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Evaluating The Nexus of Renewable Energy's in Economic Growth Realities: Autoregressive Distributed Lag Approach

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Abstract: *This article about energy in an economic context, energy fossil has become one of the causes of issues faced by humanity. These problems have cascading impacts, ranging from climate damage to individual health and global socio-economic conditions. This study aimed to elucidate the effects of renewable energy, fossil energy, labor force, foreign direct investment and carbon dioxide emissions on economic growth. The analytical tool employed was the ARDL bound test. Secondary data from annual series spanning from 1986 to 2020. The study found a two-way cointegration between labor force, foreign direct investment, and economic growth. Based on the methodology used, conclusions were drawn regarding short-run and long-run relationships. In the short run, both fossil and renewable energy had unidirectional relationships with economic growth. Carbon dioxide emissions had a negative impact on economic growth in the short-run and the long-run. Labor force and economic growth exhibited a two-way relationship in the long-run. Consequently, energy transition policies and the imposition of carbon emission taxes could have negative short-run implications for Indonesia's economic growth, while the reverse may be true in the long run. Economic growth may reach a peak and then decline and policymakers should maximize existing non-renewable energy sources. A policy requiring to control more fossil fuel energy sources and discover untapped reserves is worthy of continuation and even strengthening. The findings provide an understanding of the relationship between renewable energy and economic growth as a necessity for the energy transition. The study has limitations in assumptions when interpreting the findings.*

Keywords: Energy Consumption; Carbon Dioxide Emissions; Labor; Economic Growth, ARDL

INTRODUCTION

Energy can be defined as the ability to make something move, work, or change its position. Essentially, energy cannot be seen but can be felt. It can naturally transform or be altered by human intention to suit needs. According to physics, energy cannot be created or destroyed; it can only change from one form to another. The existence of energy correlates strongly with life on Earth. Historically, energy has played a pivotal role from the dawn of life on Earth until the present day. For example, theories about the creation of the universe, such as the big bang theory, explain the formation of galaxies due to a singular point that was extremely hot, dense, moving rapidly, and continuously expanding. The presence of heat signifies the existence of energy within this process.

Lately, energy (specifically fossil energy) has become one of the causes of issues faced by humanity. These problems have cascading impacts, ranging from climate damage to individual health and global socio-economic conditions (Tazi Hnyine et al., 2015). In 2021, the world was startled by an incredibly rare phenomenon: rainfall in Greenland. This natural event occurred for the first time, leading to the melting of ice on Greenland's surface by up to 872,000 square kilometers. It's crucial to note that Greenland holds at least 10 percent of the total volume of ice on Earth (S. Liu et al., 2023). The melting of ice in Greenland from 1992 to 2018 had resulted in a global sea-level rise of approximately 10 ± 0.9 millimeters (S. Liu et al., 2023). The primary cause of this phenomenon is the increased amount of carbon emissions resulting from the combustion of fossil fuels. These carbon emissions concentrate in the atmosphere, leading to the trapping of heat from the sun, which then struggles to escape the Earth—a phenomenon known as the greenhouse effect. Consequently, the Earth's surface temperature increases due to this trapped heat.

If not addressed seriously, it could cause anomalies in the Earth's temperature conditions in the future, around 50 to 70 years from now. During that time, it's predicted there will be a difference in air temperatures between the northern and southern hemispheres of the Earth's surface, with the northern side becoming warmer and the southern side experiencing cooling by more than 2°C to 4°C (Vohra et al., 2021). According to a report issued by the Intergovernmental Panel on Climate Change, IPCC (2021), over the next 20 years, the Earth is projected to experience a global temperature increase of 1.5°C to 2°C on average. In response to this temperature rise, various countries worldwide have reached a consensus to limit the global temperature increase to no more than 2°C. This consensus is known as The Paris Agreement, primarily aiming to enhance the use and production of clean and renewable energy (green energy) as a mitigation effort against the inevitable environmental damage caused by the reliance on non-renewable/fossil energy sources.

The negative impacts of fossil fuels aren't just caused by consumer-level combustion, even more severe impacts occur at the production level. Exploration of fossil energy sources often results in environmental damage that surpasses the opportunity cost of cleaner and healthier economies. Moreover, exploration and mining processes frequently create conflicts between companies and local communities (Oh et al., 2023). Drilling processes in exploiting natural gas energy sources also lead to prolonged disasters. Since the industrial revolution, humanity has repeatedly suffered losses caused by the exploitation of fossil and other mineral energy sources. In 2018, 8 million people died due to air contaminated by the pollution from the combustion of fossil fuels (Vohra et al., 2021).

Globally, the use of renewable energy accounts for only 15.7 percent of total energy consumption, renewable and fossil energy (British Petroleoum, 2020). Looking at country distribution, China ranks first in fossil energy usage, consuming a total of 24,500 TWh, followed by India and the United States at 5,581 TWh and 2,741 TWh, respectively. Japan and Indonesia rank fourth in fossil energy consumption, with totals of 1,365 TWh and 1,200 TWh. The contribution of fossil energy in these countries remains above 60 percent of the total energy usage (Energy Institute, 2023; Isa et al., 2013). Hence, accelerating the transition from fossil to renewable energy is crucial. However, this transition isn't easy or inexpensive; it requires budgetary preparedness and technology to achieve the intended goals.

On the other hand, a moderate energy transition could negatively impact a country's economic cycle. In specific conditions, this economic cycle can disrupt other countries' economic chains. For example, the conflict between Russia and Ukraine caused Russia to be embargoed by several countries, including the United States. This embargo eventually hindered or reduced energy supply from Russia, leading to increased prices based on economic rationality—low supply versus high demand. This was evident in the United States, where gasoline prices rose from 4.17 USD to 5 USD per gallon for 87-octane fuel. Wars and embargoes also affected oil prices in Indonesia, where the price of premium gasoline (90-octane) increased from around Rp. 7000 per liter to Rp. 10,000 per liter. The world oil price at that time even touched $133 per barrel, recorded as the highest crude oil price during that period. The increase in crude oil prices eventually led to increased prices of other goods, as a consequence of increased production input costs. The more severe impact is that the uncertainty of oil prices can affect unemployment rates in economically unstable countries (Ahmed et al., 2023).

Therefore, every country needs to consider every energy conservation step taken, especially underdeveloped and developing countries. Indonesia falls into this categorization, necessitating careful consideration in determining energy conservation policies. This is to ensure that the nation doesn't burden its people when implementing energy transition policies. From the citizens' perspective, most of the population still relies on non-renewable energy. Those with lower to middle incomes would find it challenging to transition from fossil fuel-based vehicles to electric ones due to the high cost per unit. Additionally, a significant portion of Indonesia's power plants still relies on coal, accounting for more than 70 percent of the total power plants.

In accelerating this transition, Indonesia has implemented subsidy policies to encourage the migration of people from fossil fuel vehicles to electric ones. However, these subsidy policies haven't significantly impacted the majority of the population in transitioning their vehicles. The subsidy policies are deemed inappropriate, as they could lead to negative impacts on the energy transition process due to opportunistic behaviors of economic actors (Zhao et al., 2024). Therefore, Indonesia, through its government, needs to establish alternative policies in accelerating energy transition targets. These policies should not disrupt the country's economic cycles or the economy of its citizens.

Looking at the growth of renewable energy consumption in Indonesia, the country had experienced rapid growth, with a 17.4 percent increase in 2022 and an average growth of 20.2 percent from 2012 to 2022. This growth is higher compared to neighboring Malaysia, which had a 7.6 percent growth in renewable energy consumption in the same year. However, Indonesia's growth in renewable energy is lower when compared to Vietnam, which had a 22.4 percent growth (Energy Institute, 2023). This indicates that Indonesia isn't performing poorly in contributing to the SDGs (Sustainable Development Goals) towards a better world.

Nevertheless, whether the growth rate of the renewable energy sector has a positive or negative impact on Indonesia's economy remains a relevant question, especially considering Indonesia's reliance on fossil energy sources. The relationship needs to be clarified so that the policies enacted align with Indonesia's conditions without sacrificing other sectors. Several studies had analyzed the relation between energy and economy, However, there hasn't been a discussion yet on how that relationship occurs in Indonesia. Therefore, we propose a more comprehensive and reasonable approach to elucidate this relationship. According to empirical research conducted by scientists, they found the relationship between energy and the economy varies, and haven't found a definite answer yet, all countries have their own relationship, even in the same country.

According to Tiwari et al. (2021), it was identified that energy consumption in India unidirectionally influences economic growth, with causality running from economic growth to energy consumption. On the other hand, Gregori & Tiwari, (2020) highlights the relationship between urbanization, GDP, trade, and electricity consumption in 28 China provinces. They found a unidirectional relationship from electricity consumption to GDP in the short-run, while GDP, trade, and urbanization affect electricity consumption in the long-run. Zhong et al. (2019) described the interconnection between electricity consumption and economic growth in China. They discovered a long-run positive relationship between electricity consumption, employment, and economic growth, whereas the short-run relationship is mutually influential but weak. They also indicated that endogenous variables could adapt to changes in exogenous variables before reaching equilibrium, taking more than 3 years after shocks to China's GDP. Ahmad & Zhao (2018) involving 30 provinces in China found a complex relationship between urbanization, industrialization, energy consumption, carbon emissions, and economic growth. There were bidirectional positive relationships between economic growth and energy consumption and between economic growth and industrialization. Unidirectional (one direction) relationships were also found from some factors to others, such as from industrialization to energy consumption. Acheampong (2018) results highlighted a unidirectional relationship from energy consumption to economic growth globally. However, this relationship varied across regions. For instance, in the Asia-Pacific and other regions, energy consumption was not influenced by economic growth, but vice versa (contrarily). In other areas like Sub-Saharan Africa, there was a positive relationship between energy consumption and economic growth. Faisal et al. (2018) discovered long-run cointegration between electricity consumption, economic growth, trade, and urbanization in Iceland. However, there was no relationship between electricity consumption and economic growth, both short-run and long-run, indicating that energy conservation policies did not harm economic growth in that country. Another study Faisal et al. (2017) also indicated a positive relationship between economic growth and energy consumption with a one-way causal pattern from economic growth to energy consumption. The relationship between carbon dioxide emissions and economic growth, as discussed by Zhang (2021) in China, showed a complex pattern. While initial economic growth increased carbon dioxide emissions, at a certain point, this growth reduced emissions before increasing again. This pattern reflects the N-shaped curve as described in the Kuznet curve.

The relationship can exist in short-run or long-run dynamics or might be one-directional, as found in Australia (in long-run), Belgium, Nigeria, Rome, Vietnam, China (in long-run), and the European Union countries (Emir & Bekun, 2019; Faisal et al., 2017; Sbia et al., 2017). Bidirectional connections are observed in countries like China (in short-run), Vietnam (in long-run) (Ahmad & Zhao, 2018; Nguyen & Ngoc, 2020; Zhong et al., 2019), or even a lack of association, as seen in Iceland and some cities in China (Faisal et al., 2018; Hu & Fan, 2020). Other variations may involve energy consumption as an independent variable or determinant of economic growth (Gregori & Tiwari, 2020). On the other hand, some argue that economic growth causes increased energy consumption (Acheampong, 2018; Faisal et al., 2018; Tiwari et al., 2021). However, employing different approaches, models, and methodologies, Ahmad & Zhao (2018) and Zhong et al. (2019) found contrasting results for the same country, China. Zhong et al. (2019) discovered a two-way relationship between energy consumption and economic growth in the short-run, whereas Ahmad & Zhao (2018) lacked sufficient information on that association.

As of now, there's limited analysis on the relationship between these two phenomena (energy and economic growth), especially regarding the correlation between renewable energy and economic growth, particularly in Indonesia. Hence, research within this scope is necessary, Does the energy transition have a negative impact on Indonesia's economic growth? to answer these questions we formulate research objectives. The research objective is to investigate the relationship between fossil and renewable energy, represented by the consumption of both energy types, on economic growth in Indonesia. From the previous research, we built hypothesis that both fossil energy and renewable energy have significant impact on economic growth at least in short-run. Apart from the empirical novelty in Indonesia, we're also utilizing a relatively longer data period compared to previous studies to attain smaller standard deviation values. Another novel aspect lies in the autoregressive distributed lag model, which is seldom used in Indonesia. We employ a distinct approach to analyze the relationship between energy consumption and the economy. We utilize a microeconomic perspective to examine macroeconomic relationships. Our methodology is based on production theory with slight adaptations to construct the model. When calculating capital and labor, we incorporate Foreign Direct Investment (FDI) and the labor force participation rate as variables representing each aspect within the production theory.

METHODOLOGY

This research is a quantitative study that utilizes mathematical and statistical approaches, particularly in econometrics, employing the Auto Regressive Distributed Lag (ARDL) bound test method based on the sample size recommended by Narayan (2005). The analysis of the research findings is conducted using descriptive methods to explain the impact of energy consumption, investment, labor force, and carbon dioxide emissions on economic growth. The research sources encompass various literature such as journals, papers, books, as well as statistical data to provide a detailed and comprehensive overview of the research outcomes. The scope of this study involves examining the relationship between fossil energy consumption, renewable energy, labor force, carbon dioxide emissions, foreign direct investment, and gross domestic product in Indonesia from 1986 to 2022. Data is obtained from various institutions considered credible at both national and international levels, such as the World Bank and British Petroleum. The focus is on the influence of each independent variable or predictor factor on the dependent variable or the research outcome. The distributed-lag model is considered dynamic because the effects of changes in one unit of the independent variable spread or are distributed over several time periods. The analysis process in this study includes checking the stationarity of data, cointegration testing with bound testing, Granger causality testing, classical assumption testing, and model stability evaluation.

Our unit root tests employ various approaches such as ADF, PP, and ZA. We conduct these tests to ensure robust calculation outcomes and to avoid spurious regression or false results. In the ZA testing, the researchers use two models. The first model aims to identify breaks in the intercept, referred to as model A. Meanwhile, the second model or model B seeks to identify breaks in both the intercept and trend.

Model A:

$$\Delta y_t = k + \phi y_{t-1} + \beta t + \theta_1 DU_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \dots\dots\dots (1)$$

Model B:

$$\Delta y_t = k + \phi y_{t-1} + \beta t + \theta_1 DU_t + \gamma_1 DT_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \dots\dots\dots (2)$$

Δ represents the first-order operation, εt represents the error or white noise with variance σ2, and t is the time index. Δyt-j in equations 1 and 2 indicates serial correlation and ensures the presence of white noise. DUt and DTt are dummy variables representing the movement or shift in means and trends. DUt = 1 if t > TB, and 0 otherwise; DTt = t - TB if t > TB, and 0 otherwise. Then, breaks are obtained from the estimation of the minimum t-statistic on the autoregressive variable coefficients. The asymptotic critical values for the t-statistic are based on Zivot & Andrews (1992). The calculated t-statistic results are then compared with the ZA critical values. If the absolute value of the t-statistic is greater than the ZA critical value, the null hypothesis is successfully rejected, meaning that the variable data is stationary considering structural breaks.

The use of the ARDL method in this study aims to investigate the long-run equilibrium relationship or cointegration using the Unrestricted Error Correction Model (UECM) developed by Pesaran et al. (2001). The constructed model is as follows:

$$\begin{aligned}\Delta \ln GDP_t = \alpha_0 &+ \sum_{i=1}^{n} \alpha_{1i} \Delta \ln GDP_{t-i} + \sum_{i=1}^{n} \alpha_{2i} \Delta \ln Fossil_{t-i} + \sum_{i=1}^{n} \alpha_{3i} \Delta \ln Renew_{t-i} + \sum_{i=1}^{n} \alpha_{4i} \Delta \ln Labor_{t-i} + \sum_{i=1}^{n} \alpha_{5i} \Delta \ln Carbon_{t-i} \\ &+ \sum_{i=1}^{n} \alpha_{6i} \Delta FDI_{t-i} + \alpha_7 \ln GDP_{t-1} + \alpha_8 \ln Fossil_{t-1} + \alpha_9 \ln Renew_{t-1} + \alpha_{10} \ln Emp_{t-1} + \alpha_{11} \ln Carbon_{t-1} \\ &+ \mu_{1t} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots (3)\end{aligned}$$

Δ represents the first-order difference operator, μ represents white noise or error, lnGDP signifies the natural logarithm of GDP, as do lnFossil (fossil energy consumption), lnRenew (renewable energy consumption), lnCarbon (CO2e emissions), FDI (foreign direct investment growth), and lnLabor (total labor). Parameters α (α1,2,3,4,5,6) denote short-run coefficients. Parameters α (α6,7,8,9,10,11) represent the long-run coefficients based on the ARDL model. To determine the cointegration relationship among variables, the researcher conducts significance testing simultaneously across various lag levels of the research variables using the F-test. The null hypothesis in this test assumes no cointegration among the variables if α6 = α7 = α8 = α9 = α10 = α11 = 0. Conversely, the alternative hypothesis suggests the presence of cointegration among the observed variables, with the criteria α6 ≠ α7 ≠ α8 ≠ α9 ≠ α10 ≠ α11 ≠ 0. Researchers also assess the upper and lower critical bounds in the cointegration test. If the F-statistic value is above the upper critical bound, then H0 is rejected. If the F-statistic is smaller than the lower critical bound, then H0 is accepted. However, if the F-value lies between the upper and lower critical bounds, the results are inconclusive or deemed inconclusive.

Next, the Granger causality test, introduced by Granger (1969), is employed to determine the cause-effect relationship between the dependent and predictor variables, both in one direction or bidirectional, and vice versa. Several diagnostic methods are utilized to evaluate model fitness in the ARDL test, such as LM correlation tests for serial correlation, Q-tests in correlograms, square correlogram Q-tests for autocorrelation, Jarque-Bera tests for normality, and heteroskedasticity tests for residuals. Additionally, coefficient stability tests like CUSUM tests, Square CUSUM tests, and RAMSAY RESET tests are used to measure overall modeling effectiveness.

RESULTS

Time series data that are stationary allow for stronger or more robust estimation results. Therefore, the initial step in empirical estimation involves testing the stationarity of the time series data. The results of the stationarity tests (ADF and PP), examining unit roots, can be seen in Table 1. Based on the hypotheses of the ADF and PP tests, a series is considered stationary if the testing results reject the null hypothesis (indicating no unit root).

Table 1. Augmented Dickey-Fuller Test and Philips-Perron Unit Root Test

	Variabel	ADF test	PP test
Level			
• **Intersep**	In*GDP*	-0.884230(0)	-0.884230
	In*Carbon*	-2.883640(0)[c]	-9.414468
	FDI	-5.202681(0)[a]	-5.167845[a]
	In*Labor*	-0.525510(0)	-0.523315
	In*Fossil*	-3.076003(0)[b]	-5.953719
	In*Renew*	-0.751498(0)	-0.570002
• **Intersep dan trend**	In*GDP*	-2.485765(1)	-2.001723
	In*Carbon*	-0.990226(0)	0.699167
	FDI	-4.628280(0)[a]	-5.087676[a]
	In*Labor*	-2.081327(0)	-2.289342
	In*Fossil*	-0.503247(0)	1.289896
	In*Renew*	-3.272682(0)[c]	-3.225134[c]
First difference			
• **Intersep**	In*GDP*	-3.925292(0)[a]	-3.899183[a]
	In*Carbon*	-4.378195(0)[a]	-4.361650[a]
	FDI	-5.308788(3)[a]	-16.93077[a]
	In*Labor*	-5.929539(0)[a]	-5.924792[a]
	In*Fossil*	-3.664969(0)[a]	-3.655673[a]
	In*Renew*	-5.676069(1)[a]	-8.144161[a]
• **Intersep dan trend**	In*GDP*	-3.899552(0)[b]	-3.876270[b]
	In*Carbon*	-5.531841(0)[a]	-9.461635[a]
	FDI	-5.226094(3)[a]	-16.81892[a]
	In*Labor*	-5.833062(0)[a]	-5.831980[a]
	In*Fossil*	-4.911554(0)[a]	-5.960460[a]
	In*Renew*	-5.589960(1)[a]	-8.019779[a]

The exponent notations a, b, and c represent the significance levels in the conducted tests, with significance levels of 1%, 5%, and 10% in order. The numbers in parentheses indicate the lag of the estimated variables. The t-statistic values in the table are presented as decimal numbers, serving as evidence for the alternative hypothesis. The test results in Table 1 indicate that some variables (lnCarbon, FDI, and lnFossil) are stationary or do not contain a unit root at the basic order or level ($I(0)$), while lnRenew is stationary at the intercept and trend. The first-order difference ($I(1)$) shows that all variables (lnCarbon, lnGDP, FDI, lnRenew, lnLabor, and lnFossil) are stationary at the intercept and either intercept or intercept and trend. The rejection of the null hypothesis was confirmed at a significance level of 5% or even at a stricter significance level of 1%. Both the ADF and PP approaches yield relatively similar testing outcomes, indicating no presence of a unit root for each series. Table 2 presents the results of unit root tests using the ZA approach, which accounts for the presence of structural breaks. The tests were conducted by comparing the absolute t-statistic values with the absolute critical values derived from the computations formulated by Zivot & Andrews (1992).

Table 2. Zivot-Andrews (ZA) Unit Root Test

	Variable	t-stat	*Breaks*
Level			
Intersep	In*GDP*	-6.764730(1)[a]	1998
(model A)	In*Carbon*	-2.844099(0)	2014
	FDI	-3.959435(0)	2005
	In*Labor*	-3.594859(0)	2001
	In*Fossil*	-2.155199(0)	2014
	In*Renew*	-4.216605(4)	2006
Intersep dan trend	In*GDP*	-10.77048(1)[a]	1998
(model C)	In*Carbon*	-2.856066(0)	2014
	FDI	-3.884021(0)	2005
	In*Labor*	-3.302350(0)	2002
	In*Fossil*	-2.303146(0)	2014
	In*Renew*	-4.772067(4)	2011
First difference			
Intersep	In*GDP*	-4.591609(0)[c]	1997

(model A)	ln*Carbon*	-7.194871(4)[a]	2010
	FDI	-6.559366(0)[a]	2001
	ln*Labor*	-7.921411(0)[a]	2008
	ln*Fossil*	-6.565941(4)[a]	2010
	ln*Renew*	-4.974395(5)[b]	2002
Intersep dan trend	ln*GDP*	-4.720387(0)	2000
(model C)	ln*Carbon*	-7.937886(4)[a]	2010
	FDI	-6.781232(0)[a]	2001
	ln*Labor*	-7.815023(0)[a]	2008
	ln*Fossil*	-7.272558(4)[a]	2010
	ln*Renew*	-4.479352(4)	2008
Critical value	10%	5%	1%
Model A	-4.58	-4.80	-5.34
Model C	-4.82	-5.08	-5.57

At the first order ($I(0)$), nearly all variables in the model were found to be non-stationary in both Model A (intercept) and Model C (intercept and trend), except for the lnGDP at the 1% significance level, with breaks occurring in 1998. However, in the first difference ($I(1)$), all variables showed stationary behavior in Model A at a 10% significance level for the lnGDP variable, 5% for lnRenew, and even more rigorously (lnCarbon, lnLabor, lnFossil, and FDI) at the 1% significance level. In Model C (intercept and trend), the lnGDP and lnRenew variables were found to have unit roots, causing non-stationarity even at the 10% significance level. Based on the stationarity tests using three approaches (ADF, PP, and ZA), it can be concluded that the research variables (lnGDP, lnCarbon, lnlabor, lnRenew, FDI, and lnFossil) do not contain unit roots or are stationary, both at $I(0)$ and $I(1)$ levels, at a significance level of 10% and even more strictly at the 1% significance level. Therefore, the use of the ARDL bound test method is feasible for the next stage of analysis.

The results of the cointegration test using the ARDL bound test method and critical values (based on 35 observations as proposed by Narayan (2005) are presented in Table 3. The bound test results indicate the presence of long-run equilibrium or cointegration in the lnGDP equation (lnGDP|lnCarbon, lnlabor, FDI, lnFossil, lnRenew). This is evidenced by the F-statistic being higher than the critical value at a 5% significance level. Furthermore, when the lnCarbon, lnLabor, lnFossil, FDI and lnRenew variables acted as dependent variables, only in Labor and FDI equation contain the cointegration, while Fossil, Carbon, and Renewable equations don't have the cointegration with the F-statistic falling below the critical value at a 5% or 10% level.

Table 3. Cointegration: Boundtest

Dependent Variable		Function		F-Statistik	
ln*GDP*		F_{lnGDP}(ln*GDP*|ln*Carbon*, *FDI,* ln*Labor*, ln*Fossil,* ln*Renew*)		5.230688[b]	
ln*Carbon*		$F_{lnCarbon}$(ln*Carbon*|ln*GDP, FDI,* ln*Labor*, ln*Fossil*, ln*Renew*)		2.012043	
ln*Labor*		$F_{lnLabor}$(ln*Labor*|ln*GDP, FDI,* ln*Carbon*, ln*Fossil*, ln*Renew*)		4.833553[b]	
ln*Fossil*		$F_{lnFossil}$(ln*Fossil*|ln*GDP, FDI,* ln*Carbon*, ln*Labor*, ln*Renew*)		1.627347	
ln*Renew*		$F_{lnRenew}$(ln*Renew*|ln*GDP, FDI,* ln*Carbon*, ln*Labor*, ln*Fossil*)		2.635990	
FDI		F_{FDI}(*FDI*|ln*GDP,* ln*Carbon*, ln*Labor*, ln*Fossil*, ln*Renew*)		4.454573[b]	
Critical value					
10%		5%		1%	
$I(0)$	$I(1)$	$I(0)$	$I(1)$	$I(0)$	$I(1)$
2.752	3.994	3.354	4.774	4.768	6.67

Based on the long-run parameter estimation results for the GDP equation (FlnGDP(lnGDP|lnCarbon, lnLabor, lnFDI, lnFossil, lnRenew)), it is statistically evident that renewable energy consumption (lnRenew), labor (lnLabor), and investment (FDI) significantly influence economic growth (lnGDP). Carbon emission, energy fossil consumption doesn't affect the GDP statically in long-run. Moreover, the number of labor forces (lnLabor) also statistically influences long-run economic growth (lnGDP). A 1% change in the labor force (lnLabor) leads to a positive 1.7% change in lnGDP. Additionally, lnGDP statistically impacts changes in lnLabor, indicating a two-way cointegrating relationship between lnGDP and lnLabor, similar to the relationship between FDI and GDP.

Table 4. Long-Run Estimation

Long run coefficient estimation				
Dependent Variables: ln*GDP* (2,0,1,1,1,2)			Diagnoses test	
Regressor	Coefficient [standard error]	t-statistic [*p* value]		f-statistic [*p*]
• **ln*Carbon***	-0.660939[0.306161]	-2.158794[0.1197]	*Serial correlation*	0.110774 [0.8962]
• **ln*Labor***	1.655295 [0.067475]	24.53205 [0.0001]	Normality test	10.00522 [0.2182]
• **ln*Fossil***	0.566936[0.329227]	1.722022[0.1835]	Heteroskedasticity	2.597997 [0.4764]
• **ln*Renew***	0.341783[0.020172]	16.94337[0.0004]		
• ***FDI***	0.035626[0.003316]	10.74248[0.0017]		
Dependent Variables: ln*Carbon* (1,1,0,1,2,2)			Diagnoses test	
Regressor	Coefficient [standard error]	t-statistic [*p* value]		f-statistic [*p*]

• ln*GDP*	-0.273729 [0.194991]	-1.403805 [0.1757]	*Serial correlation*	1.595741 [0.2220]
• ln*Labor*	0.716125 [0.463032]	1.546599 [0.1376]	Normality test	2.337559 [0.7305]
• ln*Fossil*	1.035504 [0.049444]	20.94279 [0.0000]	Heteroskedasticity	2.011520 [0.0806]
• ln*Renew*	0.052616 [0.043683]	1.204510 [0.2425]		
• *FDI*	0.015522 [0.009497]	1.634393 [0.1178]		
Variabel dependen: ln*Labor* (2,3,2,3,3,2)			Diagnoses test	
Regressor	Coefficient [standard error]	t-statistic [*p* value]		f-statistic [*p*]
• ln*GDP*	0.614908 [0.086096]	7.142140 [0.0000]	*Serial correlation*	0.631663 [0.4452]
• ln*Carbon*	2.107351 [0.866656]	2.431589 [0.0333]	Normality test	0.510830 [0.7746]
• ln*Fossil*	-2.209974 [0.942482]	-2.344845 [0.0388]	Heteroskedasticity	2.166490 [0.0942]
• ln*Renew*	-0.247589 [0.078400]	-3.158041 [0.0091]		
• *FDI*	-0.021518 [0.006053]	-3.555079 [0.0045]		
Dependent Variables: ln*Renew* (4,4,4,4,4,4)			Diagnoses test	
Regressor	Coefficient [standard error]	t-statistic [*p* value]		f-statistic [*p*]
• ln*GDP*	2.908644 [0.240695]	12.08436 [0.0068]	*Serial correlation*	5.142362 [0.2644]
• ln*Carbon*	2.182435 [1.314125]	1.660751 [0.2386]	Normality test	1.575392 [0.4549]
• ln*Fossil*	-1.953100 [1.410446]	-1.384739 [0.3004]	Heteroskedasticity	27.86567 [0.1489]
• ln*Labor*	-4.870468 [0.546012]	-8.920072 [0.0123]		
• ln*FDI*	-0.098603 [0.019921]	-4.949750 [0.0385]		
Dependent Variables: *FDI* (2,2,0,0,1,1)			Diagnoses test	
Regressor	Coefficient [standard error]	t-statistic [*p* value]		f-statistic [*p*]
• ln*GDP*	15.03707 [2.570491]	5.849882 [0.0000]	*Serial correlation*	0.027655 [0.8285]
• ln*Carbon*	9.312176 [10.61950]	0.876894 [0.3905]	Normality test	0.376169 [0.7942]
• ln*Fossil*	-8.295438 [11.27300]	-0.735868 [0.4700]	Heteroskedasticity	0.978540 [0.4941]
• ln*Labor*	-27.78006 [8.245615]	-3.369071 [0.0029]		
• ln*Renew*	-3.224607 [1.484874]	-2.171636 [0.0415]		
Dependent Variables: ln*Fossil* (4,4,4,4,4,4)			Diagnoses test	
Regressor	Coefficient [standard error]	t-statistic [*p* value]		f-statistic [*p*]
• ***lnGDP***	1.446795 [0.949101]	1.524385 [0.2669]	*Serial correlation*	4.436997 [0.2822]
• ***lnCarbon***	1.118951 [0.135242]	8.273719 [0.0143]	Normality test	1.584185 [0.4529]
• *FDI*	-0.049582 [0.034542]	-1.435400 [0.2877]	Heteroskedasticity	0.426058 [0.8636]
• ***lnLabor***	-2.430817 [1.461487]	-1.663249 [0.2382]		
• ***lnRenew***	-0.496731 [0.342742]	-1.449288 [0.2843]		

In Table 4, renewable energy consumption (lnRenew) demonstrates a positive impact on lnGDP in the long-run. A 1% increase in renewable energy consumption in the long-run equilibrium leads to a 0.34% increase in lnGDP. The increase may not be substantial, but it can serve as a basis for Indonesia to further enhance the use and innovation in clean energy. As a result, the carbon emissions generated are expected to decrease in aggregate, aligning with the planned targets. However, these steps are not easy and require careful consideration of existing regulations to ensure that the industrial sector, which is at the forefront of economic growth, remains undisturbed. Energy conservation policies bring beneficial effects to Indonesia's economic condition. Furthermore, reducing the use of fossil energy resources positively impacts the environmental condition in Indonesia since fossil energy consumption leads to increased carbon emissions in the long-run, as reflected in the estimated parameters of the FlnCarbon equation (lnCarbon|lnLabor, FDI, lnGDP, lnFossil, lnRenew) in line with Rauf et al. (2018) and Cherni & Essaber Jouini (2017). Concerning short-run relationships, all independent variables in the lnGDP equation significantly impact economic growth (lnGDP) but lnRenew and lnLabor.These short-run relationships are depicted in Table 5 and Table 6 using the error correction mechanism (ECM).

Based on the obtained short-run coefficient values, Indonesia's economic growth still relies on fossil energy consumption. To increase economic growth (lnGDP) by 1%, there needs to be a 1% increase in non-renewable energy consumption. Hence, aggressive fossil energy conservation would have a negative impact on Indonesia's economic growth.

Table 5. Short-Run Estimation

Dependent variables: ln*GDP* (2,0,1,1,1,2)		
Regressor	Coefficient [standard error]	t-statistic [*p*]
ΔIn*GDP*(-1)	0.526329 [0.105336]	4.996649 [0.0001]
ΔIn*Carbon*	-0.488184 [0.247286]	-1.974166 [0.0623]
ΔIn*Carbon* (-1)	-0.213166 [0.082491]	-2.584119 [0.0177]
ΔIn*Labor*	-0.261150 [0.274720]	-0.950606 [0.3532]
ΔIn*Fossil*	0.937583 [0.281781]	3.327345 [0.0034]
ΔIn*Renew*	-0.017959 [0.025493]	-0.704465 [0.4893]
ect(-1)*	-0.311827 [0.054188]	-5.754513 [0.0000]

The potential for abundant clean or renewable energy sources has not been fully utilized due to limitations in energy conversion technology, resulting in relatively limited supply of renewable energy. Furthermore, these limitations ultimately lead to higher selling prices for renewable energy compared to conventional (fossil) energy sources. The limited availability of renewable energy due to technological constraints has not yet had a positive impact on economic growth, in the short. Thus, instead of relying on renewable energy as a production input, it has remained an alternative choice to existing fossil energy sources, especially in the transportation and household electricity generation sectors.

Carbon emissions (lnCarbon) show a significant negative coefficient impact on lnGDP in the short-run, in line with findings by Ahmad & Zhao (2018) and Putriani et al. (2018). Although the changes in lnGDP caused by carbon emissions are relatively small, they still need to be considered. Tax policies on emissions generated by economic actors could create shocks for them in the short-run, considering Indonesia's declining tax revenue trend in recent years. On the other hand, carbon emissions remain a major cause of extreme weather events, thereby increasing the frequency of natural disasters. Ultimately, natural disasters lead to economic paralysis in a region or country during that period and add to the cost burden of recovery. Furthermore, the coefficient on ect(-1) in Table 6 indicates the percentage of short-run imbalances that will be corrected in subsequent periods towards long-run equilibrium or convergence. In this case, a 31% imbalance in the lnGDP equation will be corrected in subsequent periods.

The cointegration relationship among variables of fossil energy consumption (lnFossil), renewable energy consumption (lnRenew), labor force (lnLabor), carbon emissions (lnCarbon), and economic growth (lnGDP) indicates the presence of Granger causality. The error correction mechanism can demonstrate the direction of this causality. Table 6 provides information on the Granger causality results in the short run and long run.

Table 6. Granger Causality Test

Dependent variables	F-statistic [*p*]						t-statistic [*p*]
	ΣΔln*GDP*$_t$	ΣΔln*Carbon*$_t$	ΣΔln*Labor*$_t$	ΣΔln*Fossil*$_t$	ΣΔln*Renew*$_t$	ΣΔln*FDI*$_t$	ECT$_t$
Δln*GDP*$_t$	-	-1.9742 [0.0623]	-0.9506 [0.3532]	3.3273 [0.0034]	-0.7045 [0.4893]	1.9825 [0.0613]	-5.7545 [0.0000]
Δln*Carbon*$_t$	-2.6151 [0.0166]	-	0.2717 [0.7886]	24.7391 [0.0000]	1.0779 [0.2939]	-0.2270 [0.8227]	-4.2790 [0.0004]
Δln*Labor*$_t$	-0.3021 [0.7682]	1.3939 [0.1909]	-	-0.4248 [0.6791]	-4.5640 [0.0008]	1.3222 [0.2129]	-9.3338 [0.0000]
Δln*Fossil*$_t$	11.3820 [0.0015]	15.6377 [0.0006]	-0.6153 [0.5819]	-	3.3435 [0.0443]	-0.8140 [0.4753]	9.9911 [0.0021]
Δln*Renew*$_t$	-4.9720 [0.0382]	-0.6496 [0.5826]	-17.795 [0.0031]	-0.3121 [0.7845]	-	13.9881 [0.0051]	-22.9166 [0.0019]
Δln*FDI*$_t$	4.3668 [0.0003]	2.3976 [0.0259]	-0.7459 [0.4640]	-0.6951 [0.4946]	-0.3056 [0.7629]	-	-6.3318 [0.0000]

In the long run, at the 1% significance level found in the ECT, indicates a bidirectional relationship between carbon emissions, labor force, renewable energy consumption, FDI, fossil consumption and economic growth, aligning with studies by Nguyen & Ngoc (2020), Sbia et al. (2017), and Zhao & Wang (2015). However, the relationship between fossil energy consumption and economic growth is unidirectional, running from non-renewable energy consumption to economic growth. This further strengthens the notion that long-run economic growth remains dependent on fossil energy. Moving to the short run, a two-way (feedback) relationship exists between, economic growth and all variables' independents, except labor force and renewable energy. Meanwhile, renewable energy consumption variables exhibit a one-way causal relationship towards economic growth. Both short- and long-run relationships align with findings from (Zhong et al.2019). Moreover, we find consumption of renewable energy can increase employment numbers and vice versa or mutually influencing each other. On the other hand, renewable energy consumption can be increased through the investment.

Subsequently, diagnostic testing was conducted concerning assumptions such as serial correlation, heteroskedasticity, and normality to verify the validity of the estimation results. The results of these diagnostic tests are reported in Table 4. Overall, the tests conducted on the equation do not reject the null hypothesis, indicating no issues with serial correlation, heteroskedasticity, or normally distributed residuals.

Estimation results of regression parameters sometimes change over time, which is a common issue in regression equations. Failure to detect this could potentially lead to biased regression estimation results Narayan & Smyth

(2005). Below are the reported results of the Cumulative Sum (CUSUM) and CUSUM of squares recommended by Brown et al. (1975) for the lnGDP equation.

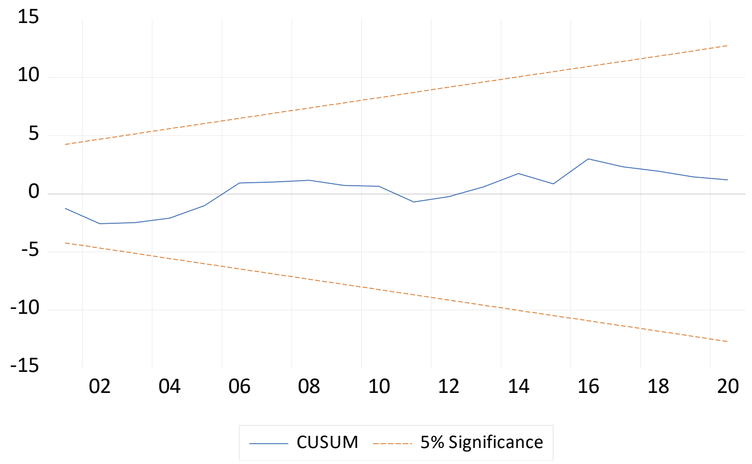

Figure 1. CUSUM stability test

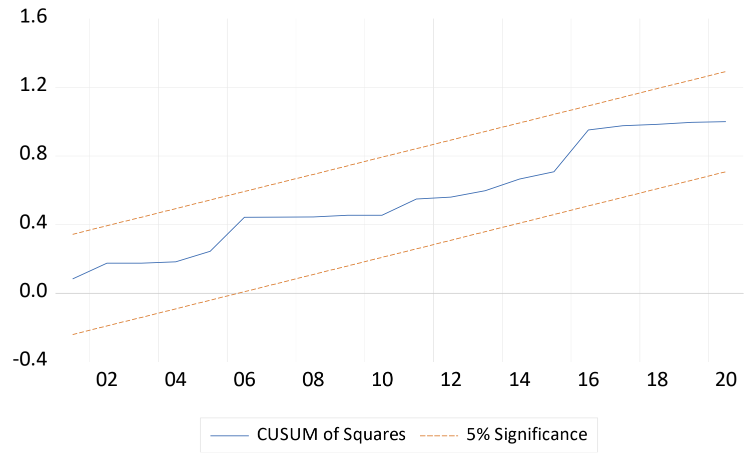

Figure 2. CUSUM of Squares stability test

Figure 1 and Figure 2 depict statistics within the 5% significance level (dotted lines), indicating stable parameter estimation results throughout the study period. Therefore, policy decisions can be drawn based on the model (Zhong et al., 2019).

DISCUSSION

Energy plays an immensely crucial role in an economy (Aisyah & Hardiyati, 2019). Without energy, no matter how advanced the technology, it cannot function. In the industrial sector, for instance, energy sources are imperative to power production tools as an outcome of technological engineering. Likewise, in other sectors such as transportation, households, and commercial areas, all require energy. In the last two years, the industrial sector no longer remains the largest consumer of energy. The transportation sector has emerged as the largest consumer of energy on a global scale. In 2018, global energy consumption in the transportation sector reached 2.89 million ktoe (kilos ton of oil equivalent), which is 1.82 percent larger than the industrial sector.

The same phenomenon has occurred in Indonesia over the past decade, with a difference in energy usage between the transportation and industrial sectors amounting to 25.5 million boe, meaning that the transportation sector in Indonesia is 6.56 percent larger than its industrial sector. Energy consumption growth in the transportation sector has surged by 49.54 percent since 2009, with an average annual growth rate of 7.28 percent. In 2019, the transportation sector experienced a 3.83 percent increase compared to the previous year. Comparatively, the industrial sector has seen a smaller average growth in energy consumption, reaching 3.27 percent, and has only grown by 27.78 percent from 2009 to 2019.

The rapid growth in energy consumption within the transportation sector is attributed to the increasingly rapid mobility of the population. Based on migration data released by the Central Statistics Agency (BPS), in 2018, the total population migrating to Java Island, which is a significant migration destination, reached 982.96 thousand people, marking a 5.57 percent increase from 2017. Additionally, there were approximately 8.5 million commuter workers, of which 83.7 percent used private vehicles. Moreover, circular workers—individuals crossing administrative boundaries regularly and returning to their original residences within weekly or monthly intervals—amounted to 2.7 million people. These phenomena are just a few examples of human movements recorded by the state. Not to mention the daily movements undertaken by individuals, which are unrecorded, such as commuting by private or public transportation from home to marketplaces. In 2019, there were at least 133 million ground transportation units circulating in Indonesia, with a consistent growth rate averaging 6.13 percent.

With such a significant contribution of fossil energy, a moderate energy transition policy, as implemented by some European countries, might not be appropriate. Such a policy could have negative impacts on the national economic growth due to many sectors reliant on fossil energy (Anas, 2019). Industries like oil and gas, fossil fuel-based power companies, and related infrastructures would be significantly affected by a swift transition to renewable energy sources.

A moderate transition policy towards renewable energy certainly requires suitable infrastructure. New power plants, transmission networks, and other supportive infrastructures need to be built and adapted to accommodate renewable energy. Considering these needs, Indonesia may not be deemed ready at present, especially if pushed forcefully as it would significantly burden the national budget. Unless it's through substantial and time-consuming investments. This could be achieved in the current neoliberal economic era where private sectors fund infrastructure. However, not all investors are willing to participate in such investments given the complexity and uncertainties associated with infrastructure investments, which involve interconnected stakeholders (Benítez-Ávila et al., 2018). In addressing such uncertainties, the government should indeed offer a Public-Private Partnerships (PPP) investment model instead of offering the Regulatory Asset Base (RAB) model. This would attract numerous investors eager to obtain infrastructure projects, yet it could also result in the country losing its ability to safeguard the interests of its citizens. This stems from private investors having full authority to determine the expected returns from their investments (T. Liu et al., 2017).

With such a scenario, it's probable that energy prices will increase due to the high investment costs resulting from the elevated transaction costs in procuring this new infrastructure. This situation poses a dilemma for the government. Its alignment will be tested: whether they stand with the people or align with corporations for the sake of growth and accelerating the energy transition to meet the set targets in the upcoming years. On the positive side, domestic innovation may flourish due to increased competition among companies. Consequently, the prices of renewable energy could become more competitive. However, striking a balance between technological advancement and renewable energy prices that align with people's incomes remains unpredictable. Moreover, facing immature regulations concerning investments in renewable energy could complicate matters further. Until achieving this equilibrium, energy transition policies will have widespread impacts on society. Steeply rising energy prices could exert significant social pressure and potentially lead to social conflicts, demonstrations, political instability, and even disruptions in international relations.

Transitions like this can affect employment in the energy sector. While new jobs are created in the renewable energy sector, there can also be a reduction in jobs in the fossil fuel sector, affecting thousands of workers employed there. Many industries heavily rely on fossil fuel-based energy. A sudden transition might lead to the collapse of these sectors and result in significant job losses. This loss might not be adequately balanced by the creation of jobs in the renewable energy sector.

Therefore, Indonesia doesn't need to rush into transitioning from fossil fuels to renewable energy. The primary objective of a policy shouldn't just be to gain affirmation from other nations about the success of its transition or to boost economic growth but rather how its people can become more prosperous. This policy could start with regulating rules that encourage investments in domestic renewable energy technology, not just controlling the energy sources. Consequently, the impact wouldn't only make technology more affordable but also expand job opportunities. Ultimately, these more affordable prices will naturally encourage people to switch, even without the use of electric vehicle subsidy policies.

This subsidy policy is considered not appropriate as it burdens the budget without significantly affecting the energy transition. Moreover, it's deemed unattractive, thus its effectiveness is uncertain. Considerations regarding spare part pricing before transitioning from conventional to electric vehicles are one of the reasons this policy hasn't reached its targets. The pricing of major spare parts, like electric vehicle batteries, is considered far beyond what consumers can manage. For instance, the cost of a complete battery component of an electric vehicle (in this case, a car) could reach 80-90 percent of the price of a new vehicle, and this component will inevitably experience a relatively quick decline in quality within 2-3 years.
Therefore, the solution that can be offered is to formulate regulations that can increase investment in environmental aspects, especially those related to renewable energy. The formulation of policies should not hinder investors from innovating in technologies that utilize renewable energy sources, perhaps by providing incentives or tax exemptions. With such policies, it is hoped that the cost of technology will become more affordable due to reduced expenses. Additionally, collaboration with the private sector in developing power plants that harness renewable energy can be pursued.

CONCLUSION

This study aims to understand the impact of energy transition on economic growth by analyzing the relationship between fossil energy consumption, renewable energy consumption, emissions, and economic growth. Using data from 1986 to 2020 and employing the ARDL bound test. The study found a simultaneous cointegration among fossil energy consumption, renewable energy consumption, carbon emissions, labor, FDI and economic growth. Here are the partial short-run and long-run effects discovered: In the short run, fossil energy consumption positively and significantly affects economic growth at a significance level of 1%. However, in the long-run, fossil energy consumption doesn’t have impacts on economic growth. Renewable energy consumption negatively affects economic growth in the short-run but positively affect in the long-run. Findings indicate that a moderate energy transition policy is hazardous for Indonesia's economic growth. Statistically, labor does not influence economic growth in the short-run and long-run. Renewable energy consumption, statistically, does not support economic growth in the short-run, but in long-run it does. The relationship in the long-run estimation of fossil energy consumption and economy growth indicates a positive signal for economic growth and environmental quality in Indonesia through long-run fossil energy conservation. However, conversely, short-run energy conservation policies tend to endanger economic growth. The adverse impact of fossil fuel energy consumption on long-run economic growth warrants attention. The depleting availability of non-renewable energy resources can no longer drive production factors. Consequently, economic growth may reach a peak and then decline. Hence, policymakers should maximize existing non-renewable energy sources. A policy requiring state-owned enterprises (SOEs) to control more fossil fuel energy sources and discover untapped reserves is worthy of continuation and even strengthening. If not, another path for the Indonesian Government is to increase the role of renewable energy in its economy. By refining Renewable Energy Policy, particularly in resource production, it could bolster the number of renewable energy producers. Consequently, renewable energy might positively influence long-run economic growth. Emission tax policies could serve as an additional solution to reduce greenhouse gas emissions. However, implementing these policies requires careful consideration, primarily to avoid potential short-run negative impacts on economic growth. Therefore, effective emission policies can effectively reduce carbon dioxide concentration and augment national income. This study is not devoid of limitations in both methodological approaches and assumptions in interpreting the study's outcomes. In determining the correction period for imbalances during cointegration testing, the ARDL bound test method lacks a precise mathematical formula. Researchers formulate their formulas, lacking logical reasons behind their choices. Hence, this study could only identify corrected imbalances in subsequent periods but couldn’t determine the time required to reach equilibrium. The method also doesn't account for the extent of its long-run estimates. Thus, creative formulations are essential for more accurate estimations. This study utilized the Cobb-Douglas equation, limiting the research to variables within that equation. Therefore, using more complex mechanisms and equations is a solution to attain more comprehensive results. Considering variables beyond the Cobb-Douglas equation or combining them with other models like the Impact, Population, Affluence, Technology (IPAT) model would yield more varied outcomes.

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