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The Role of Renewable Energy Production, Energy Efficiency and Green Finance in Achieving Sustainable Economic Development: Evidence from Indonesia

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ABSTRACT

The current study aims at analyzing the effect of renewable energy production, energy efficiency and green finance on sustainable economic development in Indonesia. The study is the pioneer one in the context of Indonesia that assesses the impact of above-mentioned variables on measuring sustainable economic development by measuring it in terms of economic growth and carbon emission. Time series data spanning over 1990-2019 period is analyzed using Autoregressive Distributed Lag Model (ARDL) because of presence of the mixed order of integration in data series. The findings of the study suggest that green finance, energy efficiency and renewable energy promote economic growth and reduce carbon emissions. The study concludes that renewable energy production, green finance and energy efficiency play positive role in achieving sustainable economic development in Indonesia. On the basis of the study findings, relevant policies for the government and policy makers to enhance sustainable economic development in Indonesia are also provided in the study.

Keywords: Renewable Energy Production, Green Finance, Energy Efficiency, Sustainable Development, Indonesia
JEL Classifications: Q2, F65, O16, P33, P45, Q01, Q32, Q57

1. INTRODUCTION

An important and difficult aspect of making appropriate decisions is achieving sustainable economic development and combating climate change simultaneously (Bai et al., 2022; Chien, 2022a). Sustainable development is defined as, "development that satisfies the needs of the current generations without compromising the future generation's potential to satisfy their own needs". Sustainable economic development aims at raising living standards by providing a stable and long-lasting source of income and reducing resource depletion and environmental damage. It is a comprehensive strategy that links economic development with environmental and social development (Chien, 2022a; Haq et al., 2020). But as global warming has increased over the past few decades, it has become one of the major obstacles to achieve sustainable development. The rising emissions of greenhouse gases such as methane, nitrous oxide and carbon dioxide produced by excessive utilization of fossil fuel energy resources are seriously threatening the sustainability of economic development and causing severe environmental damages (Chien et al., 2022c; Khan et al., 2019). Energy, no doubt is an essential component for attaining sustainable economic development (Chien et al., 2022b; Sebri, 2015) as there are various connections between the environment, energy and sustainable development, but factors like growing energy demand driven by growth in global population, resulting in the rapid consumption of traditional energy sources such as coal, natural gas, oil and the release of hazardous gases into the environment, endanger the environmental health (Chien et al., 2021; Haroon et al., 2021; Nawab et al., 2021). Therefore, a continued reliance on these resources to meet growing energy demand would only hasten environmental degradation. It is predicted that global energy consumption would increase by 48% by 2040, making the need for low-carbon solutions evident as cited in Armeanu et al. (2017). In this situation, renewable energy sources, that can replace fossil fuels and fulfill the primary energy requirements of the countries, have become the center of attention for policy makers and climate conferences. Renewable energy resources not only shield environmental quality but also assist in other challenges that economies are confronted with including lesser continuous renewal of energy resources, reduced dependence on imported resources and no safety concerns (Kamarudin et al., 2021; Khattak et al., 2021).

In addition to renewable resources, energy efficiency and environmental impacts are also directly related because greater efficiency processes use fewer resources and produce less pollution. Energy efficiency is defined as the capability to produce the identical amount of output by using lesser amount of energy. Energy efficiency can offset the restrictions placed on sustainable development by environmental pollution (Ali et al., 2022; Yuan et al., 2022). The benefits of energy efficiency are numerous. For instance, energy efficiency initiatives can stop the biodiversity loss, enhance environmental quality by lowering air pollution, increase energy security, lessens reliance on fossil fuels, reduces electricity shortages and boost competitiveness by cutting operational costs. Additionally, enhanced energy efficiency can aid underdeveloped nations in achieving their objectives for sustainable development (Hussain et al., 2021; Temiz Dinç & Akdoğan, 2019). In nutshell renewable energy production and energy efficiency programs are crucial in closing emission gaps and policies directed towards increasing energy efficiency and renewable energy production must be prioritized in order to lower emissions. Additionally, increasing energy efficiency and changing the energy mix, especially in support of renewable sources, would not only assist to lessen the negative effects of economic activity on the environment and the accompanying health expenses, but would also allow countries to lower import costs and buffer the price volatility in energy markets that encourages long-term sustainable development (Shah et al., 2021; Wenlong et al., 2022).

In addition to energy efficiency and renewable energy, a new financial innovation known as "green finance" has evolved that prioritizes ecological and sustainable development (Hanif et al., 2022; Lan et al., 2022). The organized financial activities designed to secure better environmental consequences is known as "green financing." With rising finance flows from the private and public sectors towards the goal of sustainable development targets, the green financing sector is expanding quickly globally. Additionally, it is asserted that green financing is anticipated to be crucial in achieving the Paris Agreement's climate change targets (Liu et al., 2022a; Muganyi et al., 2021). The typical initiatives included by the term "green finance" include pollution reduction, biodiversity preservation, energy efficiency and renewable energy, and sustainable resource extraction and development (Liu et al., 2022b; Mohsin et al., 2021). Despite the fact that it is clear how important green financing is in reducing environmental problems like CO_2 emission, empirical studies on the nexus between green financing and sustainable development has not yet been done in the context of Indonesia.

Motivated by these facts, the current study aims at estimating the role of renewable energy production, green finance and energy efficiency on sustainable economic development of Indonesia over 1990-2019 period. Indonesia, a developing country with plenty of natural resources, has seen tremendous growth over last 3 decades and is the sixth highest producer of greenhouse gas emissions (Lin et al., 2022; Sasana and Putri, 2018) (Figure 1). Despite tremendous growth, Indonesia is facing difficulty in finding the right balance between rapid economic expansion and a green transformation. The Indonesian government has made its financial system "green" in an effort to pursue sustainable growth. Many significant green financing instruments have been made available by the Indonesian government at state, local, bank and non-bank level such as Green Skuk bonds to promote healthy environment and sustainable development. Indonesia offers a capital market called KEHATI SRI Index that adheres to Sustainable and Responsible Investment (SRI) standards and regulations (Moslehpour et al., 2022b; Moslehpour et al., 2022c; Setiawan et al., 2021).

Intensive fossil fuel based energy consumption has major contribution in environmental degradation (22.6%) of Indonesia (Bashir et al., 2021; Moslehpour et al., 2022a). Indonesia signed a contract as part of its Nationally Distributed Contribution to the United Nations Framework Convention on Climate Change, pledging to cut its gas emissions by 26% by 2030. Of course, international financial assistance, technology transfer and capacity building are necessary to reduce greenhouse gases. Resources like wind energy, geothermal energy and solar energy all should be used in this regard because they are considered substitute energy resources. These sources of renewable energy are therefore currently receiving attention (Sadiq et al., 2022a; Sadiq et al., 2022b). But, despite the fact that Indonesia has a large capacity to produce power from a variety of sources, the country heavily depends on non-renewable resources to produce power because it is one of the top exporters of coal and has enormous oil reserves (Figure 2) (Saudi et al., 2019). Indonesia has huge renewable

Figure 1: Economic growth, energy consumption and carbon emissions over 2000-2019 period in Indonesia (WDI, 2022)

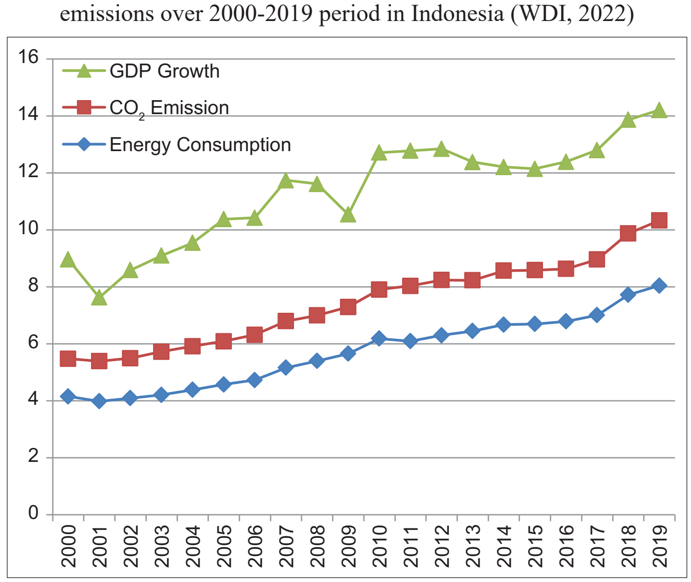
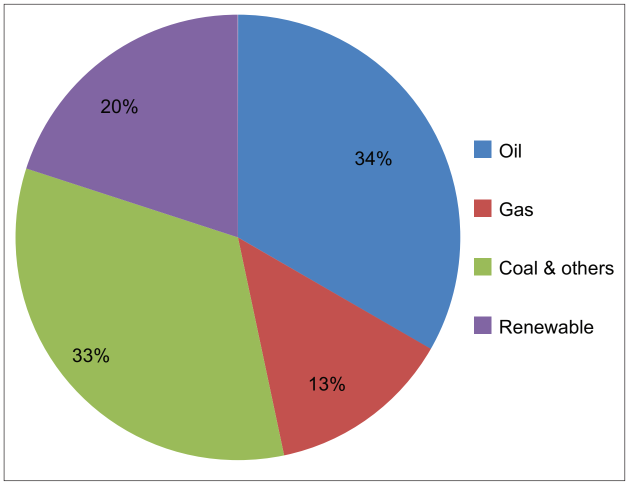


Figure 2: Energy production in Indonesia (2019)



Source: (IRENA, 2022)

energy potential, including geothermal (28 GW), which is the 40% of the global reserves, wind (3-6 m/s), biomass (33 GW), solar (4.8 kWh per day), and hydropower (76 GW). The more utilization of renewable resources for energy production can assist the country to achieve sustainable economic development (Sadiq et al., 2022c; Sadiq et al., 2022d).

There are two prominent contributions of the research in the literature, first the current study is the primary one that estimates the role of green finance, energy efficiency and renewable energy production on sustainable development in Indonesia which has never been studied by earlier researches. Second, unlike earlier studies, the present study measures sustainable economic development in terms of CO_2 emission and economic growth. The Indonesian government and policymakers can use this study to get valuable insight into how to balance the production of renewable energy, energy efficiency and green finance with sustaining sustainable economic growth. The literature review, estimation technique data and model, empirical findings, and conclusion and implications comprise the remaining sections.

2. REVIEW OF LITERATURE

2.1. Renewable Energy and Sustainable Development

Various parts of the industry have changed by the fourth industrial revolution, such as cellular phones, super-computing, robot intelligence, automatic cars and a lot more activities around us all at an exponential rate. It is clear that within the next 50 years, all areas of knowledge will undergo further transformation. In order to boost energy security and reliability while lowering emissions, the energy industry must modernize and diversify its energy sources. As a result, it has partially adapted to these developments. Another crucial step that economies must take to combat climate change is the production of renewable energy. In particular, improving energy efficiency globally has received more focus in relation to mitigation measures to manage climate change, which can effectively lower the energy demand. Numerous studies have raised concerns about how GHGs, and specifically CO_2, negatively affect human activities and hence undermine the natural ecosystem worldwide. The sustainability of mankind and their existence has been seriously endangered by energy and environmental issues (Zhao et al., 2021; Zhao et al., 2022).

The nexus between the renewable energy and sustainable development has widely been examined in various recent researches. For instance; Tan et al. (2021) studied the impact of renewable energy production, energy consumption and economic growth in Turkey over 1980-2016 period. By applying VECM approach the authors concluded that renewable energy generation and energy consumption granger caused economic growth. Similar observations were made by ÖZBEK and Apaydin (2020) for Turkey. Yikun et al. (2021) studied the role of renewable energy resources on sustainable economic development of SAARC countries over 1995-2018 period. Fixed Effects Model and Panel VECM were used for empirical estimation and authors concluded that renewable energy resources positively and significantly contributed to development. Armeanu et al. (2017) considered the data for EU countries and explored how renewable energy affected sustainable economic growth over 2003-2014 period. The findings of FMOLS and DOLS estimation proved that renewable energy affected economic growth positively. Saudi et al. (2019) scrutinized the data of Indonesia over 1980-2017 period in order to study the impact of non-renewable and renewable electricity production on economic growth through ARDL bound testing approach and concluded that these two types of electricity production had significant impact on economic growth of Indonesia.

Iqbal et al. (2022) analyzed the role of renewable energy production, economic growth and natural resources on CO_2 emission in Pakistan covering the data 1980-2019 period. The findings of NARDL estimation revealed that positive changes in renewable energy production affected CO_2 emission positively and negative changes affected CO_2 emission negatively. (Suki et al., 2022) assessed the effect of technological innovations, non-renewable and green energy consumption in green growth measured by production-based carbon emissions and CO_2 emission over 1992-2018 period using CS-ARDL and CCEMG and AMG analyses. The authors concluded the positive contribution of green energy and technological innovations on green growth whereas non-renewable energy was evident to be a hurdle in the way of green growth in ASEAN countries. (Hanif et al., 2022) estimated the role of non-renewable energy, renewable energy and globalization on CO_2 emission of ASEAN countries covering 1995-2020 period. The study also employed CS-ARDL analysis followed by AMG and CCEMG estimation and according to study findings, globalization and non-renewable energy contribute to emission while renewable energy mitigated the emission of carbon in ASEAN countries.

2.2. Energy Efficiency and Sustainable Development

Energy efficiency, according to Özcan and Özkan (2018) is the capacity to maintain a certain productivity level while consuming a relatively low amount of energy. A growing body of literature examines how energy efficiency influences sustainable development. For instance, Hamid et al. (2020) analyzed the heterogeneous effect of renewable energy consumption and energy efficiency on carbon emissions in 66 developing economies over 1990-2014 period. According to the primary findings of the panel quantile regression both energy efficiency and renewable energy had significant negative impact on emission across various quantiles. In another study by Ainou et al. (2022) for BRICS over 1990-2014 period, the authors concluded that renewable energy and energy efficiency contributed to CO_2 emission reduction. Similarly, Hossain et al. (2022) assessed the role of energy efficiency, economic growth and manufacturing value added on emission in India. The study findings based on DARDL estimation revealed that economic growth and manufacturing value added enhanced CO_2 emission but energy efficiency reduced CO_2 emission. Özcan and Özkan (2018) studied the how energy efficiency affects economic growth of G-20 economies over 1992-2012 period using panel granger causality test. Unidirectional causality was observed to exist between energy efficiency and economic performance. Similarly, Rajbhandari and Zhang (2018) considered the data for 58 middle and high income countries over 1978-2012 period to analyze the effect of energy efficiency on economic growth. The findings evidenced the presence of bidirectional causality between economic growth and energy efficiency in middle income countries. Cantore et al. (2016) studied the role of energy efficiency in economic performance both at micro and macro level in developing countries and concluded that energy efficiency was associated with higher economic performance at all levels.

2.3. Green Finance and Sustainable Development

Numerous researches have looked at the relationship between sustainable development and green finance. Wang et al. (2022) analyzed the causal relationship between green finance and growth at global level using bootstrap rolling window granger causality test and concluded that there was positive impact of green finance on sustainable economic development. Li et al. (2022) studied the impact of economic growth, green finance, natural resources, renewable energy and urbanization on carbon emissions taking MINT countries into consideration over 1990-2019 period. The findings of CS-ARDL estimation showed that there was significant role of renewable energy and green finance in CO_2 emission reduction while other variables affected CO_2 emission positively. Applying same empirical technique for 12 Asian countries Saleem et al. (2022) explored the nexus between green finance and ecological degradation and concluded that green finance was significant contributor in improving environmental quality. For E-7 countries, (Cao, 2022) also evidenced that green finance reduced CO_2 emission and promoted sustainable green growth. Nawaz et al. (2021) evidenced by applying DID approach for BRICS and N-11 countries that green finance and renewable energy promoted sustainable green growth by impacting CO_2 emission negatively. Wu et al. (2021) tried to study the green finance for a better environment with the growth of E7 and G7 countries over 2010-2018 period. The findings obtained through FMOLS and VECM estimations indicated that GGDP of these countries declined due to dirty environment and green financing was helpful in cleaning the environment.

Hence in previous literature, different studies explored the role of renewable energy production, green finance and energy efficiency and sustainable economic development in various countries and panels of countries. However, insufficient attention was given by the researchers to Indonesia for the assessment of this relationship. To our best knowledge, except Saudi et al. (2019), none of the previous studies tried to assess sustainable economic development in Indonesia, but their study analyzed only the impact of electricity production form both types of resources on economic growth. Our study goes a step further from their study by incorporating the green finance and energy efficiency variables also in addition to renewable energy production to assess the contribution of these variables on sustainable economic development in Indonesia. In addition, unlike previous studies, which considered either CO_2 emission or economic growth as proxy for sustainable development, we use both measurements to have comprehensive assessment of the above-mentioned variables on sustainable development in Indonesia. Thus, the present research contributes significantly in the literature as it fills up these significant literature gaps.

3. METHODS AND MATERIALS

The principal goal of the research is to estimate the effect of and energy efficiency, green finance, and renewable energy production on sustainable economic development in Indonesia. Following Ahmed and Shimada (2019), we consider economic growth and CO_2 emission as measures of sustainable economic development to achieve the said objective. The yearly data spanning over 1990-2019 period is used to assess the association between renewable energy production, green finance, energy efficiency and sustainable economic development. The energy intensity is widely used proxy for the energy efficiency variable. Economic growth is measured by GDP constant (US\$2015), renewable energy is measured by primary energy production by renewable (quadbtu) and carbon dioxide emission by CO_2 emission (kiloton). Table 1 provides comprehensive description and data sources of all of the study variables.

The empirical models of the research are specified as follows:

$$GDP_t = f(GF_t, REP_t, EE_t,) \quad (1)$$

$$CO2_t = f(GF_t, REP_t, EE_t,) \quad (2)$$

Where
CO_2 = carbon dioxide emission
GF = Green Finance
REP = Renewable energy production
EE = Energy efficiency

3.1. Methodology

ARDL approach is proposed by (Charemza and Deadman, 1992) which was latter improved by Pesaran and Shin (1995) and Pesaran et al. (2001). Johansen Juselius cointegration technique and the Engle and Granger cointegration approach are just two examples of conventional cointegration procedures that the ARDL technique has an advantage over. It requires small sample and introduces simultaneity bias into the relationships. Conventional cointegration methods have serious disadvantage in that all variables are required to be non-stationary or unit roots at level. Utilizing cointegration methods, such as the ARDL makes this issue to handle easily regardless of whether there

Table 1: Variable description

Variables	Measurement	Data source
Economic growth	GDP (US$ constant 2015)	WDI
CO_2 emission	CO_2 emissions (Kiloton)	WDI
Renewable energy production	Energy production from renewable and others (Quadbtu)	EIA
Green finance	Investment in products of environmental protection by residents	OECD
Energy efficiency	GDP/energy consumption (Expressed as US dollars equivalent per kilograms of oil at constant 2017 prices)	WDI

is level, differenced or mixed order of integration. The advantage of the current method is that it models are allowed to choose optimal lag number. These estimable qualities encourage the application of the ARDL model to obtain precise estimates.

The study models are specified in the econometric form as:

$$GDP_t = \alpha_0 + \alpha_1 GF_{2t} + \alpha_2 EE_t + \alpha_3 REP_t + \varepsilon_t \quad (3)$$

$$CO_{2t} = \alpha_0 + \alpha_1 GF_{2t} + \alpha_2 EE_t + \alpha_3 REP_t + \varepsilon_t \quad (4)$$

There are two main steps in the ARDL model for assessing the long run relationship. The first step involves assessment of long-term connection among variables. The ARDL models are described by Equation (5) and Equation (6) as follows:

$$\Delta GDP_t = \alpha_0 + \sum_{i=1}^{r} \alpha_{1k} \Delta GDP_{t-j} + \sum_{i=0}^{r} \alpha_{2k} \Delta GF_{t-j} + \sum_{i=0}^{r} \alpha_{3k} \Delta EE_{t-j} + \sum_{i=0}^{r} \alpha_{4k} \Delta REP_{t-j} + \beta_1 GDP_{t-1} + \beta_2 GF_{t-1} + \beta_3 EE_{t-1} + \beta_4 REP_{t-1} \quad (5)$$

$$\Delta CO2_t = \alpha_0 + \sum_{i=1}^{r} \alpha_{1k} \Delta CO2_{t-j} + \sum_{i=0}^{r} \alpha_{2k} \Delta GF_{t-j} + \sum_{i=0}^{r} \alpha_{3k} \Delta EE_{t-j} + \sum_{i=0}^{r} \alpha_{4k} \Delta REP_{t-j} + CO2_{t-1} + \beta_2 GF_{t-1} + \beta_3 EE_{t-1} + \beta_4 REP_{t-1} + \varepsilon_t \quad (6)$$

Where α_0 shows intercept, r shows lag order, Δ shows difference operator, ε_t is the disturbance error. Additionally, the F-test was utilized to analyze the long run relationship between GDP, CO_2, EE, GF, and REP. The null hypothesis (H_0) states that there is no cointegration between the variables.

$$H_0: \rho_1 = \rho_2 = \rho_3 = \rho_4$$

While the alternative hypothesis (H_1) asserts the opposite

$$H_1: \rho_1 \neq \rho_2 \neq \rho_3 \neq \rho_4$$

The upper and lower bound values are compared to the estimated F test. If the calculated F-test is greater than the upper bound, the H_0 of is rejected. If the calculated F-test is less than the upper bound, the H_0 between variables cannot be ruled out. The H_0 is inconclusive if the F-test lies in between the lower and upper ranges. Either cumulative sum recursive residuals (CUSUM), cumulative of square recursive residuals (CUSUMSQ) or Johansen cointegration can be used to confirm cointegration consistency.

The evaluation of the short-term link between GDP, CO_2, GF, EE, and REP is the second step of ARDL estimation. The ECM in the ARDL formulation can be written as

$$\Delta GDP_t \alpha_0 + \sum_{i=1}^{r} \alpha_{1k} \Delta GDP_{t-j} + \sum_{i=0}^{r} \alpha_{2k} \Delta GF_{t-j} + \sum_{i=0}^{r} \alpha_{3k} \Delta EE_{t-j} + \sum_{i=0}^{r} \alpha_{4k} \Delta REP_{t-j} + \alpha ECM_{t-1} + \varepsilon_t \quad (7)$$

$$\Delta CO2_t \alpha_0 + \sum_{i=1}^{r} \alpha_{1k} \Delta CO2_{t-j} + \sum_{i=0}^{r} \alpha_{2k} \Delta GF_{t-j} + \sum_{i=0}^{r} \alpha_{3k} \Delta EE_{t-j} + \sum_{i=0}^{r} \alpha_{4k} \Delta REP_{t-j} + \alpha ECM_{t-1} + \varepsilon_t \quad (8)$$

4. EMPIRICAL ESTIMATION AND DISCUSSION

To quantify the effects of green finance, energy efficiency and renewable energy production on sustainable economic development in Indonesia, time series data spanning over 1990-2019 period is used. Table 2 illustrates the summary statistics. Jarque Bera statistics reveal that every variable is normally distributed and has constant variance and zero covariance.

Following descriptive statistics, the stationarity of series is assessed by applying ADF test and PP unit root test. The outcomes of the both tests are displayed in Table 3. Since mixed order of integration is found in series, ARDL estimation is the most appropriate one to carry out the empirical analysis.

4.1. Short Run and Long run Estimations

4.1.1. Optimal model selection

Before moving to estimate short run and long run coefficient, it is required to choose the optimal ARDL model. The optimal ARDL model that reduces residual sum of squares (RSS) must be chosen because the ARDL model combines lagged values of both exogenous and endogenous variables. To choose the best model, the AIC is adopted. Tables 4 and 5 outline the model selection procedure in brief. For GDP Model, ARDL (1,3,0,3) model is selected as the best model on the basis of AIC. This model, which has been selected because of minimum RSS, satisfies all of the model fitness conditions.

On the basis of AIC criterion, ARDL model (3,3,2,0) is proved to be the best model with minimum RSS. Table 5 illustrates the optimal ARDL model for Equation 2.

4.2. ARDL Bound Test

Checking for cointegration of the study variables is the immediate step after choosing an ideal model using the AIC lag length selection criterion (Pesaran et al., 2001). At all acceptable levels of significance, the estimated F-statistic exceeds the I1 bound confirming the cointegration among the

Table 2: Summary statistics

Variables	GDP	CO_2	GF	REP	EE
Mean	5.643	3512.7	10.110	0.2258	2.8809
Median	4.845	3416.5	9.9100	0.1680	2.9090
Max	1.052	6198.0	20.510	0.7065	3.4700
Min	2.701	14853	2.3200	0.0810	2.3972
SD	2.309	12780	4.7083	0.1540	0.2623
Skewness	0.667	0.2206	0.3983	1.6738	0.0295
Kurtosis	2.209	2.1506	2.6231	5.5062	2.6013
JB test	3.009	1.1450	0.9062	21.860	0.2029
Prob	0.222	0.5641	0.6356	0.00189	0.9035
Obs	30	30	28	30	30

Table 3: ADF and PP test

Variables	ADF test		PP test	
	I	I & T	I	I & T
GDP	3.932	−0.668	3.4813	0.4451
CO_2	0.902	−2.948	1.7103	−1.727
GF	−6.572***	−6.435***	−6.640***	−6.497***
REP	3.120	1.8333	4.315	0.1762
EE	−3.304***	−2.323***	−3.214***	−1.936***
	1ST difference		1ST difference	
	I	I & T	I	I & T
GDP	−5.381***	−5.318***	−2.636***	−3.738***
CO_2	−1.259***	−1.488***	−4.584***	−4.782***
GF	-----------	-----------	-----------	------------
REP	−13.952***	−14.250***	−5.939***	−6.972***
EE	----------	-----------	----------	------------

Where I: Intercept, I&T: Intercept and trend, ADF denotes augumented dickey fuller, PP denotes philips-perron and *** denotes significance at 1% level, REF: Renewable energy production, EE: Energy efficiency

Table 4: ARDL optimal model for equation 1

DV=Economic growth (GDP) selected model: ARDL (1,3,0,3)				
Variables	Coeff	Std. error	t-stat	P-value
GDP (−1)	1.084	0.053	20.128	0.000
GF	1.200	7.723	3.657	0.038
GF (−1)	0.400	8.181	3.186	0.046
GF (−2)	1.850	8.730	2.119	0.052
GF (−3)	1.290	7.308	1.769	0.098
REP	1.930	5.971	3.237	0.074
EE	−3.021	3.251	−0.933	0.368
EE (−1)	5.011	4.201	1.191	0.253
EE (−2)	−3.911	4.141	−0.943	0.361
EE (−3)	6.341	3.141	2.018	0.063
CONS	−1.731	1.051	−1.639	0.123
R^2	0.805	Hannan-Quinn		9.929
Adj R^2	0.809	Criterion DW (Durbin Watson stat)		2.09
AIC criterion	9.781	F-stat		25.921
Schwarz criterion	10.317	p (F-stat)		0.000

study variables. It is confirmed that variables are cointegrated. Table 6 below represents the results of ARDL bound test for both equations.

4.3. Long Run Estimation

The results of the long-run regression demonstrate how the dependent variable (GDP and CO_2) respond to changes in the explanatory variables. Then, using the dynamic ARDL model, it is possible to forecast long-term relationships among variables. Long run coefficients for Equation 1 and Equation 2 are provided in Table 7 below.

Table 5: ARDL optimal model for equation 2

DV=CO_2 emission (CO_2) selected model: ARDL (3,3,2,0)				
Variables	Coeff	Std. error	t-stat	P-value
CO_2 (−1)	0.803	0.1981	4.0568	0.012
CO_2 (−2)	−0.360	0.2773	−1.299	0.218
CO_2 (−3)	0.525	0.202	2.590	0.021
REP	10.59	6.422	1.649	0.121
REP (−1)	1.835	8.591	2.050	0.059
REP (−2)	−1.505	1.333	−1.129	0.277
REP (−3)	−22.77	13.58	−1.676	0.115
GF	−4.336	7.071	−2.613	0.049
GF (−1)	−2.151	7.395	−0.290	0.775
GF (−2)	−16.90	67.23	−2.513	0.024
EE	−3.232	19.11	−2.702	0.018
CONS	15.744	63.88	2.469	0.0270
R^2	0.790	Hannan-Quinn		22.45
Adj R^2	0.783	Criterion DW (Durbin Watson stat)		2.06
AIC criterion	22.28	F-stat		13.39
Schwarz criterion	22.86	p (F-stat)		0.000

Table 6: Bound test

Equation 1		
Statistics	Value	K
F-stat	18.911	3
Significance	I (0)	I (1)
10%	2.37	3.2
5%	2.79	3.67
2.5%	3.15	4.08
1%	3.65	4.66
Equation 2		
F-stat	4.38	3
Significance	I (0)	I (1)
10%	2.37	3.2
5%	2.79	3.67
2.5%	3.15	4.08
1%	3.65	4.66

Table 7: Long run ARDL results

Variable	Equation 1		Equation 2	
	Coeff	P-value	Coeff	P-value
GF	2.291	0.040	−6.146	0.076
REP	2.281	0.075	−2.858	0.059
EE	−5.211	0.019	1.047	0.019
Cons	2.031	0.190	5.079	0.800

The findings of long run estimation for Equation 1 prove significant impact of the variables on economic growth in Indonesia. Green finance and renewable energy production have positive effect on economic growth whereas energy intensity (measure of energy efficiency) affects it negatively. In coefficient terms, there is an increase of 2.29 and 2.28 units in economic growth if green finance and renewable energy production increases by one unit respectively. On the other hand, there is a reduction of 5.211 units in economic growth for each unit rise in energy intensity in the long run. Likewise, long run estimations for Equation 2 reveal significant impact of renewable energy production, energy efficiency and green finance on carbon emission. For a unit increase in green finance, CO_2 emission reduces by 6.14 units. CO_2 emission also reduces by 2.58 units if renewable energy production increases by one unit. Thus, both green finance and renewable energy production reduce CO_2 emission, but in contrast, energy intensity has positive effect on CO_2 emission. There will be an increase of 1.04 units in CO_2 emission for one unit in energy intensity showing that efficient use of energy will reduce CO_2 emission.

4.4. Short-Run ARDL

Short run ARDL results of Equation 1 are given in Table 8. ECT values show the adjustment speed towards long run equilibrium. ECT is statistically significant with negative and <1 coefficient, and therefore satisfies all three requirements. The coefficient has a reasonably high value of −0.84, meaning that 84% of adjustment toward equilibrium. The model will ultimately attain long run equilibrium according to the negative sign. All of the variables are statistically significant at the 1% level.

Similar to long run, short run results also show the significance impact of variables. We found negative impact of energy intensity on economic growth which indicates that efficient use of energy increases economic growth. The finding confirms the findings of (Bayar and Gavriletea, 2019) as they conclude positive impact of energy efficiency on economic growth in emerging countries. The findings of (Rajbhandari and Zhang, 2018) for 56 economies and (Akram et al., 2021) for BRICS countries also support the current study's findings. It asserts that there are significant potential benefits from increased energy efficiency. The CO_2 emission reduction, increased well-being, high industrial efficiency, energy security, and a higher national income are just a few of the advantages that Indonesia will experience by advancing in energy efficiency. Renewable energy production is also impacting economic growth positively in the short run in line with the results of (Singh et al., 2019) who found positive impact of renewable energy production on economic growth in developed and developing countries. The finding also corrobates with (Singh et al., 2019) for Turkey and (Tiwari et al., 2015) for Sub Saharan African countries. The finding proves the fact that renewable energy is a key factor of CO_2 emission mitigation as well as it has several economic advantages. Renewable energy production has the capacity to reduce imported fuel reliance, as well as to support the growth of small-scale companies and the creation of jobs in rural areas of developing nations (Singh et al., 2019). Likewise, green finance also promotes economic growth in Indonesia- a finding consistent with (Yin and Xu, 2022) for China, (Zhang, 2022) for OECD countries and (Soundarrajan and Vivek, 2016) for India who argue that green finance can improve the macroeconomic progress by improving the supply-side quality and economic structure. It can support green consumption, stimulate green business practices, and increase the economy's micro efficiency. Economic policies work in tandem to advance the growth of a green economy. According to (Sheng et al., 2018) "green finance" refers to the best use of already-available finances and resources. The goal of green finance development is to promote sustainable economic and social life, starting with environmental protection and resource conservation.

Table 8: Short run ARDL results

Equation 1		
Variables	**Coefficient**	**Prob value**
Error correction term (ECM)	−0.849***	0.000
D (EE)	0.567	0.045
D (EE [−1])	0.125	0.000
D (EE [−2])	−1.989	0.017
D (GF)	1.209	0.000
D (GF−1)	3.140	0.000
D (GF−2)	1.290	0.000
REP	1.930	0.001
Cons	−1.731	0.000

Table 9: Short run ARDL results

Equation 2		
Variables	**Coefficient**	**Prob value**
Error correction term (ECM)	−0.031***	0.0001
D (EE)	0.567	0.011
D (GF)	−0.125	0.088
D (GF−1)	−1.989	0.041
D (GF−2)	−1.690	0.024
D (REP)	−4.336	0.061
D (REP−1)	−3.783	0.000
D (REP−2)	−2.277	0.027
D (REP−3)	−0.525	0.001
Cons	−15.77	0.020

Now we proceed towards short run ARDL estimations for Equation 2. These results are given in Table 9 below. First of all, ECT is fulfilling all the three-standard criterion (negative, significant and <1) and showing 31% adjustment towards long run equilibrium.

The results of short run analysis are consistent with long run results in terms of coefficient signs. Like long run estimation, renewable energy and green finance are found to have negative effect, whereas energy intensity affects CO_2 emission positively in Indonesia. For renewable energy production, our findings are supported by (Iqbal et al., 2022) who found the similar results for Pakistan. The findings of (Sinha and Shahbaz, 2018) for India and (Jun et al., 2022) for world's top emitting countries are also in line with our findings. It suggests that renewable energy generation is a suitable way for achieving sustainable economic development as it helps in CO_2 emission mitigation. For green finance, our findings are supported by (Meo and Abd Karim, 2022) for top green finance supporting countries, (Muganyi et al., 2021) for China and (Brandi et al., 2020) for developing countries provide support for our finding by observing that green finance is helpful in safeguarding the environment and maintaining ecological equilibrium that result in long run development. (Zhang and Zheng, 2022) for G-7 countries, (Mirza et al., 2022) for developing countries and (Qamruzzaman, 2022) for low income countries support our finding of the effect of energy efficiency on carbon emission. The negative coefficient suggests that carbon emissions can be managed by ensuring efficient use of energy.

Figure 3: CUSUM plot for equation 1 (1990-2019)

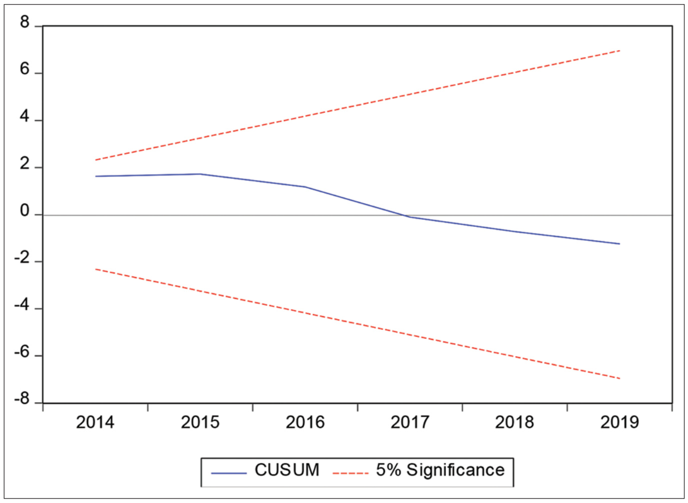


Figure 4: CUSUMSQ plot for equation 1 (1990-2019)

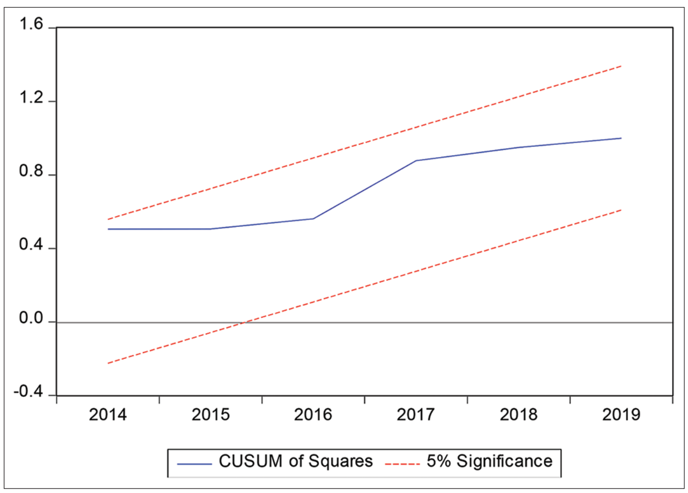
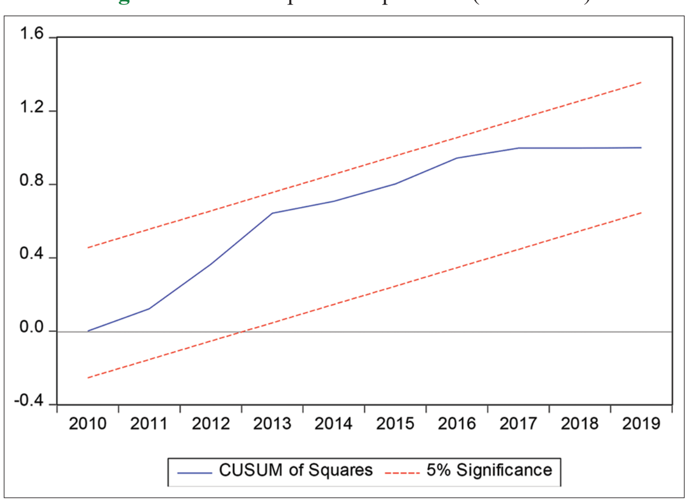
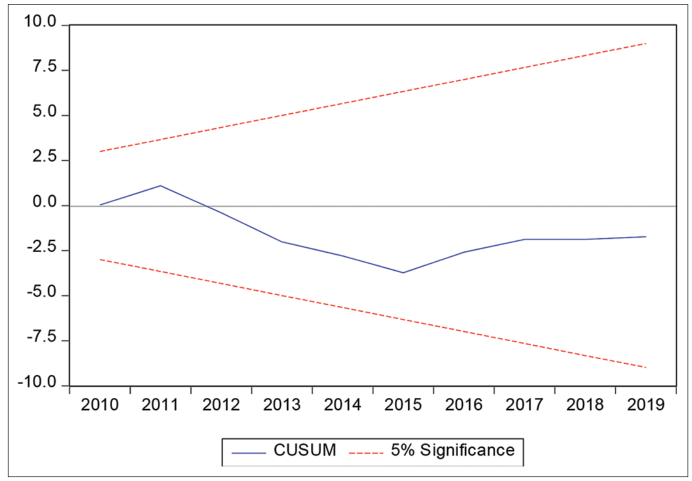


Figure 5: CUSUM plot for equation 2 (1990-2019)



Last but not the least, the study employed the CUSUM and CUSUMSQ tests devised by Brown et al. (1975) to assess stability of the coefficients due to the possibility of structural changes in series caused by single or multiple structure breaks. GDP and CO_2 lines lie under the boundaries, illustrating that both of the models are stable and fit (Figures 3-6).

Figure 6: CUSUMSQ plot for equation 2 (1990-2019)



5. CONCLUSION AND POLICY IMPLICATIONS

This research contributes to the literature by examining the impact of renewable energy production, energy efficiency and green finance on sustainable economic development of Indonesia. We studied this relationship by measuring sustainable development in terms of economic growth and CO_2 emission which is a unique contribution specifically in the context of Indonesia. The time period spans 1990-2019, and because of the mixed order of integration among series, ARDL bound testing approach is used for the purpose of empirical estimation. The primary findings reveal the positive contribution of green finance, energy efficiency and renewable energy production in sustainable economic development in Indonesia by enhancing economic growth and reducing carbon emission. Moreover, the stability of ARDL models is proved by CUSUM and CUSUMSQ diagnostic tests for parameter stability.

These findings have significant policy implications for Indonesia. Our findings demonstrate a beneficial relationship between energy efficiency and sustainable development suggesting that increased energy efficiency might spur economic growth. Therefore, policies that encourage energy efficiency should be viewed as a development strategy since they can result in long-term growth gains in addition to environmental benefits. To reap the long-term benefits of increased energy efficiency, Indonesian government should implement efficiency policies and programs. To increase the benefits of efficient utilization of energy, existing policies must also be enhanced and their documentation should be broadened. Additionally, the capacity for energy gains in efficiency must be considered in order to fully evaluate the effect of energy efficiency initiatives. Furthermore, Indonesia's growth strategies should be fully aligned with climate mitigation policies, which can actually boost growth. Finally, in order to fulfill the energy requirements of rapid and sustainable economic growth, it is also required to invest more financial resources and capital in the generation of renewable energy by small, medium, and larger corporations. In addition, given the positive contribution of green finance in environmental sustainability and sustainable development, first, local governments should focus on detailed planning for the overall growth of green finance as well as creating and enhancing legal protections for green finance. Through collaboration between the government and private capital, businesses that prioritize environmental preservation must receive favorable credit or taxation plans and capital should be directed into green financial investments. Second, along with government oversight and direction, appropriate departments must increase enterprise social responsibility in the area of green finance and strengthen the management of financial products.

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