The Nexus Between Energy Consumption, Growth and Emission in Indonesia: An ARDL Approach

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Abstract. This study aims to determine the causal relationship between economic growth, primary energy consumption, trade openness, foreign investment, CO2 emissions in Indonesia from 1990 to 2020. The data used are secondary data in the form of time series data. This study uses ARDL (Autoregressive Distributed Lag) approach which is used to determine the existence of cointegration and short-term and long-term causality of each variable. The results showed that the overall long-run coefficient of the variables had no effect on CO2 emissions. In the short run, economic growth, primary energy consumption, foreign direct investment have a positive and significant impact on CO2 emissions. However, the trade openness in the short run has a negative relationship and significant impact on CO2 emissions.

Keywords: CO2 emissions; ARDL; foreign direct investment, growth

1 Introduction

Economic growth is the process of changing the economic condition of a country on an ongoing basis towards a better condition for a certain period of time. An economy experiences a change if the level of economic activity is higher than that achieved in the past. An indicator to determine economic conditions in a country in a certain period is shown by Gross Domestic Product (GDP) data, which will illustrate the country's ability to manage and utilize available resources (Central Bureau of Statistics, 2022). Economic growth has a positive trend toward economic activity. However, in 2020, economic growth in Indonesia experienced a contraction due to the COVID-19 pandemic, which decreased by -2.07 percent. In 2021, the Indonesian economy will have improved significantly by growing by 3.69 percent, higher than its achievements in 2020. This shows the existence of community mobility, infrastructure development, and economic activities that are undergoing a process of normalization. Economic recovery will increase consumption of primary energy, which plays a role in contributing to economic activity and people's welfare. According to the Agency for the Assessment and Application of Technology (2021), the total final energy consumption in 2019 was 989.9 million BOE. Final energy consumption per type is dominated by fuel oil. In 2020, energy consumption decreased by 861 million BOE due to economic activity slowing down and restrictions due to the COVID-19 pandemic.

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During the recovery period, CO_2 emissions have increased very significantly with increased economic activity. Economic activities generally use petroleum as a source of energy in industrial activities, transportation, and economic activities related to increasing economic growth [3]. According to the hypothesis of the Environmental Kuznets Curve (EKC), there is a relationship between various indicators of environmental degradation and income per capita. At the beginning of economic growth, CO_2 emissions increase, but the quality of the environment decreases [22]. The increase in clean energy technology led to a decrease in CO_2 emissions, while the use of fossil fuels, biomass, labor productivity, transportation, and industrial improvements led to an increase in CO_2 emissions. In addition, the factors that influence CO_2 emissions have a long-term relationship [14]. It is hoped that the government will make efforts to efficiently manage renewable energy and provide other environmentally friendly energy such as clean energy, hydropower, solar, wind, wave, geothermal, and others according to the region of the country. It is hoped that with the management of renewable energy sources, it can reduce CO_2 emissions and maintain the environmental index.

2 Literature Review And Hypothesis Development

Literature on the impact of CO_2 emissions, which are influenced by various factors such as economic growth, primary energy consumption, trade openness, and foreign investment, has been examined by previous researchers regarding the relationship between economic growth and CO_2 emissions. According to [21] research (2012), which aims to determine the causal and long-term relationship between economic growth and carbon dioxide (CO_2) emissions in Malaysia, the results show that there is a long-term relationship between per capita CO_2 emissions and per capita real Gross Domestic Product (GDP). Then, there is an inverted U-shaped relationship between CO_2 emissions and GDP in the short and long term, which supports the Environmental Kuznet Curve hypothesis. And the Granger Causality test based on the VECM model shows no causality between CO_2 emissions and economic growth in the short term but shows causality in the long term.

According to [23] (2016), that cannot prove proof of EKC prediction validation. The CO_2 emission variable has increased with per capita income. Renewable energy has an effect on CO_2 emissions, and coupled with an increase in long-term effects, this energy is an efficient substitute for conventional fossil fuels. Nonetheless, the impact of renewable energy is greater than that of primary energy consumption in both the short and long term, requiring more global synergies to address environmental challenges. [10] show that for Gross Domestic Product (GDP), CO_2 emissions and renewable energy are stable in the long run. However, the Granger causality test shows a bidirectional relationship between GDP and CO_2 emissions and between renewable energy and GDP, but no relationship between CO_2 emissions and renewables.

[2] and Du (2017) show that there is a long-term relationship between variables. CO_2 emissions have a positive relationship with economic growth. Energy production has a positive effect on economic growth, then domestic investment has a bigger contribution than foreign investment. Then, [8] shows that there is no cointegration between the variables of real per capita GDP, net energy consumption, and CO_2 emissions in Canada, France, Italy, the US, and the UK. The causal relationship occurs between net energy consumption and real GDP per capita in Canada, Germany, and the United States. CO_2 emissions affect net energy consumption in Germany.

[1] explain that there is cointegration in the short and long term by showing a U-relationship between industrial growth and CO_2 emissions. Then, there is short-term causality between fossil fuel consumption and CO_2 emissions. According to [16] and others (2019), there is a bilateral

causal relationship between fossil fuel energy consumption and economic growth, as well as energy consumption and CO_2 emissions in the short and long term.

Then, according to [15], symmetrical results show economic growth, and FDI has an effect on carbon emissions both in the long and short term, while oil prices increase emissions in the long term. While the asymmetric results in the long run show that an increase in oil prices reduces emissions, an increase in oil prices increases carbon emissions. And [4] state that population density, industrialization, and trade increase CO_2 emissions while GDP per capita worsens CO_2 emissions in the long term. There is a two-way causal relationship between CO_2 emissions and industrialization, and there is a unidirectional relationship between population density and the structure of trade openness.

3 Research Methods

The analytical model used in this study is the Autoregressive Distributed Lag (ARDL) model. In the ARDL test, the method of analysis in time series modeling is determined by testing the stationarity of the data variables. In the stationarity test, if the results show that there are no variables that are stationary, both at the level, first difference, and second difference, then the model used is the ARDL model. In estimating the ARDL model, it is a direct developer (straight forward) of the Ordinary Least Squares (OLS) technique. By using this model, the test results will be able to distinguish short-term and long-term response coefficients or parameters that will be tested in several tests using the ARDL method.

$$\boldsymbol{Yt = \beta_0 + \beta_1 Y_{t-1} + \beta_2 X_{1t} + \beta_3 X_{1\,t-1} + \beta_4 X_{1\,t-2} + \beta_5 X_{2\,t} + \beta_6 X_{2\,t-1} + \beta_7 X_{2\,t-2} + \beta_8 X_{3t} + \beta_9 X_{3\,t-1} + \beta_{10} X_{3\,t-2} + \varepsilon_t} \tag{1}$$

The formula above has the notation Yt and Yt-1, and so on, to see the relationship between the current "y" variable and the previous year. The existence of lag-dependent variables can be called autoregressive. Ensuring the process of adjusting short-term forms to long-term balance. To test for errors, ECT is also implemented in the ARDL model.
The first step in analyzing time series data is the stationarity test. The test introduced by Dickey-Fuller can be applied to the Augmented Dickey Fuller (ADF) model as follows:

$$\boldsymbol{\Delta Y_t = \alpha_0 + p_1 Y_{t-1} + \textstyle\sum_{i=1}^{k} \alpha\, \mathrm{i} \Delta Y_{t-i+1} + u_t} \tag{2}$$

$$\boldsymbol{\Delta Y_t = \alpha_0 + p_1 Y_{t-1} + \alpha_2 T + \textstyle\sum_{i=1}^{k} \alpha\, \mathrm{i} \Delta Y_{t-i+1} + u_t} \tag{3}$$

ut is the error term, and Y_(t-i) = (Y_(t-i)- Y_(t-2)), Y_(t-i) = (Y_(t-i)- Y_(t-2)), and others. "k" is the lag value of Y to control for a higher correlation than the assumption. The purpose of determining the optimum lag in the ARDL model is to find out the combination of lags in the ARDL (p, q)) model so that in this model each variable will have a different lag. The optimum lag is chosen based on the base value of the Akaike Information Criterion (AIC) approach.

Differences in the level of integration between variables can be overcome by applying the bound-test cointegration model. When estimating the long-term coefficients with the F-test is carried out, the bound approach cointegration test is used. Then estimate the short-term coefficients of all the variables used in the model with error correction from ARDL. Through the error correction mechanism (ECM), it is possible to determine the speed of adjustment of the balance direction.

The ARDL model requires an ECM model with the following formula:

$$\emptyset(L)Y_t = \varphi + \theta(L)x_t + u_t \quad (4)$$

where,

$$\emptyset(L) = 1 - \varphi_1 L - \cdots - \varphi_p L^p, \quad (5)$$

$$\theta(L) = \beta_0 - \beta_1 L - \cdots - \beta_q L^q \quad (6)$$

ARDL estimation for ($p, q_1, q_2, \ldots q_k$) as follows;

$$\emptyset(L)Y_t = \varphi + \theta_1(L)x_{1t} + \theta_2(L)x_{2t} + \theta_k(L)x_{kt} + u_t \quad (5)$$

This study tests the hypothesis with an approach to two aspects: firstly, the dynamic relationship between economic growth, primary energy consumption, trade openness, and foreign investment with the following formula:

$$lnEmissionCO2_t = \alpha_0 + \alpha_1 lnGDP_t + \alpha_2 PEC_t + \alpha_3 TO_t + \alpha_4 FDI_t + \varepsilon_{it}$$

$$\Delta lnEmissionCO2_t = \alpha_0 + \sum_{i=1}^{n1} \alpha_1 \Delta lnGDP_{t-1} + \sum_{i=1}^{n1} \alpha_2 \Delta lnPEC_{t-1} + \sum_{i=1}^{n1} \alpha_3 \Delta TO_{t-1} + \sum_{i=1}^{n1} \alpha_4 \Delta FDI_{t-1} + \delta_1 lnGDP_{t-1}\, b + \delta_2 lnPEC_{t-1} + \delta_3 TO_{t-1} + \delta_4 FDI_{t-1} + \mu_t$$

In the parameter _t, i = 1, 2, 3, 4, as the long-term multiplier, while the function parameters _1,_2,_3,_4,_5 are the short-term coefficients of the mode. The cointegration test on the model is to test the value of the F-statistic.

The ARDL approach based on Wald F-Statistics is applied to check long-term cointegration between variables with the initial hypothesis (null hypothesis), which states that there is no cointegration as H0: 1 = 2 = 3 = 4 = 0, and for the alternative hypothesis results, which state that there is cointegration between alternative variables as H1: 1 2 ≠ δ3 ≠ δ4 ≠ 0. If there is cointegration, the next step is to estimate the long-term and short-term adjustment estimates. To test the stability of the environmental index hypothesis, the CUSUM and CUSUMQ tests were used, which were applied to the residual values of the model [2].

4 Results And Discussion

According to the research results, it can be seen that the minimum, maximum, average, and standard deviation scores of each variable were applied in the annual time period from 1990 to 2020. In Table 4, below, is the statistical data generated as a summary histogram for each variable. There are 31 observations. The following is a descriptive statistics table:

Tabel 1. Descriptive statistic

Variabel	*PDB*	*PEC*	*TO*	*FDI*	Emisi CO_2
Mean	4.717	5.269	53.476	1.252	363.635

Maximum	8.220	8.653	96.186	2.916	624.547
Minimum	-13.127	2.202	33.190	-2.757	145.050
Std. Dev	3.838	1.913	11.991	1.374	143.248
Skewness	-3.539	0.049	1.325	-1.300	0.1308
Kurtosis	16.531	1.787	6.506	4.222	1.764
Jarque-Bera	301.209	1.914	24.951	10.664	2.060

source: author calculation

Table 2 shows the Phillpis-Perron Unit Root Test (PP) is the same as the ADF test, where at the level there is only one significant variable, namely the X1 variable, namely the Gross Domestic Product (GDP), which has a probability of 0.026 less than α. And other variables do not show stationary results. And at the 1st difference level, it shows that the results on all variables have stationary results that have a probability smaller than α = 0.05. It can be concluded from the stationary test that variable testing in this study can use the Autoregressive Distributed Lag (ARDL) method.

Tabel 2. Unit Root Test

Unit Root Test *Philips-Perron (Level)*						
Variabel	***Constant & Trend***	***C. Values 1%***	***C. Values 5%***	***C. Values 10%***	**Prob.**	**Ket.**
PDB	-2.234	-2.644	-1.952	-1.610	0.026	Stasioner
KEP	4.260	-2.644	-1.952	-1.610	1.000	Tidak Stasioner
TO	-0.787	-2.644	-1.952	-1.610	0.367	Tidak Stasioner
FDI	1.528	-2.644	-1.954	1.610	0.116	Tidak Stasioner
Emisi CO_2	3.8974	-2.644	-1.952	-1.610	0.999	Tidak Stasioner
	1st Difference					
Variabel	***Constant & Trend***	***C. Values 1%***	***C. Values 5%***	***C. Values 10%***	**Prob.**	**Ket.**
PDB	-10.845	-2.647	-1.963	-1.610	0.000	Stasioner
KEP	-3.044	-2.647	-1.963	-1.610	0.003	Stasioner
TO	-8.409	-2.647	-1.963	-1.610	0.000	Stasioner
FDI	-5.253	-2.647	-1.963	-1.610	0.000	Stasioner
Emisi CO_2	-3.423	-2.651	-1.953	-1.610	0.001	Stasioner

Sources: author calculation

Table 3, there is a cointegration test based on the Bounds Test approach showing an F-Statistic of 8,392, which means that it is greater than the value I (0) both at a significant level of 10%, 5%, 2.5%, and 1% or greater than the upper limit and the lower bound of all alpha (α) in the table. It can be concluded that the F-Statistic value has cointegration in the variables in the model tested, so that there is a short-term and long-term balance in the variables.

Tabel 3. Cointegration test

Test Statistic	**Value**	**K**
F-Statistic	**8.392**	4
	Critical Value Bounds	
Significance	I (0)	I (1)
10%	2.2	3.09
5%	2.56	3.49
2.5%	2.88	3.87
1%	3.29	4.37

Sources: Author calculation

Table 4 shows the results of the long-term test coefficients for each variable. The foreign investment variable has a coefficient of 0.278, a t-table comparison value of 2.045 greater than the t-count of 0.853, and a probability value of 0.409 greater than $\alpha = 0.05$, so it can be interpreted that accepting H0 means accepting that the variable foreign investment in Indonesia has no positive effect on CO2 emissions in the long term. The GDP variable has a coefficient of -0.151, a t-table comparison value of 2.045 greater than a t-count of -0.754, and a probability value of 0.464 greater than $\alpha = 0.05$, so it can be interpreted that accepting H0 means that the GDP variable in Indonesia does not negatively affect CO2 emissions in the long term. The primary energy consumption variable has a coefficient of 0.072, a t-table comparison value of 2.045 greater than the t-count of 0.347, and a probability value of 0.734 greater than $\alpha = 0.05$, so it can be interpreted that accepting H0 means accepting that the PEC variable does not have a positive effect on CO2 emissions in the long term. And the trade openness variable has a coefficient of 0.006 with a t-table comparison value of 2.045 greater than the t-count of 0.887 and a probability value of 0.391 greater than $\alpha = 0.05$, so it can be interpreted as accepting H0 or it can be concluded that the TO variable does not positively affect environmental CO2 emissions in the long run. The entire independent variable has no influence on the dependent variable; this is due to the need for a longer period of time in the study.

Tabel 4. Long run estimation

Variable	***Coefficient***	**T-Tabel**	**T-*Statistic***	**Prob.**
FDI	0.278	2.045	0.853	0.409
PDB	-0.151	2.045	-0.754	0.464
PEC	0.072	2.045	0.347	0.734
TO	0.006	2.045	0.887	0.391

***), **), dan *) Signifikan pada taraf nyata 1%, 5%, dan 10%

Sumber: Data diolah

Tabel 5. Short run estimation

Variable	***Coefficient***	**T-Tabel**	***T-Statistic***	***Prob.***

FDI(-1)	-0.030	2.045	3.665	0.0029
PDB(-1)	-0.016	2.045	-2.935	0.0116
D(FDI)	0.016	2.045	2.599	0.0220
D(PDB)	-0.006	2.045	0.002	0.0068
D(PDB(-1))	0.007	2.045	2.367	0.0341
D(PEC)	0.199	2.045	14.578	0.0000
D(TO)	-0.002	2.045	-3.122	0.0081
D(TO(-1))	-0.003	2.045	-2.649	0.0200
CointEq(-1)	-0.1087	2.045	-8.3498	0.0000

***), **), dan *) Signifikan pada taraf nyata 1%, 5%, dan 10%

Sources: author calculation

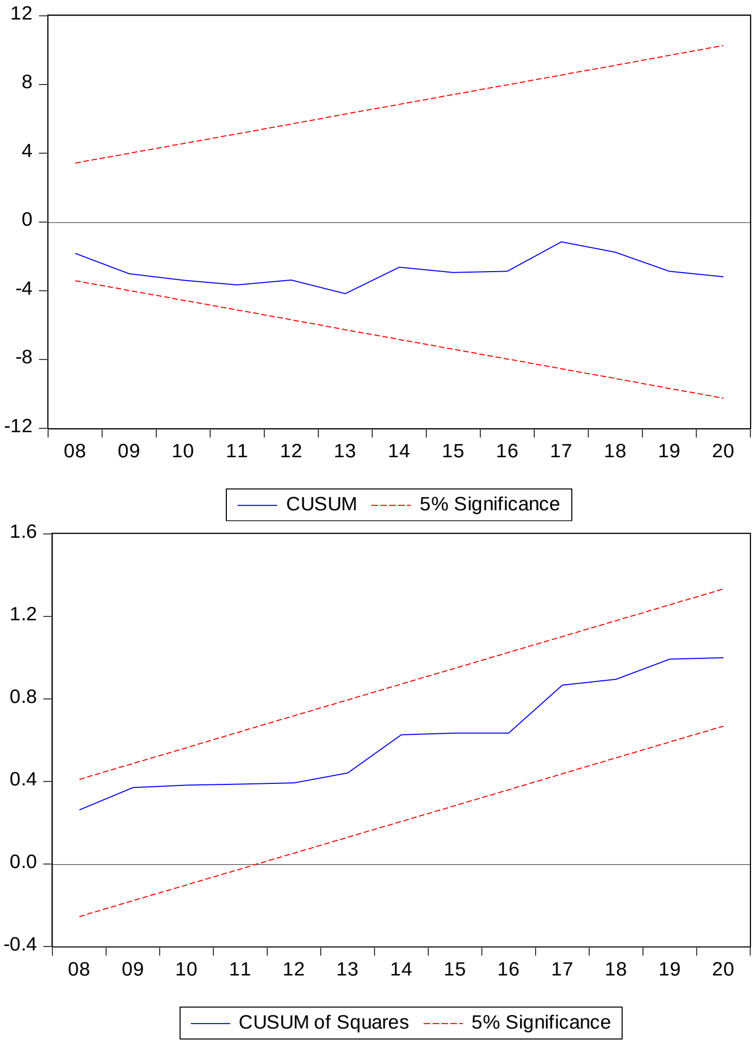
Table 5 shows the short-term coefficients for each variable. The foreign investment variable has a coefficient of 0.016, meaning that in the short term, if foreign investment increases by 1%, it will increase CO2 emissions by 0.016%. With a t-table comparison value of 2.045, less than the t-count of 2.599, and a probability value of 0.0220, less than α 0.05, it means rejecting H0. So it can be concluded that the FDI variable in Indonesia has a positive effect on CO2 emission variables. The test results are in line with the results of research from [11], [2] , [15], and [19]. It is known that rapid economic growth will support foreign investment in Indonesia due to the interest of investors in investing with the aim of supporting national economic activity. According to the results of research by [13], foreign investment has a positive impact on increasing economic growth, but foreign direct investment will cause higher industrial pollution and environmental degradation, which will contribute to increased CO2 emissions from international trade and economic activity.

The Gross Domestic Product variable for viewing economic growth has two coefficients of -0.006 and 0.007, meaning that in the short term, if economic growth increases by 1%, it will reduce CO2 emissions by -0.006% and increase CO2 emissions by 0.007% in the previous year. With a t-table comparison value of 2.045 less than the t-count of 2.367 and probability values of 0.0068 and 0.0341 smaller than α = 0.05, which means rejecting H0. So it can be concluded that the GDP variable in Indonesia has a negative effect on the CO2 emission variable, and GDP in the previous year (Lag-1) has a positive effect on CO2 emissions. The test results are consistent with the results of research from [21]; [10]; [2]); [1] ; [16]; [15]; [4]); [20]; and [7]. It is known that economic growth supported by factors such as natural resources, organization, capital accumulation, technological advances, division of labor, and production scale will increase economic productivity, which means that economic activity such as the industrial sector will require energy sources to meet the needs of production factors to support economic growth. With the increase in economic growth supported by technological advances, there will also be an increase in the consumption of fossil-based primary energy sources. This new discovery will build a production process for economic activities that requires more resources and fossil fuels [12]. The development technology used in Indonesia is not environmentally friendly, which means that the development process still has a negative impact on environmental degradation and resource use. Excess fuel will affect CO2 emissions and have an impact on climate change in Indonesia.

The primary energy consumption variable has a coefficient of 0.199, meaning that if primary energy consumption increases by 1%, CO2 emissions will increase by 0.199%. With a t-table comparison value of 2.045 less than the t-count of 14.578 and a probability value of 0.0000 less than α = 0.05, which means rejecting H0. So it can be concluded that the primary energy consumption variable in Indonesia has a positive effect on the CO_2 emission variable. The test results are consistent with the results of previous research from [17], [23], [8], [9], [1] , [16], and [19]. Economic growth is very closely related to the consumption of available primary energy. The existence of a link with the Environmental Kuznet Curve Hypothesis in Indonesia indicates that there is environmental degradation caused by the industrial sector. Increasing carbon emissions in the industrial sector will cause a decrease in environmental quality because there is an indirect correlation between economic growth and environmental degeneration (Primary 2022). The increase in environmental problems is a consequence of economic growth using fossil fuels, which are believed to produce products that pollute the environment and contain sulfur and exhaust gases that are detrimental to health. Sulfur content is the cause of acid rain and the presence of greenhouse gases. The use of energy in encouraging industrialization will cause CO_2 emissions.

The trade openness variable to see economic growth has two coefficients of -0.002 and -0.003, meaning that in the short term, if trade openness in Indonesia increases by 1%, it will reduce CO_2 emissions by 0.002% and reduce CO_2 emissions in the previous year (Lag-1) by -0.003%. With a t-table comparison value of 2.045 greater than the t-count of -3.122, the t-table of 2.045 is greater than the t-count of -2.649, which means accepting H0. Then these variables have probability values of 0.0081 and 0.0200, which are less than α = 0.05, which means that they reject H0. So it can be concluded that, when viewed from the coefficient value, the variable Trade Openness in Indonesia has a negative effect on the CO_2 emission variable, and this variable in the previous year had a negative effect on the CO_2 emission variable. In the research of [7] and [12], an increase in trade openness indicates environmental degradation. The more open the economy in a country, the more indications there are of an increase in economic activity followed by an increase in environmental pollution. This means that economic development with economic openness in developing countries does not implement environmental impact control policies. One of them is in export-import activities. This is because the export sector in Indonesia is dominated by the goods sector from natural resources and the manufacturing and industrial sectors, which are the cause in the short term of exports causing environmental damage and increasing CO_2 emissions.

The same table shows the results of the Error Correction Term (ECT/CointEq(-1)) with a coefficient of -0.1087 and a probability value of 0.000 smaller than $<\alpha = 0.05$, which means that when an error occurs in the short term, the model will correct it, and regaining balance in the long run will take 11 years.Figure 1 shows that the stability testing of the model can be divided into two categories: CUSUM (Cumulative Sum of Recursive Residual) and CUSUMQ (Cumulative Sum of Square of Recursive Residual). The following are the results of the CUSUM test with the environmental index variable as the dependent variable.



Sumber: Hasil pengolahan Eviews 12

Fig. 1. CUSUM and CUSUM Q test

Based on Figure 7, the results of the CUSUM and CUSUMQ tests show that the blue line does not cross the upper-lower limit in the form of a red dotted line at a significant alpha level of 5%, which means that the CUSUM and CUSUMQ tests show that the model in this study is stable.

5 Conclusion

In the long term, the overall coefficient of the independent variables shows no effect on CO2 emissions. Due to the need for a longer period of time in research. Then, economic growth, primary energy consumption, and foreign investment in Indonesia have a positive and significant effect on CO_2 emissions in the short term. However, the trade openness variable has a negative and significant effect on CO_2 emissions in the short term.

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