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Exploring the Factors behind Renewable Energy Consumption in Indonesia: Analyzing the Impact of Corruption and Innovation using ARDL Model

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ABSTRACT

The study examines the relationship between corruption, innovation, and renewable energy consumption in Indonesia using the Marshalian Demand Function (MDF) framework. The research analyzes data from 1990 to 20 and applies several statistical tests to validate the model's accuracy. The Autoregressive Distributed Lag (ARDL) approach is applied to evaluate the long and short-term effects of several variables on renewable energy consumption. The study finds that economic growth, number of patents, and FDI positively impact renewable energy consumption in the long term, while urbanization has a negative impact. Trade openness has no long-term impact on renewable energy consumption. In the short term, FDI, corruption, and the number of patents were found to have a significant negative association with renewable energy consumption, while GDP had a significant positive correlation. Diagnostic tests validate the model's suitability and ensure that it lacks heteroscedasticity and serial correlation. The study emphasizes the importance of encouraging renewable energy consumption and addressing the problems of urbanization and corruption in Indonesia to achieve a more sustainable and energy-efficient future.

Keywords: Renewable Energy, Corruption, Innovation, Autoregressive Distributed Lag Model
JEL Classifications: Q430, Q470, Q530, Q560, Q480

1. INTRODUCTION

To combat global warming, it has become increasingly important to use sustainable energy sources like solar, biomass, wind, hydroelectricity, and many others (Ghosh et al., 2023). Climate change's danger to humanity's future is generally acknowledged, Kumaran et al. (2020). By the year 2050, the world economy, according to the World Bank's projections, will be both more prosperous and more evenly distributed (World Bank, 2006). The installation capacity of Indonesia for renewable energy sources was projected to increase by only 386 MW by the end of Q3 2021, which is significantly less than what is required to meet the 23% goal. The rise can be broken down as follows: 291 MW from hydropower; 55 MW from geothermal; 19 MW from bioenergy; and 21 MW from solar PV. Still, coal generation accounted for roughly 66% of overall power generation, making it the dominant source. However, only about 13% came from sustainable sources, IESR (2022).

In addition, green energy is a cutting-edge and environmentally friendly choice for reliable power, Majekodunmi et al. (2023). In addition to being crucial for the planet, the consistent and low-cost advantages of renewable energy can improve social and fiscal prospects in developing nations (Rahman et al., 2022; Ergun et al., 2019; Akizu-Gardoki et al., 2018). Therefore, cleaner air is produced as more individuals and companies adopt green energy sources, which indirectly helps to increase longevity. "Renewable energy" refers to using energy replenished naturally, such as the sun's rays. These resources supply steady and dependable electricity throughout the year, allowing for higher efficiency in developing nations. In the future, we will rely more and more on renewable energy sources, which generate power through replenishing natural processes (Voumik et al., 2023; Promsri, 2018). Alternatives to traditional fossil fuels are often called "elective energy." The annual growth rate of renewables was nearly 5% between 2009 and 2019, far exceeding that of conventional fuels (1.7%). In 2020, renewable energy broke another milestone for new power capacity, bringing the total percentage of renewable energy to about 29% of total energy production, Henner (2017).

Indonesia's GDP growth ranks second among G20 countries. According to projections, India's economy will outpace the rest of the Group of Twenty by 2023 (5.4%). Following closely behind at 4.8% is Indonesia, then at 4.7% in China, Nugraha (2023). Compared to other Southeast Asian nations, Indonesia's economic expansion rates are among the highest, making it the most fertile ground for new renewable energy (EBT) research and development. The "National Energy Policy" of Indonesia recognizes that the country has a significant chance to promote the growth of EBT investment, making implementing EBT in Indonesia a top priority for the country's energy sector. "Solar, hydro, bioenergy, wind, geothermal, and maritime energy" are just some of the many forms of EBT that Indonesia can tap into to ensure the country's continued economic growth and prosperity, Bhwana (2022).

Foreign direct investment (FDI) flows into clean energy infrastructure are rising quickly, but the proportion of FDI going toward renewables is still relatively low. While Indonesia has long been an attractive location for foreign direct investment (FDI), its balance of FDI inflows to ASEAN has decreased in recent years. The decline in foreign direct investment (FDI) is attributed to increased worldwide uncertainty, OECD (2020). In 2020, compared to 2019, "cross-border equity flows" in Indonesia have dropped considerably as businesses have delayed some M&A transactions and Greenfield projects in the face of growing uncertainty. During 2010-2019, the industry attracted the lion's share of foreign direct investment (FDI), but this proportion is gradually shrinking as more money is invested in services.

Trade plays a crucial role in the sustainable development of any country. It is necessary to realize the association between trade and energy. The inefficiency of energy policy, for example, can have an undesirable effect on trade and the economy, highlighting the significance of this relationship. The "trade liberalization policies" designed to stimulate global trade will be balanced out by "energy conservation policies" that cut down on energy usage (Koengkan, 2018; Sadorsky, 2014). Greater economic activity, resulting from more trade openness policies, could raise the country's energy needs. As a developing nation, Indonesia is a country that maintains a relatively stable export value, as shown by the fact that its export development increased by 10% between 2017 and 2018, while its import value remained unchanged, Statistic Indonesia (2019). As exports expanded and imports declined, Indonesia's trading surplus jumped sharply in December 2022, from USD 1 billion to USD 3.89 billion. This was below market forecasts of USD 4.01 billion earned, Trading Economics (2023).

Housing, infrastructure, transit, and other highly energy-intensive activities contribute to the rise in urbanization's overall energy demands. Growing urbanization has been shown to benefit energy usage, as demonstrated by Wang et al. (2018). Growing manufacturing activities associated with urbanization have a beneficial effect on the consumption of energy, Bakirtas and Akpolat (2018). In 2021, 57.29% of Indonesia's people resided in urban settings, Statista (2023). As cities grew, people increasingly turned to green sources of power (Komendantova et al., 2021; Müller et al., 2020; Polcyn et al., 2023). Energy usage and environmental state are affected by urbanization as a social and economic factor because it can lead to the expansion of energy-intensive sectors like steel and concrete production, the power industry, and the transportation sector, which in turn can cause upward disturbances to the health of the environment, Li et al. (2022). Despite its pervasiveness, corruption is rarely addressed in the energy industry. Corruption in the power industry largely depends on the accessibility of resources and the dominance of political officials, claimed Rimšaitė (2019). Since government officials can be unscrupulous in the public sphere if motivated by selfish motives, more significant expertise, and imperfect monitoring, Acemoglu and Verdier (2000). Public organizations in power generation and supporting sectors need to be more productive due to corruption, which raises manufacturing costs for businesses operating in these industries. This makes it harder for emerging nations to utilize innovations like renewable energy. More and more Indonesians recognize the importance of pursuing environmentally responsible growth strategies. The transmission of environmentally friendly technologies to underdeveloped regions relies heavily on safeguarding proprietary information (Patent application). It is crucial that developing nations' intellectual property rights be protected during the transfer of sustainable technologies, Kasih (2022). Developing countries have complained that they cannot obtain life-saving technologies because of IP laws. Having this kind of security in place as an incentive to award inventors for their work is a great way to get more people thinking about and working on similar transition strategies. Inventors who don't have the security of IPRs may feel compelled to resort to concealment if they want to keep their innovations under wraps, Tee et al. (2021). Consequently, with innovation, nations can thrive. By contrast, more technological improvement promotes more renewable power. Downey (2012) and Li et al. (2020) examined the association between patent applications and renewable energy.

This paper uses Indonesian data from 1984 through 2020 to predict the effect of structural factors on renewable energy usage. This paper has crucial implications for Indonesia because it explains the impact of corruption, FDI, GDP, and trade openness on renewable energy based on Indonesia's socioeconomic advancements, and it serves as an informative guide for policymakers in Indonesia areas. Therefore, learning more about the possible connections between macroeconomic metrics and renewable energy is essential. Chung (2014) argues that macroeconomic variables influence the likelihood of growing renewable energy consumption.

The consumption of renewable energy has gained significant importance in Indonesia, as the government strives to reduce its reliance on fossil fuels and combat climate change. To understand the factors that impact the usage of renewable energy in the country, this paper employs the autoregressive distributed lag (ARDL) model to analyze the effects of corruption, patents, urbanization, FDI, and income. The study utilizes time series data from 1984 to 2020 to examine both short-term and long-term correlations between the variables. The research's findings will provide valuable insights to authorities in Indonesia on how to promote and expand the use of renewable energy sources, based on complex data. This study is particularly significant as it will offer suggestions to researchers on how to better comprehend the factors that motivate renewable energy usage in Indonesia and can also serve as a reference for other developing nations interested in expanding their use of renewable energy sources.

2. LITERATURE REVIEW

The implications of different macroeconomic factors on renewable energy in Malaysia from 1971 to 2020 were calculated by Yusoff et al. (2023). Using the ARDL technique, they discovered that rising levels of urbanization and GDP boost the share of green energy. On the contrary hand, higher trade liberalization and foreign investment threaten to dampen enthusiasm for these green sources of power. Lawal (2023) looked into the influence of urbanization and corruption in Sub-Saharan Africa starting in 1990 and ending in 2019. The corruption demonstrated that it alleviated the clean energy demand. Despite the negative findings regarding corruption, the SGMM result of urbanization is favorable and empirically critical, indicating that urbanization facilitates the rapid implementation of green power in the economies under study. In a study spanning 116 nations, Su et al. (2022) looked into how urbanization, GDP, and trade openness influenced the use of green power. The researchers concluded that accelerating trade openness and urbanization both boosted renewable energy. From 2000 to 2018, Polcyn et al. (2021) studied what variables influenced renewable energy in European countries. The concluding result of the "fixed effect and random effect" demonstrated that renewable energy usage went up as GDP went up.

Amoah et al. (2022) looked into how corruption impacted clean energy in Africa from 1996 to 2019. The final finding of the "Generalized Method of Moments techniques" found that corruption was detrimental as it alleviated renewable energy sources. Kumaran (2020) looked at what influenced ASEAN nations' use of renewable energy from 1990 to 2016. Both FMOLS and DOLS showed that urbanization significantly boosted the performance of green energy. Renewal energy is severely hampered by rising GDP and trade openness. Chen (2018) claimed that GDP fluctuations significantly and positively affect the usage of renewable energy. Moreover, using renewable energy has benefited considerably from urbanization shifts, particularly in areas with a large urban population. He applied a "dynamic system-GMM panel model" in 30 Chinese regions between 1996 and 2013. Ghimire and Kim (2018) argued that corruption is a hindrance to the growth of green energy. Corruption causes a waste of public money and slows down the distribution of government aid. From 1991 to 2017, Zheng et al. (2021) discovered that economies, particularly those of the OECD, reacted alongside fewer innovations in sustainable energy.

Solarin et al. (2022) examined how technological advancements influenced green energy in the BRICS nations spanning 1993-2018. Quantile regression found that technological advances had net favorable implications for the growth of renewable energy. How intellectual property rights impacted green energy was figured out by Tee et al. (2021) in 59 countries. According to the findings of the SGMM, "intellectual property rights" are a significant motivator in the development of green energy sources. Improved legal safeguards encourage renewable energy companies to boost their output of green power. Roespinoedji (2019) found that FDI and GDP expanded renewable power production in Malaysia. Kang et al. (2021) analyzed how GDP, FDI, trade openness, and urbanization contributed to the determination of renewable energy in South Asian countries from 1990 to 2019. The FMOLS model demonstrated that GDP enhanced clean energy, as it favorably impacted sustainable power, but FDI mitigated the usage of renewable energy.

Using a traditional panel analysis approach to analyze data from China, Jin et al. (2018) discovered a favorable and reciprocal relationship between energy consumption and technological advancement. Their research shows that technological advances can help developing nations become sustainable by boosting energy savings. Numerous studies have examined how factors like GDP, domestic investment, FDI, trade openness, urban population, financial growth, and CO_2 pollution affect the spread of renewable energy. Few previous works, however, have concluded that FDI has both excellent and opposing sides. Taking a more optimistic tack, it has the potential to serve as a means of decreasing energy usage. However, foreign direct investment (FDI) can also pose environmental risks (Chung, 2014; Friedman et al., 1992; Aliyu, 2005). FDI has a much smaller impact on "low-and middle-income countries (LMICs)" and there is no evidence between the association of FDI and renewable energy, Lee (2013). However, Doytch and Narayan (2016) stated that foreign direct investment (FDI) is a critical factor in the development of sustainable energy use in upper-middle-income countries (UMICs).

Research into what factors influence the adoption of renewable energy sources in developed and underdeveloped nations is expanding in academic journals, particularly in African countries (Uzar, 2020; Olanrewaju et al., 2019; Nyiwul, 2017). While these prior research investigations offer solid concrete results, they have yet to consider all relevant factors, such as corruption, that may affect the fair distribution of renewable energy in Africa. Thus, the research may offer beneficial conclusions for academic investigators, lawmakers, and policymakers crafting policies to foster technical innovations in clean energy sources to increase energy efficacy and acclamation the previous studies on BRICS, CHINA, and Russia (Wang and Dong, 2022; Strielkowski et al., 2021; Sharma et al., 2021).

Despite the growing importance of renewable energy in Indonesia, there is a lack of research on the drivers of its consumption. Thus, this study aims to address this gap by examining the key factors that influence renewable energy adoption in Indonesia from 1990 to 2020. Specifically, the study will investigate the impact of environmental, economic, and socio-political factors, including urbanization, GDP, population, FDI, corruption, and trade openness. To achieve this, the study will employ an ARDL analysis framework to comprehensively capture the relationships between the variables. The results of the study will not only contribute to a better understanding of the forces that drive renewable energy consumption in Indonesia but also provide insights for policymakers on how to encourage and expand the use of renewable energy sources. Overall, the study's findings will fill an important knowledge gap in the field and be relevant to other developing nations seeking to increase their use of renewable energy.

3. METHODOLOGY

3.1. Data

This study investigates the relationship between corruption, innovation, and renewable energy consumption in Indonesia through the Marshalian Demand Function (MDF) framework. This research also intends to examine the effects of several variables, such as urbanization, trade openness, FDI, and economic growth, on the usage of renewable energy in Indonesia. This research analyzed data from 1990 to 2020 to accomplish this aim and applied several statistical tests to confirm the accuracy of the data. Pesaran et al. (2001) ARDL's methodology for cointegration was used in this work. The dependent variable was renewable energy use, whereas the explanatory factors were economic growth, FDI, trade openness, corruption, innovation, and urbanization. Logarithms were applied to the data to verify normal distribution Table 1 summarizes the variables and their respective measurement units.

3.2. Theoretical Framework

The correlation between a nation's usage of energy and its current economic condition and energy costs is established in the theoretical discourse (Nicholson et al., 2021; Samuelson, 1986; Varian, 2010). Given the equilibrium state in the energy market, where the energy demand is equivalent to energy use, we can express the energy demand function at time t using the Marshallian demand function, Friedman (1949).

$$E_{Dt} = f(Y_t, P_{et}) \tag{1}$$

The variables in Equation (1) are E_{Dt}, Y_t, and P_{et}, representing energy demand, income, and energy cost at a given time t.

As previously mentioned, the relationship between a nation's use of renewable energy and trade openness, FDI, corruption, urbanization, and technological innovations can manifest in various manners. Equation 2 is the updated version of the previous Equation:

$$RE_{Dt} = f\,(Y_t, P_{et}, TO_t, PAT_t, COR_t, URB_t, FDI_t) \tag{2}$$

In Equation (2), TO_t is denoted by trade openness, PAT_t represents the number of patent applications used as a proxy of technological innovation, COR_t shows corruption, URB_t is characterized by urbanization, and FDI represents a foreign direct investment.

The variable of technological innovation is considered crucial due to its significant impact on the economy, as evidenced by numerous studies. This is attributed to its ability to facilitate more efficient energy utilization. In addition to their accessibility, patents offer the benefit of serving as a reliable gauge of inventive attempts and exhibit a strong association with various other metrics of innovation, Grossman and Helpman (1991). An essential consideration in this context pertains to the evaluation of the correlation between innovations in technology and renewable energy usage. It is imperative to explore the appropriate methodology for measuring technological innovation, Ang (2011). Regarding this matter, it is noteworthy to mention the research conducted by Griliches (1998), which advocates for using patents to assess innovation. Griliches (1998) delineated the principal features of patents and patent data and consequently suggested the adoption of patents as a metric for innovation. Prior research, demonstrated by Acs et al. (2002) and Nagaoka et al. (2010), employed patents as a metric for evaluating innovation originating from specific regions and businesses. This study delves deeper into the correlation between innovation and renewable energy consumption.

Equation 3 represents the econometric formulation of the Equation as mentioned above.

$$lnREN_t = \gamma_0 + \gamma_1\, lnGDP_t + \gamma_2\, lnFDI_t + \gamma_3\, lnTO_t + \gamma_4\, lnURB_t + \gamma_5\, lnCOR_t + \gamma_6\, lnPAT_t + \epsilon_t \tag{3}$$

Table 1: Variables description

Variable	Symbol	Definition	Source
Renewable Energy Use	lnREN	Renewable energy consumption (% of total final energy consumption)	World Development Indicator (2023)
Gross Domestic Product Per Capita	lnGDP	GDP per capita (constant 2015 US$)	
Foreign Direct Investment	lnFDI	Foreign direct investment, net inflows (% of GDP)	
Innovation	lnPAT	The number of patents application	
Corruption	lnCOR	Corruption Perception Index	
Urbanization	lnURB	Urban population growth (annual %)	
Trade Openness	lnTO	Trade (% of GDP)	

Table 2: Unit root test results

Variable	ADF unit root Test			
	Intercept		Intercept+Trend	
	Level	1st Difference	Level	1st Difference
LNRE	1.777 (0)	-4.024 (0)***	-0.329 (0)	-4.410 (0)***
LNGDP	-0.389 (0)	-3.827 (0)***	-1.577 (0)	-3.737 (0)**
LNFDI	-1.900 (0)	-4.860 (0)***	-2.854 (3)	-4.784 (0)***
LNTO	-1.552 (0)	-5.508 (1)***	-2.068 (1)	-5.758 (1)***
LNURB	-0.389 (0)	-5.519 (0)***	-2.266 (0)	-5.411 (0)***
LNCOR	-4.147 (0)**	-7.267 (0)***	-3.843 (0)**	-6.899 (0)***
LNPAT	0.253 (6)	-4.801 (3)***	-7.709 (1)***	-9.202 (1)***
Variable	**PP Unit root test**			
	Intercept		**Intercept+Trend**	
	Level	**1st Difference**	**Level**	**1st Difference**
LNRE	2.641 (5)	-3.969 (2)***	-0.316 (3)	-4.324 (4)**
LNGDP	-0.389 (0)	-3.740 (3)***	-1.774 (1)	-3.643 (3)**
LNFDI	-2.095 (2)	-4.860 (0)	-2.172 (1)	-4.784 (0)***
LNTO	-1.299 (3)	-7.461 (0)***	-2.703 (2)	-9.085 (4)***
LNURB	-0.340 (3)	-5.593 (4)***	-2.348 (1)	-5.480 (4)***
LNCOR	-4.104 (4)	-7.614 (2)***	-4.045 (4)**	-7.074 (1)***
LNPAT	-3.632 (0)	-9.665 (28)***	-13.567 (26)***	-13.126 (28)***

***, ** and * denote significance at 1%, 5% and 10%, respectively.

The research variables' coefficients were shown here in the range of parameters from $\gamma0$ to $\gamma6$. All the variables used in this research are presented in logarithmic form in Equation (3).

3.3. Econometric Methodology

3.3.1. Unit root test

A unit root test is essential in econometrics and time series analysis. It determines if a variable in a time series is non-stationary, meaning that the mean and variance change over time. Non-stationary time series can lead to spurious regression results, which can have severe consequences for policy and decision-making, Voumik et al. (2023a). The unit root test helps prevent this by checking if a time series is stationary before performing a regression analysis, Yusoff et al. (2023). If a time series is non-stationary, the unit root test can differentiate the series until it becomes stationary, a prerequisite for many econometric techniques, including cointegration analysis. Thus, the unit root test is crucial in ensuring the validity and reliability of regression results in time series analysis. It's widely acknowledged in the empirical literature that the integration order of the series must be defined before exploring any relationships between variables. Many studies have suggested that using multiple unit root tests is crucial in determining the integration order since the effectiveness of such tests can vary depending on the sample size. In this study, three different unit root tests were used: the Augmented Dickey-Fuller (ADF) test, the Dickey-Fuller generalized least squares (DF-GLS) test, and the Phillips-Perron (P-P) test. These tests were employed to ensure that no variable in the regression had an integration order higher than expected and to justify using the ARDL instead of conventional cointegration methods.

3.3.2. ARDL model

The ARDL model, developed by Pesaran et al. (2001), was utilized in this study as a robust method of estimation to investigate the short- and long-term relationships between the model's parameters. The ARDL bound test, a widely-used econometric technique, was employed to examine the long-run linkages between time series variables. A cointegration analysis enables short- and long-run dynamics to coexist in the data. Compared to traditional cointegration methods, the ARDL bound test offers several advantages, Borhan et al. (2023). It can accommodate various data structures, including I(0) and I(1) variables, deterministic terms, and lags. This feature makes it an adaptable tool for modeling diverse economic linkages. Furthermore, the ARDL bound test provides more accurate estimates than other cointegration methods, especially when the number of lags is high. It can also handle small sample sizes, which is a common challenge in time series analysis. Additionally, the ARDL bound test can determine the direction of causality between variables, which is not possible with traditional cointegration approaches. Lastly, the ARDL bound test includes model selection criteria, such as the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC), which help to determine the optimal number of lags for the cointegration relationship. The ARDL bound test is a superior method of cointegration analysis due to its flexibility, efficiency, ability to test for causality, and incorporation of model selection criteria. Equation (4) shows the ARDL long-run estimation.

$$
\begin{aligned}
lnREN_t &= \omega_0 + \omega_1 \mathrm{lnREN}_{t-1} + \omega_2 lnGDP_{t-1} \\
&+ \omega_3 lnFDI_{t-1} + \omega_4 lnTO_{t-1} + \omega_5 lnURB_{t-1} + \omega_6 lnCOR_{t-1} \\
&+ \omega_7 lnPAT_{t-1} + \sum_{i=1}^{w} \varphi_1 \Delta lnRE_{t-i} + \sum_{i=1}^{w} \varphi_2 \Delta \mathrm{lnGDP}_{t-i} \\
&+ \sum_{i=1}^{w} \varphi_3 \Delta \mathrm{lnFDI}_{t-i} + \sum_{i=1}^{w} \varphi_4 \Delta lnTO_{t-i} + \sum_{i=1}^{w} \varphi_5 \Delta \mathrm{lnURB}_{t-i} \\
&+ \sum_{i=1}^{w} \varphi_6 \Delta \mathrm{lnCOR}_{t-i} + \sum_{i=1}^{w} \varphi_7 \Delta \mathrm{lnPAT}_{t-i} + €_t \qquad (4)
\end{aligned}
$$

The null hypothesis of no cointegration is compared against the evidence of cointegration (the alternative hypothesis). We cannot accept the null hypothesis if the F-statistic exceeds the upper and lower limit values. Equations 5 and 6 represent the null hypothesis (H_0) and alternative hypotheses (H_1).

$$H_0 = \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \varphi_5 = \varphi_6 \quad (5)$$

$$H_1 = \varphi_1 \neq \varphi_2 \neq \varphi_3 \neq \varphi_4 \neq \varphi_5 \neq \varphi_6 \quad (6)$$

Determining that the parameters are co-integrated, we turned to the ARDL technique. After establishing long-term relationships, the Error Correction Term (ECT) and short-term correlations are assessed using the error correction model (ECM) proposed by Engle and Granger (1987). The ARDL estimation in the short term uses Equation 7:

$$lnRE_t = \varphi_0 + \sum_{i=1}^{w} \varphi_1 \Delta \text{lnRE}_{t-i} + \sum_{i=1}^{w} \varphi_2 \Delta \text{lnGDP}_{t-i} + \sum_{i=1}^{w} \varphi_3 \Delta \text{lnFDI}_{t-i} + \sum_{i=1}^{w} \varphi_4 \Delta lnTO_{t-i} + \sum_{i=1}^{w} \varphi_5 \Delta \text{lnURB}_{t-i} + \sum_{i=1}^{w} \varphi_6 \Delta \text{lnCOR}_{t-i} + \sum_{i=1}^{w} \varphi_6 \Delta \text{lnPAT}_{t-i} + \ell\, ECT_{t-i} + \epsilon_t \quad (7)$$

Where ℓ is the rate of adaptation.

3.3.3. Diagnostic test

Multiple diagnostic approaches were employed in the inquiry to ensure the reliability of the data. This research used the Breush-Pagan-Godfrey test to identify heteroscedasticity, Breusch and Pagan (1979), the Ramsey Reset test to evaluate specification error, Ramsey (1969), the Breush-Godfrey LM test for serial correlation (Breusch, 1978; Godfrey, 1978), and the CUSUM and CUSUMsq test to determine predicted model stability. The results of the various diagnostic procedures are summarized in (Table 2).

Table 3: ARDL bound test

Item	Test statistics	Value	K
	F	3.608	6
	Significance level		
Critical Bounds	10%	5%	1%
I (0)	2.12	2.45	3.15
I (1)	3.23	3.61	4.43

ARDL: Autoregressive distributed lag

Table 4: ARDL short-run and Long-run estimation

Variables	ADJ	LR	SR
L. lnGDP		1.811 (0.289)[a]	
L. lnFDI		0.0547 (0.250)[b]	
L. lnTO		−0.0543 (0.0941)	
L. lnCOR		0.0706 (0.045)	
L. lnURB		−0.323 (0.132)[b]	
L. lnPAT		0.184 (0.082)[b]	
Constant		16.673 (2.105)[a]	
D. lnRE	0.688 (0.211)[a]		
D. lnGDP			1.602 (0.373)[a]
D. lnFDI			−0.081 (0.027)[a]
D. lnTO			−0.053 (0.087)
D. lnCOR			−0.090 (0.027)[a]
D. lnURB			0.213 (0.239)
D. lnPAT			0.181 (0.068)[b]

Standard errors enclosed by brackets. [c]P<0, [b]P<0.05, [a]P<0.01

4. EMPIRICAL FINDINGS

4.1. Unit Test Results

The stationarity of each variable is tested using ADF and PP unit root test. This step is important as it can indicate a suitable cointegration analysis for the proposed model. Based on the unit root test as shown in Table 2, it is found that LNCOR is significant at level for both at intercept and intercept plus trend. While the rest variables are only stationary at first different. These mixed results lead to another more powerful unit root testing which is based on PP test. Again, their result showed that LNCOR and LNPAT are significant at level but only for intercept and trend. Meanwhile, LNFDI is found to be not significant at 1st difference for intercept. The mixed stationarity of these tests indicates the need to perform ARDL analysis that is able to forecast the long and short run elasticities for the model.

4.2. ARDL Bound Test Results

Table 3 provides the results of a test of ARDL cointegration between two or more time series variables. The "Test Statistic" column refers to the F-Statistic, the test statistic used in the bounds test approach. The value of the F-Statistic is 3.608. The "K" column refers to the number of lags included in the model. In this case, K is equal to 6. The "Critical Value Bounds" section displays the critical values for the F-Statistic at various significance levels (10%, 5%, and 1%) for different hypotheses about the presence of a long-run relationship between the variables. The critical values correspond to the I(0) and I(1) hypotheses, where I(0) represents the null hypothesis of no cointegration, and I(1) represents the alternative hypothesis of cointegration. To interpret the results, we can compare the F-statistic (3.608) value to the critical values at the desired significance level. The findings of the ARDL bound test depicted in Table 3 showed that F-Statistic is greater than the critical value at the 5% and 10% significance level, the null hypothesis of no cointegration is rejected, and evidence of cointegration between the variables is verified.

4.3. ARDL Results and Discussion

The ARDL long-term and short-term estimation results are displayed in Table 4. According to ARDL estimation findings, the long-run coefficient of lnGDP is 1.811, which is highly significant at the 1% significance level. Positive significant coefficients of lnGDP indicated that a 1% increase in GDP would result in a 1.811% increase in renewable energy use in the long term, and vice versa. The findings are similar to Chang et al. (2009) and Chien and Hu (2008). There are several ways in which a rise in GDP might aid in the spread of renewable energy use. Investment in renewable energy R&D, production, and distribution can increase with GDP. Improved efficiency and lower costs for renewable energy technologies are needed to compete with fossil fuels (Ridzuan et al., 2020; Voumik et al., 2023b). Tax credits, feed-in tariffs, and renewable energy requirements are only some of the measures that governments can employ to encourage the use of renewable energy by the general public. There may be a shift in public opinion toward sustainability and renewable energy use as national GDP rises. This could increase

Figure 1: CUSUM and CUSUM squares test

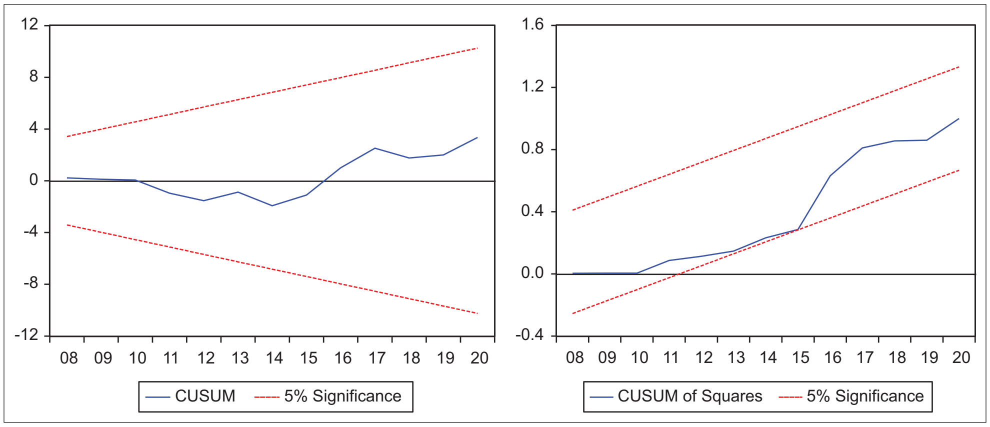

Table 5: Diagnostic test

Diagnostic test	F-statistics	P-value
BG LM test	0.538563	0.5982
BPG test	1.008342	0.4991
Ramsey reset test	1.153127	0.304
CUSUM and CUSUM	Stable	

public backing for efforts to promote renewable energy sources. Moreover, the coefficient of lnFDI is 0.0547 and significant at the 5% significance level. In the Long-term, a 1% increase in FDI will increase renewable energy use by 0.0547%, and vice versa. The findings are similar to Shahbaz et al. 2022. Foreign direct investment (FDI) can attract capital, which is used to build renewable energy infrastructure like wind or solar farms. The funds generated from this investment can be used to construct and maintain these facilities, contributing to a rise in the use of renewable energy sources. Foreign direct investment (FDI) can also usher in cutting-edge renewable energy technologies and know-how from outside firms. This can result from increased acceptance of renewable energy technology and the development of the domestic renewable energy sector (Doytch and Narayan, 2016; Fan and Hao, 2020). In addition, the lnURB coefficient is negative and statistically significant at the 5% significance level. Long-term ARDL estimation revealed that a 1% increase in lnURB will reduce renewable energy consumption by 0.323% and vice versa. The findings are similar to Salim and Shafiei (2014). Some difficulties that make it harder to adopt renewable energy sources are exacerbated by the fact that urbanization is on the rise. Space for renewable energy installations like solar panels or wind turbines is often scarce in urban areas due to the high population density. Because of this, it may be challenging to generate renewable energy on-site, which may slow the widespread acceptance of such energy. Due to the higher population density and concentration of commercial and industrial operations, urban areas often have higher energy consumption. Due to space and grid constraints, using renewable energy to meet this demand may take much work (Yang et al., 2016; Ridzuan et al., 2017; Shaari et al., 2022). The coefficients of lnPAT demonstrated a positive and significant association with lnRE, implying that a 1% increase in lnPAT will result in a 0.184% increase in lnRE over the long term. ARDL long-run estimation revealed that lnTO and lnCOR have insignificant long-term effects on lnRE. There are multiple ways in which an increase in patents for renewable energy could lead to more use of this type of energy. Financial incentives provided by patents can encourage the development of innovative renewable energy solutions by both businesses and individuals. This could improve the effectiveness and affordability of renewable energy solutions, boosting their widespread implementation and utilization. Patents can attract investment by proving that innovative renewable energy solutions have commercial viability. This can entice investors like venture capitalists to put money into renewable energy firms, speeding the arrival of game-changing new technology into consumers' hands, (Kumaran et al., 2020; Voumik et al., 2023c).

Table 4 also includes the ARDL short-run estimate outcomes. The results demonstrated that lnGDP and lnRE had a strong positive association, with a 1% rise in lnGDP increasing lnRE by 1.602% in the short term. Additionally, the results demonstrated a strong negative association between lnFDI and lnRE, with a 1% rise in lnFDI resulting in a 0.081% short-term reduction in lnRE. The study's results also show that lnCOR and lnRE have a strong negative association; a 1% rise in lnCOR would decrease lnRE by 0.090% in the short term. Additionally, the results of the ARDL estimation indicated that a 1% rise in lnPAT would result in a 0.181% increase in lnRE. Finally, the ARDL estimate revealed an insignificant link between lnRE and lnTO in the short term.

4.4. Diagnostic Test Results

Table 5 displays the outcomes of several diagnostic tests performed to validate a statistical model employed in this research. The study initially employed the Breush Godfrey LM test to examine serial correlation, which assesses the potential correlation among the model's residuals. The statistical analysis yielded an F-statistic of 0.538563, with a corresponding P = 0.5982. Given that the P-value exceeds the standard significance threshold of 0.05, it is considered insufficient to reject the null hypothesis positing the absence of serial correlation within the residuals. The model fulfills the assumption without serial correlation. The Breush-Pagan-Godfrey test for heteroscedasticity was also used in the research to determine if the variance of the residuals is consistent across all values of the independent variables. For this test, the P = 0.4991, and the F-statistic is 1.008342. We cannot rule out the null hypothesis that the model has no heteroscedasticity since the P-value is larger than the customary significance threshold of 0.05. The premise of constant variance is thus satisfied by the model. Additionally, the research utilized the Ramsey Reset test to detect specification errors and assess whether the model is accurately specified. The results indicate that the F statistic value is insignificant, suggesting that the model has no specification error and is correctly specified. Finally, the study utilized the CUSUM and CUSUM square tests to assess the stability of the model over time. The test results suggest that the model exhibits stability over time (Figure 1). Thus, Table 5 presented in the research article indicates that the statistical model utilized in the study satisfies the assumptions of no serial correlation, constant variance, correct specification, and stability over time.

5. CONCLUSION

Renewable energy consumption has become an increasingly critical issue worldwide, with the need for a sustainable energy source to address climate change concerns. Indonesia, being a developing nation with a large population and expanding economy, is no exception to this trend. This research aims to examine the impact of various factors, including urbanization, trade openness, FDI, innovation, and corruption, on the use of renewable energy in Indonesia. To achieve this goal, the study analyzed data from 1990 to 2020 and conducted several statistical tests to ensure data accuracy.

To confirm the stationarity of the variables, the study used ADF, DF-GLS, and P-P unit root tests. Results showed that the variables were stationary and free of unit root issues. Using the ARDL bound test approach, the study identified long-run cointegration among the variables, as they displayed mixed orders of integration. The ARDL long-run estimation was then carried out to determine the effects of various factors on renewable energy consumption in Indonesia. The study found that economic growth, innovation, and FDI had significant positive effects on renewable energy consumption in the long run. However, urbanization had a significant negative correlation with renewable energy consumption, while trade openness had no long-term effect on renewable energy consumption.

In the short term, the study found that FDI, corruption, and innovation had a significant negative correlation with renewable energy consumption, while GDP had a significant positive correlation. However, urbanization and trade openness had negligible effects on Indonesia's renewable energy consumption. Several diagnostic tests, including the Breush pagan Godfrey test, the Breush Godfrey LM test, the Ramsey Reset test, and the CUSUM and CUSUMSQ test, were conducted to validate the model, and the results confirmed the model's suitability and stability.

Overall, this study provides crucial insights into the factors that influence renewable energy consumption in Indonesia. Policymakers in Indonesia should prioritize promoting renewable energy consumption while addressing the challenges posed by urbanization and corruption. This approach will lead to a more sustainable and energy-efficient future for Indonesia. The study also emphasizes the importance of economic growth, innovation, and FDI in driving renewable energy consumption. Further research could be carried out to investigate the specific mechanisms by which these factors influence renewable energy consumption in Indonesia.

This study highlights the importance of policy interventions in promoting the adoption of renewable energy sources in Indonesia. The research findings suggest that factors such as foreign investment and innovation have a positive impact on renewable energy consumption, while economic development and urbanization may lead to lower usage. Policymakers in Indonesia can use these results to prioritize attracting foreign investment and promoting innovation in the renewable energy sector.

To encourage foreign investment, tax incentives and subsidies could be provided to foreign investors. Additionally, bureaucratic procedures for renewable energy projects could be simplified, and technology transfer facilitated to promote innovation. Public awareness and education on the benefits of renewable energy sources must be raised through information campaigns and awareness-raising activities.

Policymakers should also implement regulations and policies that encourage the use of renewable energy and discourage the use of fossil fuels. Taxing or penalizing fossil fuels and incentivizing individuals and organizations that use renewable energy sources are some strategies that can be implemented.

Overall, this study suggests that a combination of policy interventions targeting investment, innovation, education, and regulation could help accelerate the adoption of renewable energy sources in Indonesia. By promoting sustainable development and mitigating the impacts of climate change, the country can set an example for other developing nations to follow. Future research can investigate the effectiveness of these policy interventions and assess their impact on renewable energy consumption in Indonesia.

While the study provides valuable insights into the relationship between corruption, innovation, and renewable energy consumption in Indonesia, its findings may not be applicable to other nations. This is due to the study's primary focus on Indonesia, and the accuracy and availability of data, which may be limited or biased, leading to unreliable conclusions. Additionally, the study's econometric methodology may not establish a causal relationship between corruption, innovation, and renewable energy adoption. Moreover, the study does not consider other factors such as government policy, economic expansion, law and order, and public knowledge, which could affect renewable energy consumption. Lastly, the study's brief time frame may not adequately account for the long-term impacts of corruption and innovation on renewable energy usage.

To address these limitations, future research could compare Indonesia's renewable energy consumption to that of other developing nations to determine the generalizability of the results. Longitudinal studies could be conducted to evaluate the long-term impacts of corruption and innovation on renewable energy usage. Qualitative research methods could explore stakeholder attitudes, beliefs, and behaviors towards renewable energy sources, and the variables influencing their choices. Future research could also examine how corruption and innovation affect renewable energy usage at the social, organizational, and individual levels. Finally, the model could be expanded to include additional factors such as government regulations, economic expansion, and public awareness that could influence the use of renewable energy.

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