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Energy and Economic Growth Nexus: A Long-run Relationship in Indonesia

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Abstract

Energy plays an important role in economic growth in which it affects total factor productivity (TFP). Energy conservation efforts to address global climate change may adversely affect economic growth, particularly in the long run. This study analyses the short- and long-run relationship between energy consumption (both non-renewable (NREC) and renewable (REC)) and economic growth in Indonesia within the period of 1985 to 2019. Using the vector-error correction model (VECM), the paper discovered a short-run unidirectional causality from NREC and REC to economic growth. Economic growth in Indonesia is dependent on energy consumption. The finding proves the growth hypothesis in the energy and economic growth nexus (EGN). In the long run, only NREC has a unidirectional causality to economic growth, while REC is independent. REC supports the neutrality hypothesis rather than the growth hypothesis. The neutrality of REC in promoting economic growth in the long run indicates that Indonesia remains highly dependent on NREC to generate economic growth. Consequently, lowering NREC will adversely affect economic growth both in the short and long run. Nevertheless, Indonesia has signed a commitment to reduce carbon emissions vis a vis NREC in the context of climate change. The findings suggest that Indonesia should conduct energy transition toward REC, while conserving NREC in addition to accumulating physical and human capital to sustain high economic growth in the long run.

Keywords: economic growth, renewable energy, non-renewable energy, Granger causality, Indonesia

JEL classifications: C13; O044; Q43

1. Introduction

Energy plays an important role in the growth of the economy because it is a factor of production in addition to physical and human capital (Dat et al. 2020). In developing countries, energy use correlates with GDP due to the use of energy particularly in industrial manufacturing in an urban area. Total energy consumption in Indonesia increases over time; electricity consumption per capita was 386 kWh in 2000 and increased to 808 kWh in 2014 and 1,084 kWh in 2019 (World Bank 2023). Nevertheless, the electricity consumption per capita in Indonesia is far less than in ASEAN-5 and even Vietnam (see Table 1). Meanwhile, the primary energy intensity in Indonesia is 5.4 MJ per $1,000 GDP (constant 2017 purchasing power parity (PPP)) and decreases to 3.2 MJ (International Energy Agency [IEA] 2023). The data demonstrate improvement in energy efficiency, implying that less energy is used to produce GDP over time.

Although energy has a positive correlation with GDP, it is also related to carbon dioxide emissions. Carbon emissions from energy have reached 558.89 million tons in 2017, which is 63% higher than in 2001 (Figure 1). The increase in carbon emissions raises the concern about the negative impact on global climate and ecosystem. In 2050, it is predicted that global greenhouse gas emissions will increase by 50% due to a 70% growth in energy-related carbon emissions. It will cause the global average temperature to increase to between 3°C and 6°C. To mitigate this global problem, the Paris Agreement has set a goal of limiting it to 2°C,

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Table 1. Energy Use

Country	Energy intensity (MJ per $1000 GDP)	Electric power consumption (kWh per capita)
	2019	2014
Indonesia	3.2	808
Malaysia	4.3	4,539
Singapore	2.6	8,845
Thailand	4.5	2,484
Philippines	2.7	691
Vietnam	4.92	1,431
Brunei Darussalam	6.4	10,121
Myanmar	3.6	220
Cambodia	4.7	273
Lao Republic	4.4	N/A
World	4.7	3,105

Source: World Bank (2023) and IEA (2023)

and Indonesia is also committed to tackle climate change by ratifying the Paris Agreement through Law No. 16/2016 (UN Climate Change 2021).

One of the factors causing high carbon emissions from energy is because energy consumption in Indonesia is dominated and highly dependent on non-renewable energy. Within the last 20 years, the renewable energy share in the proportion of primary energy supply has not shown much improvement, only increasing by 3% of the proportion of the energy supply mix. In 2021, total renewable energy in Indonesia only reaches 8% of the total energy supply (Figure 2).

Muchran et al. (2020) suggest that higher renewable energy consumption (REC) in Indonesia means less carbon emissions. Meanwhile, higher non-renewable energy consumption (NREC) contributes to higher carbon emissions. Renewable energy is the major solution to mitigate high carbon emissions in the energy sector. Renewable energy mitigates emissions by around 53% with a total of 34.2 million tons of carbon dioxide in 2020 (IESR 2021), as presented in Figure 3.

Indonesia has abundant sources of renewable energy. In terms of geographical location, the position of Indonesia on the equator provides an advantage of having high temperatures ranging between 20–30°C ideal for solar energy. Its location between Asia and Australia also exposes Indonesia to monsoon storms ideal for wind energy. Moreover, Indonesia controls 40% of the geothermal reserves and other natural resources of the globe. Figure 4 displays the potential of renewable energy in Indonesia in each province. West Java has the highest potential energy generated from renewable energy at nearly 28.000 MV, followed by West Kalimantan, East Java, and East Kalimantan.

Although Indonesia has considerably large and diverse potential of renewable energy sources reaching approximately 400GW, the utilization of renewable energy in 2020 is merely 2.1% of the potential (Ministry of Energy and Mineral Resource of Indonesia 2020). The majority of existing and planned renewable energy power plants rely on hydro or geothermal power. Of the installed capacity of 7 GW, 66% are hydroelectric power plants (PLTA) while 27% are geothermal power plants (PLTP). The planned construction of a solar power plant (PLTS) is only 7% despite the potential of nearly 50% of the potential of renewable energy in Indonesia (UN Climate Change 2021).

The reduction and mitigation of carbon emissions as well as the strategic geographical location of Indonesia for renewable energy show that the development of renewable energy is promising for future use vis a vis economic growth. The Government Regulation No. 79 of 2014 on the National Energy Policy sets a target to change the energy mix to achieve at least 23% in 2025 and 31% in 2050 in renewable energy. Another energy source in the new energy policy is to reduce oil proportion to not

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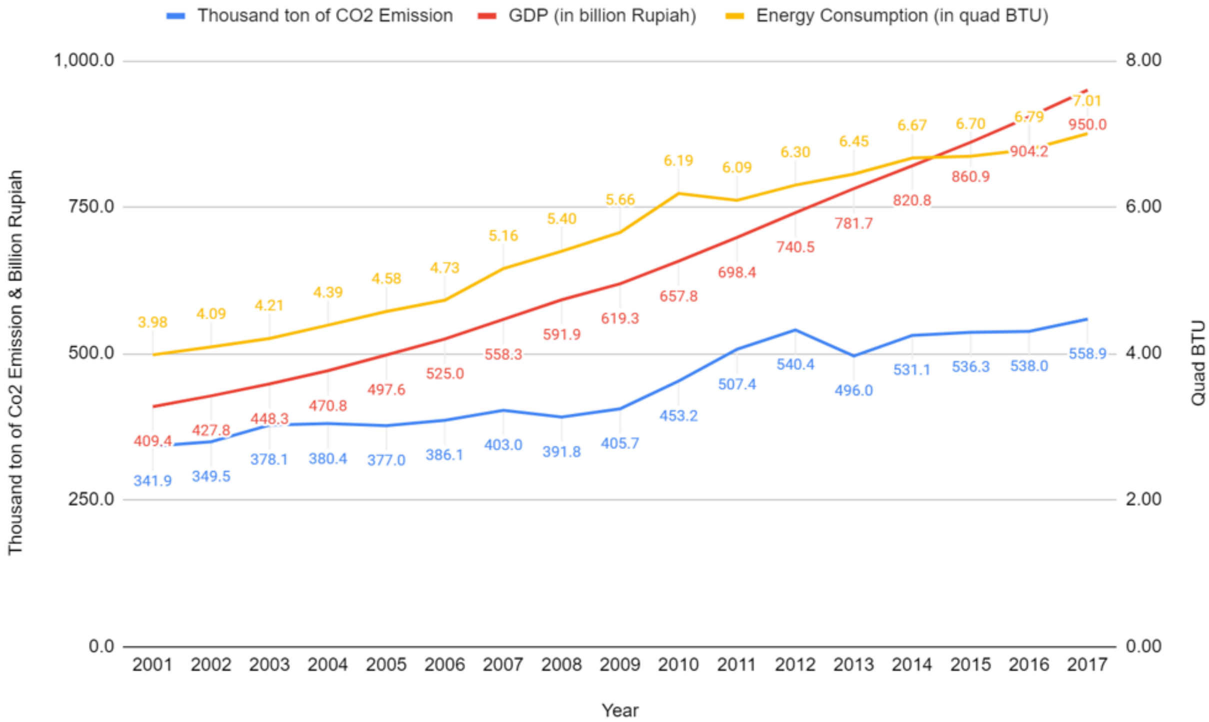

Figure 1. CO2 Emissions of Indonesia from Energy, GDP and Energy Consumption 2001–2017
Source: BPS - Statistics Indonesia (2020), Ministry of Energy and Mineral Resources (2020), and World Bank (2023)

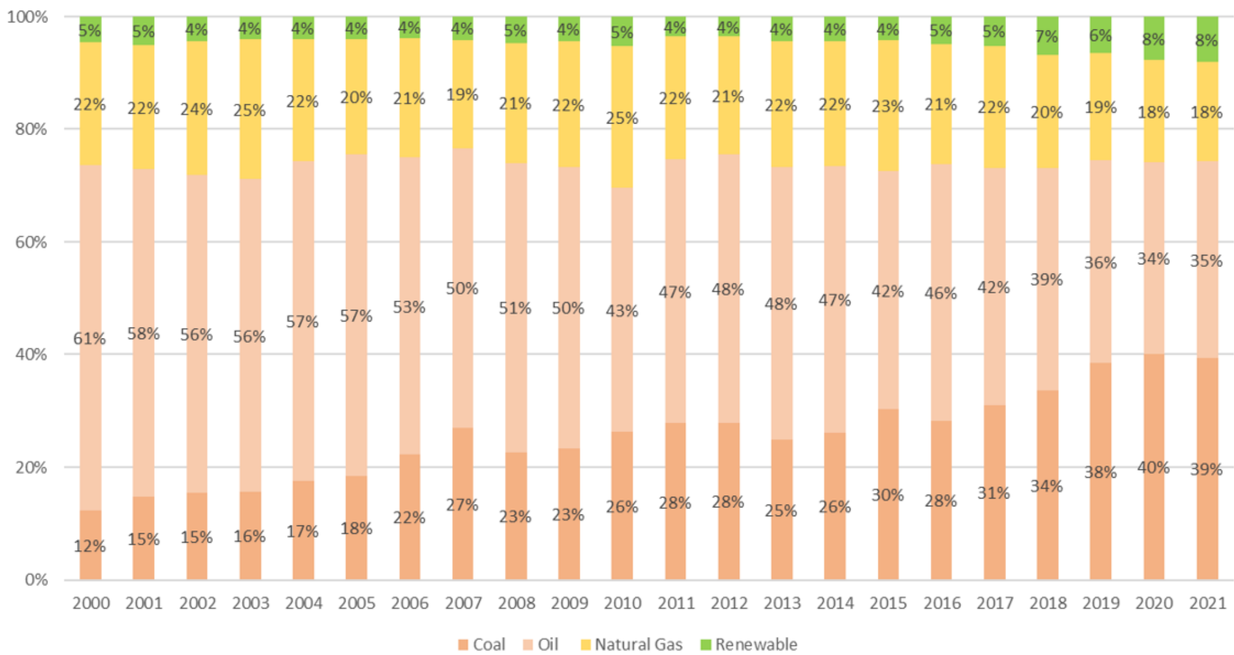

Figure 2. Primary Energy Mix of Indonesia in 2000–2021
Source: Ministry of Energy and Mineral Resources Indonesia 2021

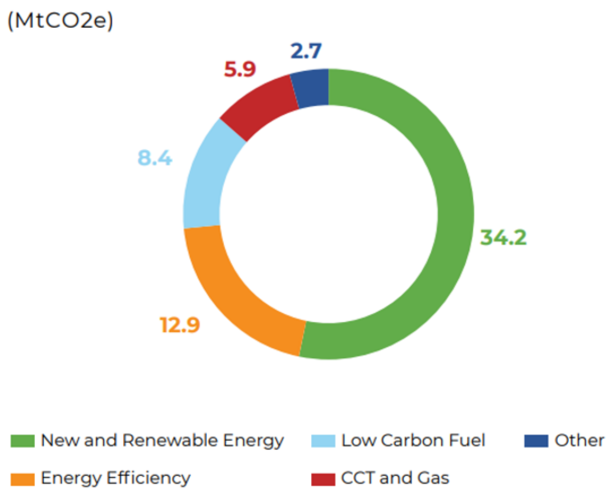

Figure 3. The Distribution of Mitigated Emission in the Energy Sector in Indonesia in 2020
Source: IESR 2021

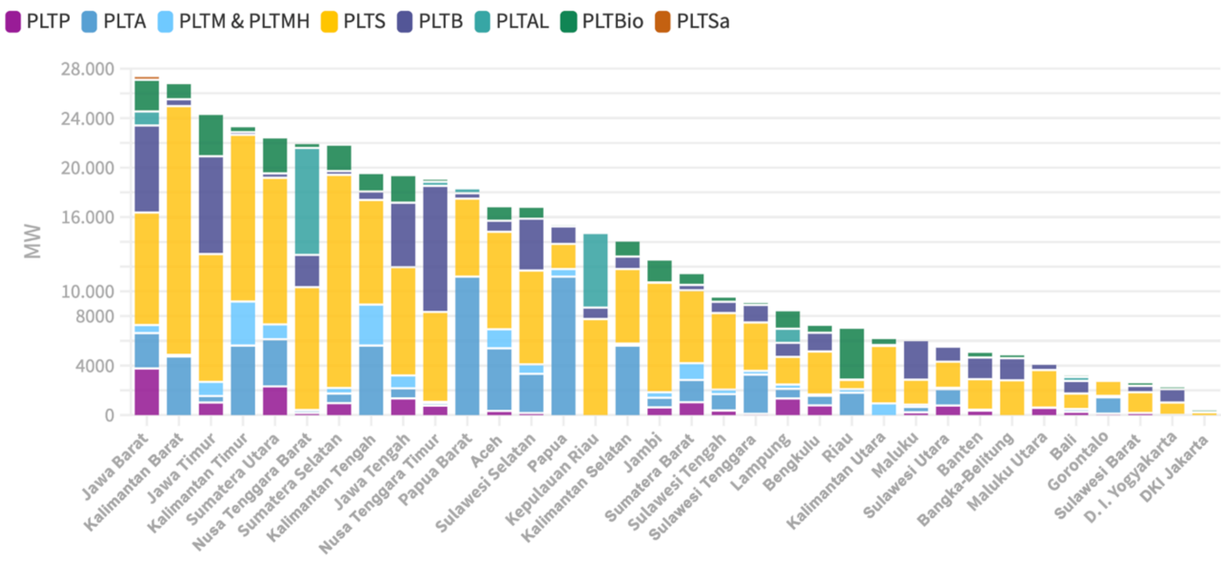

Figure 4. Distribution of Renewable Energy Potential by Province
Source: Ministry of Energy and Mineral Resources, 2016

exceed 25% in 2025 and 20% in 2050, decrease coal proportion to no more than 30% in 2025 and 25% in 2050, and lower gas proportion to be at least 22% in 2025 and 24% in 2050 (IRENA 2017).

Developing renewable energy and reducing dependence on fossil energy remain a challenge for Indonesia. The two main reasons for this challenge are economic and non-economic barriers. The non-economic barriers include the inconsistent regulation of renewable energy in Indonesia which renders the renewable energy market of Indonesia less attractive to investors. Secondly, the pricing structures of renewable energy in Indonesia are also still inconsistent, making it difficult for investors to predict and lessen the incentives to invest in the renewable energy market of Indonesia. Thirdly, the local banks still discern renewable energy as a high-risk project causing a high interest rate. Lastly, a small number

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of local renewable manufacturing industries is far from the potential capacity. This results in an excessive cost of renewable energy which is one of the economic barriers to renewable energy development in Indonesia (IESR 2018). Research and development of renewable energy technology and manufacturing by the government will result in a higher number of domestic renewable energy producers needed to reduce renewable energy costs (Adiatma & Arinaldo 2018).

Nevertheless, global renewable energy demand, excluding the traditional use of biomass, has escalated from 2009 to 2019 at an annual rate of 4.4%. Higher awareness of the environmental issues of greenhouse gases results in an increase in global renewable energy investment by 2% in 2020, totaling USD303.5 billion. The REC share of the global final energy consumption reaches 11.2% in 2019, increasing by 2.5% within a decade. The global trend of renewable energy costs has significantly decreased due to technological advancement (REN21 2021).

The global weighted average cost of electricity has decreased significantly. Specifically for solar PV, the cost has decreased from USD0.381/kWh in 2010 to USD0.057/kWh in 2020, or around 85%. The average cost of coal generation is around USD0.05 to 0.07/kWh (IESR 2021). The global weighted average cost of electricity generated from onshore wind energy between 2010 and 2020 has declined by 56%, while the cost of offshore wind energy has dropped by 48%. This trend of decreasing cost of global renewable energy is a bright spot for the promising future renewable energy development in Indonesia, in which renewable energy can offer a lower price compared to non-renewable energy and the ability to compete in the energy market.

Studies on the nexus between energy consumption and economic growth (EGN) have been increasing over the past years in different economic regions. It is because of its role in quantifying the impact of energy policies on economic growth through its cause-effect relationship and how energy policies can be improved to be more effective (Heckman & Pinto 2022). However, previous studies on the direction of the cause-effect relationship between energy consumption and economic growth generate different results (see for instance Wolde-Rufael 2005; Squalli 2007; Ocal & Aslan 2013; Payne 2009). The different results signify a different focus of studies on particular countries (developed and developing countries) and particular energy sources (oil, coal, nuclear).

The empirical study of EGN in Indonesia is still limited. Economic growth and energy consumption have a positive correlation, however their cause-effect relationship provides a different direction (Dat et al. 2020). Hence, this study aims to understand the relationship between energy consumption and economic growth in Indonesia. It focuses on the question of the direction of causality of energy consumption and economic growth in Indonesia, both in the short and long run. By understanding the direction of the cause-effect relationship between energy consumption and economic growth and the magnitude of the impact, Indonesia can balance energy efficiency and conservation and high economic growth. It is particularly important for Indonesia in planning strategically carbon emission reduction to achieve Nationally Determined Contribution (NDC) in the context of Paris Agreement.

2. Literature Review

Energy can directly affect total factor productivity (TFP) vis a vis economic growth in a given production function that incorporates capital and labor. Energy may be a constraint or an enabler of economic growth. While mainstream growth models do not take energy into account in the models explicitly (e.g. Solow growth model, 1956), other schools of thought including ecological economics, geographical economics, and historical economics believe that energy has a direct relationship with economic growth (Stern 2011). There are different approaches to explicitly account for energy in economic growth. Nevertheless, Stern (2011) proposes integrating different approaches by modifying the Solow growth model and adding energy-related variables into the production function. Kümmel et al. (1985) also propose an augmented function to the Solow growth model. They explain that energy-related variables are closely linked to technical progress that affects production increase for economic growth. Kümmel et al. (1985) emphasize that energy is a fundamental factor of production because goods and services in industrialized countries cannot be produced without energy. There are three main arguments on how energy-related variables are closely linked to technical progress affecting production increase for economic growth. First, they argue that the higher amount of energy consumption reflects how technological improvement in energy-providing sectors provides higher availability of primary energy for production. Secondly, technological improvement reflects a technological-intensive production process and increased need for energy. Lastly, technological progress in the service sector is growing rapidly in electronic information processing that requires energy. The augmented growth function can be written as follows:

$$\mathrm{Y_t = f(K_t, L_t, T_t)} \quad (1)$$

$$\mathrm{T_t} = \beta \mathrm{E_t} \quad (2)$$

where Y is output or production, K is physical capital, L is labor, T is technology, E is energy and t is time.

By substituting $\mathrm{Tt} = \beta\mathrm{Et}$ in equation 1 into the Solow growth model in the equation 2, the augmented production function will be as follows:

$$\mathrm{Y_t} = \beta \mathrm{E_t K_t L_t} \quad (3)$$

Previous empirical studies on EGN result in four different directions of causality. First, a unidirectional causality from energy consumption to economic growth known as the "growth hypothesis". This hypothesis suggests that energy consumption affects economic growth as a necessary factor of production. Consequently, an increase in economic growth will require an increase in energy consumption. Energy conservation policies and efforts will adversely affect GDP. It creates an energy-dependent economy. Second, a unidirectional causality from economic growth to energy consumption, also known as the "conservation hypothesis". This second hypothesis argues that economic growth is a contributing factor to energy consumption (Menegaki 2018). Theoretically, the conservation hypothesis signifies that energy saving policies may not negatively affect economic growth. A more efficient use of energy can be achieved without sacrificing high economic growth. Third, a bidirectional causality between energy consumption and economic growth, also known as the "feedback hypothesis". An increase in energy consumption causes an increase in economic growth, and vice versa. It implies an interdependence between economic growth and energy consumption. This hypothesis implies that the energy conservation policies can adversely affect economic growth through less consumption of energy and then will adversely affect economic growth further. Lastly, no causality between energy consumption and economic growth, also known as the "neutrality hypothesis". Energy consumption has no causal effect on economic growth, and economic growth has no causal effect on energy consumption as well. It is because energy consumption is considered as a small component of total output that has little or no impact on economic growth. Hence, energy conservation policies will not also influence economic growth (Menegaki 2018).

Previous empirical studies (see for instance Gozgor, Lau & Lu 2018; Apergis & Payne 2009; Chien & Hu 2008; Khobai & Roux 2018; Bimanatya & Widodo 2018; Lee 2005) support the growth hypothesis, in which energy consumption affects economic growth. Meanwhile, studies by Faisal et al. (2017) and Omri et al. (2015) support the conservation hypothesis in which economic growth influences energy consumption for particular countries. Other studies by Apergis & Payne (2010,2011), Pao & Fu (2013), and Sebri & Ben-Salha (2014) support the bidirectional cause-effect relationship between energy consumption. Meanwhile, studies by Menegaki (2011) and Payne (2009) support the neutrality between energy

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consumption and economic growth.

Due to the different results of previous studies, this study hypothesizes a unidirectional relationship from energy consumption, distinguished into non-renewable and renewable, to economic growth either in the short or long run.

3. Method

This study focused on the causal relationship between energy consumption (both non-renewable energy and renewable energy) and economic growth in Indonesia. The analysis used annual time series data in Indonesia from 1985 to 2019 due to limitations in available data on the labor force, REC, and NREC. The data on REC and NREC used in this study were obtained from BPS - Statistics Indonesia and the Ministry of Energy and Mineral Resources. The data on the labor force were taken from BPS - Statistics Indonesia. The data on economic growth and gross fixed capital formation were collected from World Economic Development Database of the World Bank.

Economic growth is represented by the first difference of constant GDP in 2015 prices. The independent variables used in this study are: renewable energy consumption (REC) measured by the total consumption of renewable energy in quadrillion Btu, non-renewable energy consumption (NREC) measured by the total consumption of non-renewable energy in quadrillion Btu. The total NREC is calculated by the sum of energy consumption of coal, natural gas, and petroleum.

3.1. Estimation Model

This study adopted the augmented production function of Kümmel et al. (1995) by taking into account energy-related variables in the Solow growth model as stated in equation 3. To estimate EGN in Indonesia, the following equation will be used:

$$\begin{aligned} \mathrm{GDP_t} &= \beta_0 + \beta_1 \mathrm{REC_t} + \beta_2 \mathrm{NREC_t} + \beta_3 \mathrm{GCFC_t} \\ &+ \beta_4 \mathrm{LF_t} + \mathrm{u_t} \end{aligned} \quad (4)$$

where K which represents Capital will be transformed to Gross Fixed Capital Formation expressed in GFCF and L which represents Labor will be transformed into Labor Force expressed in LF. Variable E will be represented by REC and NREC which represent renewable energy and non-renewable energy consumption, respectively. Subsequently, the natural logarithm form will be used because the coefficients are directly interpretable as approximate proportional differences (Gelman & Hill 2007):

$$\begin{aligned} \mathrm{lnGDP_t} &= \beta_0 + \beta_1 \mathrm{lnREC_t} + \beta_2 \mathrm{lnREC_t} \\ &+ \beta_3 \mathrm{lnGCFC_t} + \beta_4 \mathrm{lnLF_t} + \mathrm{u_t} \end{aligned} \quad (5)$$

3.2. Method of Analysis

The analysis was performed in three steps. Firstly, a unit root test was conducted to check the stationary of the time series and the order of integration of the variables used. The most common statistical test for stationery and order of integration is the Augmented Dickey-Fuller (ADF) test (Dickey & Fuller 1981). Supposing the time series is non-stationary, the results obtained will be spurious and unreliable. To fix the non-stationary time series, the data need to be differentiated (Farabi, Abdullah & Setianto 2019). The cointegration test can only be conducted when all data are stationary and have the same order of integration.

When all variables are stationary and have the same order of integration, the Johansen maximum likelihood test (Johansen & Juselius 1990) can be used to analyze the cointegration relationship between variables. The cointegration test is meant to determine the presence of a long-run relationship between variables (Dickey, Jansen & Thornton 1994). Supposing two variables are integrated in order of one and cointegrated, then a Granger causal relationship exists between them in at least one direction, either unidirectional or bidirectional (Engle & Granger 1987). Thus, a Granger causality test should be performed to determine the direction of causality using the following VECM models:

$$\begin{aligned}\Delta \mathrm{lnGDP_t} &= \gamma_{10} + \sum_{i=1}^{m} \gamma_{11i} \Delta \mathrm{lnGDP_{t-1}} + \sum_{i=1}^{m} \gamma_{11i} \Delta \mathrm{lnREC_{t-1}} + \sum_{i=1}^{m} \gamma_{11i} \Delta \mathrm{lnNREC_{t-1}} \\ &\quad + \sum_{i=1}^{m} \gamma_{12i} \Delta \mathrm{lnGFCF_{t-1}} + \sum_{i=1}^{m} \gamma_{13i} \Delta \mathrm{lnLF_{t-1}} + \delta_1 \mathrm{ECT_{t-1}} + \mu_t \quad (6)\end{aligned}$$

$$\begin{aligned}\Delta \mathrm{lnEC_t} &= \gamma_{20} + \sum_{i=1}^{m} \gamma_{21i} \Delta \mathrm{lnGDP_{t-1}} + \sum_{i=1}^{m} \gamma_{21i} \Delta \mathrm{lnREC_{t-1}} + \sum_{i=1}^{m} \gamma_{21i} \Delta \mathrm{lnNREC_{t-1}} \\ &\quad + \sum_{i=1}^{m} \gamma_{22i} \Delta \mathrm{lnGFCF_{t-1}} + \sum_{i=1}^{m} \gamma_{23i} \Delta \mathrm{lnLF_{t-1}} + \delta_2 \mathrm{ECT_{t-1}} + \mu_t \quad (7)\end{aligned}$$

$$\begin{aligned}\Delta \mathrm{lnGFCF_t} &= \gamma_{30} + \sum_{i=1}^{m} \gamma_{31i} \Delta \mathrm{lnGDP_{t-1}} + \sum_{i=1}^{m} \gamma_{31i} \Delta \mathrm{lnREC_{t-1}} + \sum_{i=1}^{m} \gamma_{31i} \Delta \mathrm{lnNREC_{t-1}} \\ &\quad + \sum_{i=1}^{m} \gamma_{32i} \Delta \mathrm{lnGFCF_{t-1}} + \sum_{i=1}^{m} \gamma_{33i} \Delta \mathrm{lnLF_{t-1}} + \delta_3 \mathrm{ECT_{t-1}} + \mu_t \quad (8)\end{aligned}$$

$$\begin{aligned}\Delta \mathrm{lnLF_t} &= \gamma_{30} + \sum_{i=1}^{m} \gamma_{41i} \Delta \mathrm{lnGDP_{t-1}} + \sum_{i=1}^{m} \gamma_{41i} \Delta \mathrm{lnREC_{t-1}} + \sum_{i=1}^{m} \gamma_{41i} \Delta \mathrm{lnNREC_{t-1}} \\ &\quad + \sum_{i=1}^{m} \gamma_{42i} \Delta \mathrm{lnGFCF_{t-1}} + \sum_{i=1}^{m} \gamma_{43i} \Delta \mathrm{lnLF_{t-1}} + \delta_4 \mathrm{ECT_{t-1}} + \mu_t \quad (9)\end{aligned}$$

ECT is the error correction term which is the lagged residuals from the cointegration regression (Engle & Granger 1987). The short-run causal relationship of the model will be obtained supposing the coefficient of cointegration is significant. The long-run causal relationship of the model will be obtained supposing the coefficient of ECT is negative and significant, as it represents the long-run variable. Δ is the first-difference operator and t is the error term. The speed of adjustment, denoted by δ, measures the speed at which the values of variables come back to the long-run equilibrium level when a disturbance or shock occurs that make variables violate the long-run equilibrium relationship (Pao & Fu 2013).

4. Results and Analysis

4.1. Cointegration Test

The result reveals that the absolute value of the test statistic at level one, I(1), is higher than the absolute 5% critical value. Thus, the differences become stationary and indicate that the variables are integrated at order one, I(1).

In model 1, the trace statistic at rank 0 exceeds its critical value, thus the hypothesis of no cointegrating equation is rejected. At rank 1, the trace statistic is below its critical value, thus the hypothesis that there are one or fewer cointegrating equations cannot be rejected. The results of the cointegration test imply that there is at least one cointegrating equation in the model. In model 2 and rank 2, the trace statistic is lower than the critical value, thus the hypothesis that there are two or fewer cointegrating equations cannot be rejected. Thus, there are at least two cointegrating equations for model 2.

4.2. Vector Error Correction Model

Table 5 shows the result of the relationship and the significance level between variables by conducting VECM. When the p-value is less than the significance level, it indicates that the test statistic is statistically significant, implying a short-run causal relationship between variables.

Table 2. Unit Root Test Result

	Test Statistics		Interpolated Dickey-Fuller		
	Level	1st Difference	1% Critical Value	5% Critical Value	10% Critical Value
GDP	-0.397	-3.649	-3.702	-2.980	-2.622
GFCF	-0.644	-3.095	-3.709	-2.983	-2.623
LF	-1.715	-6.420	-3.696	-2.978	-2.620
REC	0.127	-5.500	-3.709	-2.983	-2.623
NREC	-2.540	-5.453	-3.696	-2.978	-2.620

Table 3. Johansen Cointegration Test Result

Model 1: lnGDP, lnGFCF, lnLF, lnREC				
Maximum Ranks	LL	Eigenvalue	Trace statistics	5% Critical value
0	25.541.794		507.674	47.21
1	26.666.554	0.49423	28.2722*	29.68
2	27.691.787	0.46278	77.676	15.41
3	28.065.661	0.20275	0.2901	3.76
4	28.080.166	0.00875		

Model 2: lnGDP, lnGFCF, lnLF, lnNREC				
Maximum Ranks	LL	Eigenvalue	Trace statistics	5% Critical value
0	30.334.282		659.131	47.21
1	31.980.963	0.63138	329.795	29.68
2	33.121.502	0.49904	10.1687*	15.41
3	33.628.575	0.26458	0.0273	3.76
4	33.629.938	0.00083		

Table 4. Vector Error Correction Model (VECM) Test Result

Granger Causality Test Result					
Model 1: lnGDP, lnGFCF, lnLF, lnREC					
Dependent variable	△GDP	△GFCF	△LF	△REC	ECT
△GDP		-0.25***	0.36	0.13*	-0.03***
△GFCF	4.48*		0.79	0.32*	-0.13**
△LF	-0.16	0.04		-0.01	0.01**
△REC	-1.97	0.38	-0.01		0.03
Model 2: lnGDP, lnGFCF, lnLF, lnNREC					
	△GDP	△GFCF	△LF	△NREC	ECT
△GDP		-1.15*	0.33	0.66***	-0.94*
△GFCF	8.53		0.24	1.83**	-2.59*
△LF	-0.23	0.01		0.14	0.17***
△NREC	1.35	-0.73	0.78		-0.58
Johansen Normalization Restriction Imposed					
Model 1	lnGDP	lnGFCF	lnLF	lnREC	Intercept
	1*	1.42*	-8.45*	1.16	95.69*
Model 2	lnGDP	lnGFCF	lnLF	lnNREC	Intercept
	1*	-0.313*	-2.49*	0.5*	26.64*

Note: * Indicate 1% level of significance
** Indicate 5% level of significance
*** Indicate 10% level of significance

As presented in Table 5, Model 1 shows a significant unidirectional causality relationship from REC to economic growth, supporting the growth hypothesis. Even though renewable energy only takes a small proportion of the primary energy mix of Indonesia, the findings of this study imply that renewable energy of Indonesia is currently in a transitional stage through investments that positively affect economic growth in the short run (Marinaș et al. 2018).

Similarly, in Model 2, there is also a significant unidirectional causality relationship from NREC to economic growth in the short run. It means the economy needs higher total NREC to have positive economic growth. As a developing country, Indonesia is more likely to be an energy-dependent economy compared to developed countries, where energy consumption will increase in the upcoming years due to economic growth (Menegaki 2018). Referring to the energy mix portfolio of Indonesia in 2021, 92% of energy consumption is still non-renewable and mostly consumed for direct economic activities (Ministry of Energy and Mineral Resources Indonesia 2021). The final energy consumption by sectors in Indonesia is mostly used for industrial and transportation purposes, reaching more than 75% of the total energy consumption for the past decade (Ministry of Energy and Mineral Resources 2021). In industrial activities, coal is 90% consumed by the cement industry while others use gas as the main energy source. As for the transportation sector, the biggest energy demand in transportation in 2018 is fuel (96%), followed by biodiesel and gas (General Secretariat of National Energy Council 2019). It is reasonable to infer that NREC currently still plays a significantly important role in productive sectors that directly affect economic growth.

The result from Table 5 for Johansen Normalisation Restriction Imposed, which shows the long-run equation from which the error correction term (ECT) is derived, suggests that a 1% increase in NREC will increase economic growth by 0.5% in the long run. The positive and significant causal effect indicates the presence of a unidirectional causal relationship to economic growth. The findings of this study provide evidence supporting the theory proposed by Kummel that non-renewable energy as an energy input positively and significantly affects the economic growth of Indonesia in the long run.

The result of Model 1 indicates that the coefficient of REC to economic growth is not significant in the long run. It shows that the cause-effect relationship between REC and economic growth in the long run supports the neutral hypothesis. The difference in the short- and long-run results of the causal relationship is caused by the short run estimates of the economy in different stages of transitions in the energy consumption mix. Meanwhile, the long-run analysis enables us to capture the impact of the energy transition through the assessment of the equilibrium between economic growth and a higher share of renewable energy (Marinaș et al. 2018). Apergis & Payne (2009) and Menegaki (2011) also reveal a neutral relationship between renewable energy and economic growth. The authors argue that the absence of a relationship between these variables in the long run is because of the notably small proportion of renewable energy in energy consumption vis a vis economic growth as also suggested by Apergis & Payne (2009) and due to the early stage of development of renewable energy and insufficient utilization of renewable energy as stated by Menegaki (2011). Therefore, REC has not played an important role in economic growth.

The result of neutral causality in the long run also suggests that the energy policy during the period of observation still focuses more on non-renewable energy than renewable energy, thus non-renewable energy remains dominant in the share of energy mix of Indonesia. The share of renewable energy in the proportion of primary energy supply has not shown much improvement over the past years, namely less than 10% of share. Hermawan & Hadi (2006) discover that the renewable energy sources in Indonesia are abundant yet greatly underdeveloped, which result in a poor supply of renewable energy. Therefore, a transition towards renewable energy is essential as the expanded use of renewable energy over time may result in a causal relationship between renewable energy and economic growth in the long run.

Without significant changes in the energy mix, Indonesia will remain dependent on non-renewable energy and will exacerbate environmental problems in the long run, failing to achieve the new National Energy Policy and commitment in the Paris Agreement. To achieve these goals, Indonesia has to implement a long-run strategy with energy efficiency measures and enhance renewable energy in power, transport, and industry. This may raise the trade-

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off between economic growth and climate change. Decreasing non-renewable energy will negatively affect the economic growth of Indonesia since the findings of this study support the growth hypothesis. It suggests that increasing energy efficiency measures and enhancing renewable energy development will adversely impact economic growth.

Nevertheless, studies show that the cost of environmental problems caused by higher non-renewable dependency is high. According to a sensitivity analysis of climate change impact on the GDP of Indonesia, a future increase in climate change can have a negative impact of 0.66% to 3.45% on national GDP or costing around 110.38 to 577.01 trillion rupiah (UN Climate Change 2021).

Even though non-renewable energy, particularly coal, is considered to offer less cost in generating energy than renewables, in reality, the efficiency of coal-fired power plants has declined in the last decade due to the declining efficiency of ageing coal-fired power plants, the low quality of the coal consumed, and the high costs of operation and maintenance, including the purchase of coal. By comparing the new coal-fired power plant (PLTU) of Java 7 with solar PV power plant (PLTS) of Likupang; the levelized cost of electricity (LCOE) is between USD0.03–0.08 per kWh for PLTU and between USD0.01–0.05 per kWh for PLTS (Shalati & Dillon 2022). Moreover, the cost of electricity generated from coal highly depends on the global price of coal. Global coal prices tend to increase over time, reaching USD435 per barrel in 2022. Figure 3 shows that the price of coal in Indonesia is also increasing over time. This suggests that in the long run, aside from exacerbating environmental problems due to high emissions of CO2, non-renewable energy may also negatively affect the economic stability and energy security due to price fluctuations. Electricity subsidies in Indonesia also can affect energy efficiency and energy transition toward renewables. Electricity subsidies aim to make electricity price affordable mostly for the underprivileged people. Nevertheless, the electricity subsidies will increase demand for electricity, particularly for unproductive activities. In addition, the electricity subsidies for coal power plant will provide unfair competition with renewable energy. The cost of electricity generated from renewable is referred to the cost of electricity of coal power plant that obtain subsidies (Cindy 2020; IESR 2022)

On the contrary, the renewable energy industry is currently in the developing phase where it has become a global trend in the power sector due to the rapid decline in technology costs. A recent study on the renewable energy of Indonesia reveals that if renewable power plants are built instead of coal-fired power plants as planned in the 2018–2027 RUPTL, it shows potential cost savings of USD10 billion. The potential benefits that can emerge from the plan include greater employment opportunities, higher economic growth in the industry, as well as potentially lower renewable energy costs in Indonesia. It can also produce cheaper and cleaner electricity in line with public needs and government policies. In 2017, an additional 140 GW of installed capacity enabled the creation of 500,000 jobs in the renewable energy industry, excluding hydropower (Arinaldo & Adiatma 2019).

5. Conclusion

This study concludes that NREC still plays an important role in influencing the economic growth of Indonesia in the short and long run. The result estimates that a 1% increase in NREC will increase economic growth by 0.5% in the long run. Lowering NREC will adversely affect economic growth, both in the short and long run. Nevertheless, there remains room for Indonesia to utilize NREC more efficiently by continuously lowering the energy intensity with little effect on economic growth in the long run (i.e. the conservation hypothesis). In addition, the cost of climate change due to the high proportion of NREC is high, and non-renewable energy development has entered the declining stage in the past decade with the price of coal increasing and non-renewable energy power generation getting more inefficient.

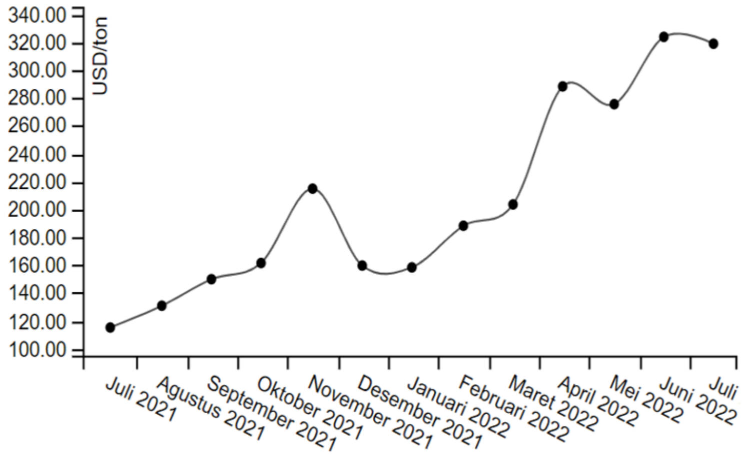

Figure 5. Reference Coal Price of Indonesia
Source: Ministry of Energy and Mineral Resources 2022

A transition toward REC will offset the adverse effect of non-renewable energy conservation on economic growth. In the short run, this study demonstrates the significant effect of REC and NREC on economic growth; a 1% increase in REC and NREC will increase economic growth by 0.13% and 0.66% respectively. In the long run, while a 1% increase in NREC will increase economic growth by 0.5%, REC does not provide a significant effect on economic growth. The smaller effect of REC on economic growth both in the short and long run is because of its little contribution to the energy mix of Indonesia. By increasing REC in the energy mix of Indonesia, it should play a more important role in economic growth both in the short and long run. In order to accelerate renewable energy development in Indonesia, the government regulations and policies should remove the barriers to renewable energy expansion. Policymakers in Indonesia can improve and provide a consistent regulation and pricing of renewable energy to be classified as a low-risk project and make it attractive to investors. In addition, since renewable energy projects are still extremely costly in Indonesia due to below-potential local manufacturers of renewable energy technology, the government can focus more on the Research and Development (R&D) of renewable technology and manufacturing. Incentive mechanisms are also recommended by establishing feed-in tariffs, investment subsidies, tax incentives, and sales tax exemptions.

For further research, the authors suggest analyzing the nexus between renewable energy, non-renewable energy, and economic growth by specifying the types of energy sources such as solar PV, hydropower, geothermal, wind, coal, natural gas, and oil. It will enhance the analysis of the causal relationship between different types of renewable energy and economic growth. It will provide more insightful results for the purpose of energy policy recommendations and for further development of renewable energy and economic growth of Indonesia.

As data availability increases over time, it is advised to use more data for stronger result accuracy. Additionally, other factors or variables that can affect economic growth and REC and NREC can be added to the analysis to obtain clearer energy policy recommendations.

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