GDP_t + a_2 FDI_{1t} + a_3 co2_{2t} + a_4 UPG_{3t} + a_5 IDR_{4t} + a_6 TR_{5t} + e_t \quad (1)$$

Where renewable energy consumption (REC) is modeled as a function of economic growth (GDP), foreign direct investment (FDI), carbon emissions (CO_2), urbanization (UPG), Indonesia's exchange rate (IDR), and tax revenue (TR). To capture the short-run dynamics and the speed of adjustment toward long-run equilibrium, the error correction model (ECM) is formulated as follows:

$$REC_t = a_0 + a_1 D(GDP)_t + a_2 D(FDI)_{1t} + a_3 D(CO2)_{2t} + a_4 D(UPG)_{3t} + a_5 D(IDR)_{4t} + a_6 D(TR)_{5t} + ECT(-1)_t + e_t \quad (2)$$

In this specification, Δ denotes the first difference of each variable, while ECT_{t-1} represents the lagged error correction term derived from the long-run equation, indicating the speed at which deviations from the long-run equilibrium are corrected over time. The term ε_t is the error term, and t denotes the time period of observation.

3. Results and Discussion

3.1. Result

The unit root test evaluates whether a variable has a stationary property or contains a unit root, which is characterized by an autoregressive coefficient of one. The first step in this test is to estimate an autoregressive model for each variable to identify long-term data movement patterns. In this study, the augmented Dickey-Fuller (ADF) test was used as the main method to test the stationarity of the data, ensuring that the variables used did not contain random trends that could lead to biased or misleading regression relationships.

Table 1. Stationarity test

Variabels	Unit Root Test			
	Level		First Difference	
	ADF	Probability	ADF	Probability
REC	-0.331	0.909	-6.326	0.0000
GDP	0.685	0.9899	-4.192	0.0026-
FDI	-2.201	0.209	-5.361	0.0001
UPG	0.435	0.8911	-5.376	0.0001
CO2	-0.443	0.888	-4.505	0.0015
IDR	-1.091	0.706	-6.732	0.0000

As shown in Table 1, the test results at this level indicate that none of the variables meet the stationarity requirements because the probability value still exceeds 0.05. However, after the first differentiation (1st difference), all variables became stationary, as indicated by a probability value that dropped below 0.05. Therefore, all variables passed the stationarity test and were prepared for use in the next stage of the analysis.

Table 2. Long-term estimates

Variables	Coefficient	Probability
GDP	-0.002***	0.0006
	(0.0005)	
FDI	-0.157	0.5691
	(0.272)	
CO2	-17.150***	0.0000
	(2.823)	
UPG	-1.605*	0.0753
	(0.866)	
TR	0.375	0.1061
	(0.224)	
IDR	-0.0006***	0.0028
	(0.0002)	
C	77.250	0.0000
	(5.853)***	
R-squared: 0.990216		
Adjusted R-squared: 0.987959		

Based on Table 2, economic growth significantly affects energy consumption, with a coefficient of determination of -0.002 indicating a negative relationship between the two. Energy consumption, indicated by a negative correlation between the two variables (a coefficient of determination of -0.002). Table 2 shows that economic growth has a significant effect on energy consumption, with a coefficient of determination of -0.002 indicating a negative relationship between the two variables. Table 2 shows that economic growth has a significant impact on energy consumption, with a coefficient of determination of -0.002 indicating a negative relationship between the two. For example, when the economy is experiencing difficulties, energy consumption tends to decrease. Emissions decreased significantly, with a coefficient of determination of -17.150, indicating that an increase in carbon emissions decreases along with a decrease in energy consumption. In addition, the foreign investment and tax revenue variables do not have a significant effect on the use of new energy. Emissions have decreased significantly with a coefficient of determination of -17.150, indicating that an increase in carbon emissions decreases along with a decrease in energy consumption. Tax revenue does not have a significant impact on the use of new energy. With a coefficient of determination of -1.605, urbanization shows a significant negative impact on energy consumption, indicating that increasing urbanization is inversely proportional to the level of energy consumption. Urbanization has a large negative impact on energy consumption. This shows that increasing urbanization is inversely proportional to the level of energy consumption. In addition, the rupiah exchange rate against the dollar has a significant effect with a coefficient of -0.0006, indicating that changes in the ratio value can affect the level of new energy consumption in the economy. can affect the level of new energy consumption in the economy. The rupiah exchange rate against the dollar has a significant effect with a coefficient of -0.0006, indicating that changes in the ratio value can affect the level of new energy consumption in the economy.

Table 3. Cointegration test

Variable	Prob.	Std. Error
ECT (-1)	0.0002	There is Cointegration

As shown in table 3, the probability of the ECT variable is 0.002, which is below the threshold of 0.05. This shows that the ECT variable is stationary at the data level and confirms the cointegration relationship between renewable energy use, GDP, FDI, urbanization, carbon emissions, exchange rates,

and income taxes. This indicates that the ECT variable is stationary at the data level and confirms the cointegration relationship between renewable energy use, GDP, FDI, urbanization, carbon emissions, exchange rates, and income taxes. With this long-term relationship, the analysis can proceed to the short-term dynamic estimation stage. To analyze the interaction of these variables in the short term, the ECM method is applied. This model assesses the level of error correction and adjusts deviations, thereby returning the system to long-term equilibrium. The Error Correction Model (ECM) estimation results are presented in Table 4.

Table 4. Short-term estimates

Variables	Coefficient	Probability
D(GDP)	0.001*	0.0859
	(0.0009)	
D(FDI)	-0.092	0.5589
	(0.156)	
D(CO_2)	-14.509	0.0000
	(2.015)	
D(UPG)	-0.197	0.8108
	(0.816)	
D(TR)	-0.056	0.6696
	(0.131)	
D(IDR)	0.0001	0.2573
	(0.131)	
ECT (-1)	-0.561***	0.0003
	(0.133)	
C	-0.874	0.0006
	0.22	
R-squared: 0.766		
Adjusted R-squared: 0.697		

Based on Table 4, the Error Correction Model (ECM) equation can be analyzed as follows. The value of the ECT(-1) coefficient of 0.003, which is smaller than 0.05, indicates that the ECM model has a significant influence in the short term. In other words, the model can adjust imbalances in the previous period towards long-term equilibrium. In addition, an adjusted R-squared value of 0.697 shows that independent variables namely, GDP, FDI, urbanization, carbon emissions, exchange rates, and tax revenues–contribute to explaining 69.7% of the variation in the dependent variables. The remaining 30.3% was influenced by other factors that were not included in this research model. This indicates that the model has a fairly good fit level in explaining the relationship between variables. In these circumstances, incorporating additional factors would not significantly improve explanatory power but could instead lead to redundancy, multicollinearity, and overfitting, thus undermining the robustness of inference.

Subsequent estimates reveal that, in the near run, GDP exerts a substantial influence on the dependent variable, with a coefficient of 0.001, signifying that economic growth affects the variation in the variable. Simultaneously, carbon emissions exert a considerable influence, evidenced by a coefficient of -14,509, indicating an inverse correlation between heightened carbon emissions and the utilization of renewable energy. In other terms, increased carbon emissions correlate with a diminished demand for renewable energy. Conversely, other factors in this model exhibit no substantial impact in the short term; therefore, they do not directly affect the dynamics of changes in the dependent variables during that time frame.

Moreover, the core of the ECM is not in formulating the most intricate specification but in clarifying the error-correcting mechanism that connects short-term imbalances to long-term equilibrium.

This study distinctly delineates these mechanisms; for example, GDP has a favorable short-term impact on renewable energy usage, which becomes negative in the long term, whereas carbon emissions consistently have a negative influence in both timeframes. These findings underscore that the selected specification is both parsimonious and robust, rendering supplementary variables or comparative modeling superfluous. Model simplicity combined with analytical rigor bolsters the trustworthiness of the results and offers clearer insights into the issues of Indonesia's energy transition.

Table 5 Classical assumption

Classical Assumptions	Coeffient	Information
Normality	0.835	Normally distributed
Autocorrelation	0.639	No autocorrelation
Heterokedastiness	0.776	There is no heterodoxy

The results of the classical assumption test in Table 5 indicate that the regression model in this study met the requirements because all coefficients were above the threshold of 0.05. The normality test with a coefficient of 0.835 showed that the data were normally distributed; therefore, the model could be used without concerns related to the residual distribution. Furthermore, the autocorrelation test with a coefficient value of 0.639 confirmed that there was no autocorrelation in the model, ensuring that the independent variable was not affected by serial correlations that could interfere with the validity of the analysis results. Meanwhile, the heterokedasticity test, which produced a coefficient of 0.776, showed that the residual variance remained stable; therefore, there were no heterokedasticity problems that could interfere with the parameter estimation. With all classical assumptions satisfied, the regression model can be considered reliable and worthy of use in the analysis.

3.2. Discussion

Dumitrescu and Hurlin (2012) employed the Granger causality test to illustrate a reciprocal relationship between conventional energy consumption and economic growth, wherein economic growth stimulates an increase in renewable energy consumption and carbon dioxide emissions, while carbon dioxide emissions maintain a neutral relationship with both conventional and renewable energy consumption. The study's findings demonstrated that short-term economic growth substantially enhanced renewable energy usage, whereas the effect became negative in the long term. The findings were corroborated by Yadav et al. (2024b), who asserted that economic growth exhibited a favorable correlation with renewable energy utilization in Brazil, Russia, India, China, and South Africa (BRICS). Conversely, Shafira Annisa et al. (2024b) discovered in their study that GDP exerted a considerable negative impact on renewable energy usage. A multitude of factors can explain these findings. In the short term, swift economic expansion stimulates heightened investment in renewable energy technology and the advancement of sustainable infrastructure, bolstered by governmental policies and incentives that facilitate the energy transition (Abban et al., 2021; Dirma et al., 2024). In the long term, escalating industrial activity and heightened energy demands will likely lead to increased reliance on more stable and cost-effective conventional energy sources, resulting in a relative decrease in renewable energy use in relation to total energy consumption. Xu et al. (2022) emphasized the pivotal influence of governmental incentives and regulatory frameworks in fostering the expansion of the renewable energy sector in China, while also revealing the intricate interplay between state control and market dynamics. Mehta et al. (2023) investigated the governance problems of renewable energy investment in South Africa, indicating that although current regulations seem advantageous, their execution is impeded by bureaucratic inefficiencies and insufficient stakeholder cooperation. Furthermore, obstacles, including restricted renewable energy capacity, elevated operating expenses, and fluctuations in policies and regulations, may lead to a transition in the effects of economic expansion from favorable in the near term to detrimental in the long run. Although the short-term benefits of GDP on renewable energy are evident, Indonesia seems to encounter difficulties in sustaining its commitment to green energy following the

early phase of industrialization. This indicates that the sustainability component remains a concern that has not been completely incorporated into the national economic growth strategy (Fadhilah and Susanti, 2019).

Foreign investment, in both the short and long terms, does not affect renewable energy usage. This aligns with Tiwari et al. (2022), who found no significant association between stock market development and renewable energy consumption in Asia. The ineffectiveness of foreign investment in impacting renewable energy consumption in Indonesia, both in the short and long terms, can be attributed to several primary causes. Most foreign investments are still focused on the industrial and manufacturing sectors that rely on conventional energy because they are more stable, cheaper, and more accessible than renewable energy, which requires high initial costs and adequate supporting infrastructure (Nor et al., 2024; Mauro, 2024). In addition, regulations and incentives from the government related to renewable energy are still not strong enough to attract foreign investors to switch to cleaner energy sources. Policy uncertainty, fluctuations in energy prices, and limited technology and production capacity of renewable energy in Indonesia are also obstacles to foreign investments encouraging its use. As a result, although foreign investments contribute to national economic growth, their influence on renewable energy usage remains negligible. This underscores the growing significance of private and foreign finance in the renewable energy sector, highlighting the necessity for a more robust regulatory framework to guarantee the sustainability of financing (Nepal et al., 2021). The experience in Brazil (de Deus et al., 2022) illustrates that the effective incorporation of green finance in renewable energy initiatives, particularly in the solar and wind domains, is facilitated by aggressive governmental policies and international cooperation.

This study included a changeable exchange rate of the dollar relative to the rupiah to assess the influence of foreign investments. The results demonstrated that, over the long term, it exerts a substantial negative effect; however, in the near term, it becomes negligible for renewable energy. The prolonged adverse impact of the dollar exchange rate relative to the rupiah on renewable energy consumption, which is negligible in the short term, can be ascribed to Indonesia's dependence on foreign investments in the non-renewable energy industry. In the immediate term, exchange rate variations have not directly affected renewable energy initiatives, which typically require considerable time to develop and continue to depend on government policies and the availability of technology (Li et al., 2025). However, in the long term, the depreciation of the rupiah against the dollar could increase the cost of importing renewable energy technology and equipment, most of which are sourced from abroad. This situation can inhibit investments in this sector, as foreign investors tend to be more cautious about committing capital to countries with unstable exchange rates. Additionally, the weakening of the rupiah may also lead investors to favor fossil-energy-based projects, which are perceived as more profitable and supported by more established infrastructure than renewable energy.

The findings of this study indicate that urbanization exerts a substantial negative effect on renewable energy consumption in the long term, although this effect is negligible in the short term. This aligns with Shafira Annisa et al. (2024c), who suggest that urbanization exerts a modest short-term influence and a large negative effect on renewable energy usage in ASEAN. Conversely, this diverges from the conclusions of Vo et al. (2024), who indicate that urbanization adversely affects renewable energy consumption in the short term but yields a beneficial impact in the long run throughout growing ASEAN markets, with the exception of Malaysia. The long-term adverse impact of urbanization on renewable energy consumption in Indonesia, although negligible in the short term, can be ascribed to the initial phases of urbanization, where urban development emphasizes infrastructure, residential areas, and industrial sectors that continue to depend on conventional energy due to its economic viability and availability. The shift to renewable energy requires substantial expenditures in technology and distribution systems, which are frequently deprioritized during the first development phase. Nonetheless, as urbanization persists over time, the escalating energy demand resulting from urban expansion, population growth, and heightened energy consumption in industrial and transportation sectors further

solidifies dependence on fossil fuels, constraining the use of renewable energy. The absence of policies to effectively advocate for the integration of renewable energy in urban design has intensified this issue.

Carbon emissions have a significant negative impact on renewable energy consumption, both in the short and long terms. Abdullah Abbas Amer et al. (2024) corroborate these findings, indicating that renewable energy utilization has a substantial negative association with carbon emissions (CO_2) in Gulf Cooperation Council (GCC) nations. The detrimental effect of carbon emissions on renewable energy utilization in Indonesia, both in the short and long terms, is due to the significant reliance on fossil fuels as a primary energy source across multiple sectors, including industry, transportation, and power generation. In the immediate term, increasing carbon emissions signify the prevalence of fossil fuels, which are more economical and accessible than renewable energy sources, thereby obstructing the shift to cleaner alternatives. In the long term, substantial investments and infrastructure established for fossil fuels pose structural impediments to the advancement of renewable energy. The absence of effective emission control policies and insufficient incentives for green energy development exacerbate this adverse trend. Zeraibi et al. (2024) proposed that developing countries can expedite the transition to renewable energy by enhancing green electricity generation capacity and achieving sustainable economic growth through CO_2 emission reductions. Governments may implement taxes and incentives to motivate entrepreneurs and citizens to produce low-carbon, environmentally friendly technologies.

4. Conclusions

This study analyzed the short- and long-term factors influencing renewable energy usage in Indonesia using an error correction model. The results indicate that economic expansion positively influences renewable energy usage in the near term; however, in the long term, it tends to exacerbate dependence on fossil fuels, a trend frequently observed in developing economies. Foreign direct investment has no significant impact, indicating the predominance of traditional energy-intensive sectors and the restricted focus of foreign funds on renewable energy. Fluctuations in the exchange rate against the U.S. dollar adversely affect the long-term utilization of renewable energy, as the nation's reliance on imported green technologies and equipment intensifies. Urbanization also adversely impacts the long term, as urban expansion increases the demand for fossil fuels to sustain infrastructure and industrial growth. Moreover, increasing carbon emissions correlate with a sluggish transition to renewable energy, underscoring the continued cost-effectiveness and availability of fossil fuels relative to cleaner options. The findings indicate that fortifying regulatory frameworks, augmenting incentives for green investments, and extending renewable energy infrastructure are crucial for expediting Indonesia's clean energy transition. By tackling structural and policy impediments, Indonesia can reduce its reliance on fossil fuels and attain a more sustainable energy future.

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Ethics Statement

This study did not involve human participants, animals, or sensitive data; therefore no ethical approval was required.

CRediT Author Statement

Hoerun Nisa: Idea Development, Investigation, Formal Analysis, Data Curation, Visualization, Manuscript Draft Preparation. **Dessy Rachmawatie:** Supervision, Research Design, Manuscript Review

and Revision. **Younes Ziat:** Supervision, Resources, Manuscript Review and Revision. **Dyah Titis Kusuma Wardani:** Supervision, Manuscript Review and Revision.

References

Abdullah. Abbas Amer, E.A., Ali Meyad, E.M., Meyad, A.M., and Mohsin, A.K.M. 2024. Impacts of renewable and disaggregated non-renewable energy consumption on CO_2 emissions in GCC countries: a STIRPAT model analysis. Heliyon 10, e30154.

Abban A., and Hasan M. 2021. Revisting the determinants of renewable energy investmen-new evidence from political and government ideology. Energy Policy 151, 112184.

Ahmad, W., Ullah, S., Ozturk, I., and Majeed, M.T. 2021. Does inflation instability affect environmental pollution? Fresh evidence from Asian economies. Energy & Environment 32, 1275–1291.

Alam, Md. M., Murad, and Md. W. 2020. The impacts of economic growth, trade openness, and technological progress on renewable energy use in organization for economic co-operation and development countries. Renew Energy 145, 382–390.

Anthony, C., and Patra, F. 2022. The development of renewable energy in an effort to realize sustainable development in PT Pertamina 11.

Azam, A., Rafiq, M., Shafique, M., and Yuan, J. 2021. An empirical analysis of the non-linear effects of natural gas, nuclear energy, renewable energy, and ICT-Trade in leading CO_2 emitter countries: policy towards CO_2 mitigation and economic sustainability. Journal Environmental Management 286, 112232.

Aziz, G., Bakoben, H.B.M., and Sarwar, S. 2024. Repercussions of Pakistan's renewable and non-renewable energies on the environmental footprint: applying the non-linear ARDL estimation. Heliyon 10, e33472.

Basuki, A. T., and Prawoto, N. 2016. Analisis regresi dalam penelitian ekonomi & bisnis: dilengkapi aplikasi SPSS & Eviews. Depok: PT Rajagfindo Persada.

Bouzaid, A., Ziat, Y., Belkhanchi, H., Hamdani, H., Koufi, A., Miri, M., Laghlimi, C., and Zarhri, Z. 2024. Ab initio study of the structural, electronic, and optical properties of MgTiO 3 perovskite materials doped with N and P. E3S Web of Conferences 582, 02006.

Chen, C., Pinar, M., and Stengos, T. 2022. Renewable energy and CO_2 emissions: new evidence with the panel threshold model. Renew Energy 194, 117–128.

De Deus, J.L., Crocco, M., and Silva, F.F. 2022. The green transition in emerging economies: green bond issuance in Brazil and China. Climate Policy 22, 1252–1265.

Dewan Energi Nasional. 2023. Outlook energi indonesia 2023. Jakarta, 1–85.

Dilanchiev, A., Nuta, F., Khan, I., and Khan, H. 2023. Urbanization, renewable energy production, and carbon dioxide emission in BSEC member states: implications for climate change mitigation and energy markets. Environmental Science and Pollution Research 30, 67338–67350.

Dirma, V., Neverauskienė, LO, Tvaronavičienė, M., Danilevičienė, I., and Tamošiūnienė, R. 2024. Dampak pengembangan energi terbarukan terhadap pertumbuhan ekonomi. Energi 17 24, 6328.

Dumitrescu, E.-I., and Hurlin, C. 2012. Testing for Granger non-causality in heterogeneous panels. Economic Modelling 29, 1450–1460.

Fadhilah, R., and Susanti, H. 2019. Analysis of the impact of new and renewable energy power plant development across Indonesia on the Indonesian economy. Journal of Economic Policy 14, 105–121.

Group, W.B. 2024. World development indicators. World Bank.

Hannah Ritchie, P.R., M.R. 2024. Energy. Our world in data.

Hao, L.-N., Umar, M., Khan, Z., and Ali, W. 2021. Green growth and low carbon emission in G7 countries: how critical is the network of environmental taxes, renewable energy, and human capital? Science of The Total Environment 752, 141853.

Kartal, M.T., Magazzino, C. and Pata, U.K., 2024. Marginal effect of electricity generation on CO_2 emissions: disaggregated level evidence from China by the KRLS method and high-frequency daily data. Energy Strategy Reviews 53, 101382.

Kementrian Energi dan Sumber Daya Mineral (ESDM), Wahyu Kencono, A., Dwinugroho, M., Satra Baruna, E., Ajiwihanto, N. 2023. Handbook of energy & economic statistics of Indonesia 2023. 73.

Li, B., Zheng, S., and Majeed, M. T. 2023. Pathways for China's sustainable energy transition: examining the effects of exchange rate volatility on renewable energy investment. Energy & Environment 36 (6), 2749-2769.

Mauro, MR. 2024. Keamanan energi, transisi energi, dan investasi asing: hubungan kompleks yang berkembang. Hukum 13 (4), 48.

Mehta, R., Oyedokun, D., Merven, B., and Larmour, R. 2023. Multi-nodal energy systems modelling scenarios of South Africa's power sector.In: 2023 31st Southern African Universities Power Engineering Conference (SAUPEC). IEEE. 1–6.

Nathaniel, S., and Khan, S.A.R. 2020. The nexus between urbanization, renewable energy, trade, and ecological footprint in ASEAN countries. Journal of Cleaner Production 272, 122709.

Nepal, R., Paija, N., Tyagi, B., and Harvie, C. 2021. Energy security, economic growth, and environmental sustainability in India: Do FDI and trade openness play a role? Journal of Environmental Management 281, 111886.

Nor, B. A., and Hassan Mohamud, I. 2024. Assessing the influence of foreign direct investment on renewable energy consumption in Somalia: an ARDL model analysis. International Journal of Sustainable Energy 43

Rahman, A., Farrok, O., and Haque, M.M. 2022. Environmental impact of renewable energy source-based electrical power plants: solar, wind, hydroelectric, biomass, geothermal, tidal, ocean, and osmotic. Renewable and Sustainable Energy Reviews 161, 112279.

Sulfa, A.M.F., Abduh, A.R.P., Azharil, M.Y., and Husain, F. 2024. The future of renewable energy at sea: the role of marine power technology in climate change mitigation. Riset Sains dan Teknologi Kelautan (SENSISTEK) 7, 113-120.

Shafira Annisa, Rachmawatie, D. and Kusuma, D.B.W. 2024. The effect of urbanization, industrialization and economic growth on renewable energy consumption in ASEAN-6, period 1994–2020. El-Mal: Jurnal Kajian Ekonomi & Bisnis Islam 5.

In ASEAN-6, period 1994–2020. El-Mal: Jurnal Kajian Ekonomi & Bisnis Islam 5.

Shittu, W., Adedoyin, F.F., Shah, M.I., and Musibau, H.O. 2021. An investigation of the nexus between natural resources, environmental performance, energy security, and environmental degradation: Evidence from Asia. Resources Policy 73, 102227.

SolarKita. 2023. Barriers to the development of new and renewable energy in Indonesia.

Tiwari, A.K., Nasreen, S., and Anwar, M.A. 2022. Impact of equity market development on renewable energy consumption: do the roles of FDI, trade openness, and economic growth matter in Asian economies? Journal of Cleaner Production 334, 130244.

Tsandra, N.A., Sunaryo, R.P., Syafri, S., and Octaviani, D. 2023. The impact of energy consumption and economic activity on CO_2 emissions in G20 countries. E-Journal of Economics, Business, and Accounting 10, 69.

Vo, D.H., Vo, A.T., and Ho, C.M. 2024. Urbanization and renewable energy consumption in the emerging ASEAN markets: a comparison between short and long-run effects. Heliyon 10, e30243.

Xu, D., Salem, S., Awosusi, A.A., Abdurakhmanova, G., Altuntaş, M., Oluwajana, D., Kirikkaleli, D., and Ojekemi, O. 2022. Load capacity factor and financial globalization in Brazil: the role of renewable energy and urbanization. Frontiers in Environmental Science 9.

Yadav, A., Gyamfi, B.A., Asongu, S.A. and Behera, D.K., 2024. The role of green finance and governance effectiveness in the impact of renewable energy investment on CO_2 emissions in BRICS economies. Journal of Environmental Management 358, 120906.

Yin, C., and Qamruzzaman, M. 2024. Empowering renewable energy consumption through public-private investment, urbanization, and globalization: evidence from CS-ARDL and NARDL. Heliyon 10, e26455.

Zeraibi, A., Radulescu, M., Khan, M.K., Hafeez, M. and Jahanger, A., 2024. Analyzing the linkage between public debt, renewable electricity output, and CO2 emissions in emerging economies: does the N-shaped environmental kuznets curve exist? Energy & Environment 35, 2407–2430.

Zhiznin, S.Z., Vassilev, S. and Gusev, A.L., 2019. Economics of secondary renewable energy sources with hydrogen generation. International Journal of Hydrogen Energy 44, 11385–11393.

Ziat, Y., Benyounes, A., Rhazouani, O. El, Laghlimi, C. and Hammi, M., 2018. Single-walled carbon nanotubes for enhanced performance of Li-ion batteries. Turkish Journal of Materials 3, 61–64.