Carbon Emissions, Economic Growth, And Renewable Energy In Indonesia: An Autoregressive Distributed Lag Model

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CARBON EMISSIONS, ECONOMIC GROWTH, AND RENEWABLE ENERGY IN INDONESIA: AN AUTOREGRESSIVE DISTRIBUTED LAG MODEL

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Abstract

This research aims to analyze the effect of economic growth, foreign direct investment (FDI), oil consumption, and hydroelectricity generation on emission in Indonesia from 1986-2022. The data are generated from World Bank and British Petroleum. This study employs Autoregressive Distributed Lag (ARDL) to estimate the secondary data. Carbon dioxide emissions (CO2) is treated as dependent variable, while economic growth, FDI inflows, oil consumption, and hydroelectricity generation are treated as independent variables. The results revealed that economic growth positively affect CO2 in the short run. Foreign Direct Investment (FDI) affect CO2 negatively but not significant on CO2. The result implies that the Pollution Halo is exist. Oil consumption affect CO2 positively significant both in short and long run. Furthermore, hydroelectricity generation as renewable energy affects CO2 negatively in the short run and positively in the long run but not significant. The result suggests to the stakeholders to enhance the innovation of the renewable energy to decline the CO2 emissions. Further, this study surely provides a new model in estimating the determinant of CO2 emissions as a proxy of environmental degradation especially in Indonesia.

Keywords*: CO2 emissions, economic growth, FDI, oil consumption, renewable energy*

1. INTRODUCTION

The world is facing inevitable climate change. The factors that cause climate change is the increasing amount of greenhouses gases. One of the gases is carbon dioxide emission (CO_2). Some studies highlighted that the increasing economic activities will cause the increasing amount of CO2. It happened because the increasing economic activities lead to the more massive production activity. This condition will increase the resources utilization and produce not only good and services but also waste that can endanger environment.

Figure 1 shows the world CO2 emissions and economic growth. The World Bank reported that the growth of carbon dioxide emission in the past 10 years from 2012 to 2022 is volatile.

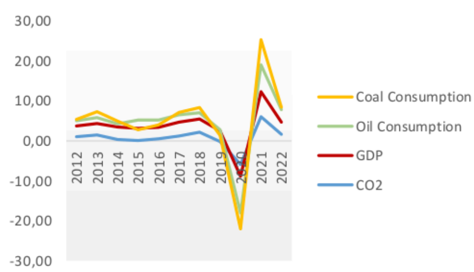

Figure 1. CO2 emissions, economic growth, coal consumption, and oil consumption in the world

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However, the data is showing an uptrend line. Further, Energy Institute in 2024 also reported that the greenhouse gas generated from energy use, industrial processes, flaring, and methane is increase by 2.1% since 2022. The increasing growth of CO2 is aligned with the economic growth movement. There was a significant decline in 2020 for both CO2 and economic growth because of the activity limitation due to Covid-19 outbreak.

The utilization of fossil fuel such as oil is one of the factors causing higher concentration of CO2 emissions. The fossil fuel combustion causes most of man-made emissions including CO2 [1]. Further, coal combustion causes high amount of CO2 emissions [2]. Figure 1 also shows the growth of CO2 emissions is followed by the coal consumption growth with the same pattern of volatility. Following this fact, renewable energy is stated to utilize to minimize the negative effect of fossil fuel combustion in generating greenhouse gases such as CO2. The renewable energy can be in the form of solar energy, hydroelectricity, or wind. Energy Institute reported that in 2023 there are only 51 countries that started to utilize the other renewable energy. It means that there is a progress but not quite significant. The renewable energy utilization is important to minimize the CO2 waste that can endanger our environment but still able to fulfil our needs as a production factor.

Indonesia is one of the countries with high carbon dioxide emissions concentration. In 2006, IEA reported that Indonesia is one of the highest CO2 emitting countries [3]. Furthermore, Lestari et al (2024) revealed that in 2021, Indonesia has the highest CO2 emissions among ASEAN countries. This research aims to capture the determinant of carbon dioxide emissions (CO2) from 1986 to 2022 including the utilization of hydroelectric generation as renewable energy in Indonesia.

Research regarding to the relationship between economic growth and environment has broadly conducted with different approaches in various country and time period. The theory of Environmental Kuznet Curve (EKC) explains that there is a reverse U-inverted between economic growth and environmental degradation that covers three stages. The first stage shows positive relationship which an increase economic growth will increase environmental degradation. It happens usually at the developing countries which tend to utilize cheaper technology which is not yet adopt greener innovation. At the second stage, the curve is getting lower as a sign of a developing countries that have better economic conditions and ready to adopt and efficient technology. The third stage shows the negative relationship between economic growth and environmental degradation. It means that the countries started to adopt newer and greener technology which is environmentally friendly. This condition will lead to the increasing environmental quality. This study contributes to the literature regarding to the relationship between economy and environment. This study fills the gap by utilizing renewable and non-renewable energy as independent variable in the same model. Further, this study utilizes time series data since most of the study in the same area using panel data.

The results on the relationship between economic growth and CO2 emissions are vary. Some studies showed the positive result, and some others showed negative results. Kaya et al (2017) found that there is a positive relationship between GDP and CO2 emissions in Turkey from 1974 to 2010. The results imply that the EKC hypothesis is exist. The positive relationship also shown in 95 countries from 1996 to 2015 [6]. Furthermore, a study by [7] revealed that there is short run and long run positive effect of economic growth on CO2 emissions in Thailand from 1971 to 2018. On the other hand, Namahoro et al (2021) revealed that there is a negative effect of economic growth on CO2 emissions in Africa. The study emphasized that there is renewable energy project in Africa that contribute to decrease the emissions.

Foreign Direct Investment (FDI) also considered as one of the factors that can affect environmental quality. Global trends index of pollution, CO2 emission, and environmental protection's general government expenditure can be the proxy of environmental quality

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indicators Chen et al (2019) in Cahyadin et al. (2021) The effect of FDI on environmental quality can be positive or negative. Y. Liu et al., 2017) explained that there are two hypotheses regarding to the relationship between FDI and environment which are Pollution Haven Hypothesis and Pollution Halo. The first hypothesis is Pollution Haven Hypothesis (PHH). [12] explained PHH is a condition where the foreign investment will flow the investment to the developing countries which have low environmental stringency and tax. This condition will affect environment since the lower environmental is a comparative advantage to the host country that led to the environmental degradation. It can be implied that there is a negative relationship between FDI and environment. The increasing FDI will lead to the decreasing environment quality. Research by [10] revealed that there is a positive relationship between FDI and Environmental Index as a proxy of environmental quality in 97 developing countries from 1991 to 2014.

The second hypothesis is Pollution Halo. Mert & Caglar (2020) explained that the home countries bring newest and greener technologies to the host countries that reduce the emissions. Research by Nguyen-Thanh et al (2022) revealed that there is positive relationship between FDI and CO_2. An increase FDI will result in a higher CO_2 emission in 1056 observations from 2004 to 2014. It means that the Pollution Halo is not exist. Meanwhile, Kaya et al (2017) found that FDI affects CO_2 negatively in the short run. It implies that pollution halo is exist. The increasing FDI will decrease CO_2 emissions in Turkey from 1974 to 2010.

Oil consumption is also considered as a factor that increase emissions. Oil combustion increase the gas concentration which can endanger the environment resulted in global warming [15] in [16]. (Fitriyanti & Fatimura (2019) also highlighted that oil utilization increase carbon dioxide (CO2). Thus, most studies revealed that there is a positive re;ationship between oil consumption and CO2 emission. Research related to the effect of oil consumption has been conducted by [18]. The results revealed that oil consumption positively affect CO2 in the long run which is the increase oil consumption will increase CO2 emissions in 20 Organization of Islamic Cooperation (OIC) countries. Furthermore, the results also showed that the effect of oil consumption is greater than gas consumption. Another study by Dong et al (2017) confirmed that there is a positive relationship between oil consumption and CO2. The results of the study showed that BRICKS countries oil consumption increase CO2 in the long run.

Rahman & Majumder (2021) mentioned that the utilization of renewable energy such as solar panel and other small power producers (SPP) contribute to reduce CO2 emissions. Renewable energies are available in many forms such as hydropower, wind, solar, and geothermal. Bilgili et al (2021) explained that hydropower as an environment-friendly power generation considered as the oldest and most familiar renewable source of electricity. Research by Bello et al (2018) revealed that the utilization of hydroelectricity helped to reduce CO2 emissions in Malaysia.

The negative relationship between hydroelectricity and CO2 is a confirmation that water-moving utilization is a green energy [22]. A study by Xiaosan et al (2021) treat hydroelectric generation as a proxy of renewable energy. The results showed that hydroelectric generation decrease CO2 in short run and long run in China. The results are in line with the China government that plan to boost greener energy utilization.

2. METHOD

This study employs ARDL approach to examine secondary data generated from World Bank and British Petroleum in Indonesia from 1986 to 2022. The data estimation is performed by using E Views. This study treats CO2 as dependent variable. Furthermore, economic growth, FDI inflows, oil consumption, and hydroelectricity generation treated as independent variables.

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Table 1. Variable Specification

No	Variable	Specification	Source	Symbol
	Dependent Variable			
1.	Carbon Dioxide Emission	Carbon emission from energy such as oil, gas, and coal combustion (Million tonnes)	British Petroleum	lnco2
	Independent Variable			
1.	Economic Growth	Annual GDP growth rate at current price (%)	World Bank	growth
2.	FDI	Foreign Direct Investment Foreign direct investment, net inflows (BoP, current US$)	World Bank	fdi
3.	Oil Consumptions	Oil consumption (barrels)	British Petroleum	lnoil
4.	Hydroelectricity Generator	Gross primary hydroelectric generation (Terawatt-hours)	British Petroleum	lnhydro

ARDL stands for Autoregressive (AR) and Distributed-Lag Model (DL). Gujarati (2009) explained distributed-lag model as a regression model that not only include the current independent variable but also the lagged or the past value of it. While autoregressive model is a model that covers more than one lagged value of the dependent variable among the independent variable. The model explains the relationship between the time path of dependent variable and its lagged value. Thus, ARDL is considered as a dynamic model. There are six steps in estimating ARDL: (1) Stationary test; (2) Determining optimum lag; (3) Bound test cointegration; (4) Estimating the short and long-run coefficient; (5) Classical assumption test, and (6) Model stability.

The ARDL model requires all variables are stationary. The advantage of ARDL regarding to the unit root test is it can be applied whether the independent variables stationary at I(0) or I(1) [25]. Sam et al (2019) in Kurniawan & A'yun (2022) explained that the variables should not transformed into I(2). It is because can result a spurious regression. However, ARDL not require all variables are stationary at the same order. This study employs ADF test to check the stationary. Generally, there are four methods in testing unit roots: Durbin-Watson (DW), Dickey-Fuller, Augmented Dickey-Fuller (ADF), and Philip-Perron (PP). The most popular method is Dickey-Fuller or Augmented Dickey Fuller (ADF). ADF is also the most common used because it is easy to applicate [28], This study employs Augmented Dickey-Fuller (ADF) method.

The next step is Bound-Test Cointegration. Bound-test cointegration should be conducted to check whether there is a long run relationship. Since ARDL is able to estimate the long-run effect a dynamic model. If there is cointegration the short-run and long-run estimation can be performed. [28] explained that cointegration is an econometrics approach to imitate the presence of a long-run equilibrium among underlying time series which converges over time. This step assists to know the cointegration of the underlying variables in the model, given the endogenous variable. If the value of F-test of bound test estimation results higher than the critical value of lower and upper bound at the 1%, 5%, and 10% critical value it implies that there is a long-run effect in the model [29].

Pesaran et al. (2001) apply the bound test cointegration model to deal with the difference in integration between variables. The cointegration test with the bound test approach is employed to estimate the long-term coefficient with the F-test. The next step, the short-term coefficient estimation of all the variables, can be done along with the estimation of the long-term coefficient by using the model with the error correction format of ARDL. The error correction mechanism (ECM) format can determine the speed of adjustment of the balance direction (Pesaran and Pesaran, 1997) with the following formula:

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$$\emptyset(L)y_t = a_0 + a_1 t + \beta' x_t + \sum_{i=0}^{q-1} \beta_j^{*\prime} \Delta x_{t-j} - \emptyset^*(L)\,\Delta y_t + \mu_t \qquad (1)$$

Where $\emptyset(L) = 1 - \sum_{j=1}^{p} \emptyset_j L^j$, dan $\beta(L) = \sum_{j=0}^{q} \beta_j L^j$, y_t is the dependent variable, x_t is an independent variable, and L is *lag operator*. The ARDL model based on Pesaran et al. (2001) requires an ECM model with the adjustment method and error correction in the short term to get the balance in the long run. This study analyzes the effect of economic growth, FDI inflows, oil consumption, and hydroelectricity generation on CO2 emissions with the following equation:

$$lnCO_{2_t} = \alpha_0 + \alpha_1 lngrowth_t + \alpha_2 FDI_t + \alpha_3 lnoil_t + \alpha_4 lnhydro_t + \varepsilon_t \qquad (2)$$

Where lnCO2 is carbon emissions; growth is economic growth, FDI is foreign direct investment; lnoil is oil consumption; and lnhydro is hydroelectricity generation; notation (ln) indicates the data is transformed into natural logarithm (ln); _1, _2, _3, dan _4 are coefficient values; _0 constant value; and _t is the error term. Based on Pesaran et al. (2001), the ARDL error correction model formula is as follows:

$$\Delta lnCO_{2_t} = \alpha_0 + \sum_{i=1}^{n1} \alpha_1 \Delta \ln CO_{2t-1} + \sum_{i=1}^{n1} \alpha_2 \Delta growth_{t-1} + \sum_{i=1}^{n1} \alpha_3 \Delta fdi_{t-1} + \sum_{i=1}^{n1} \alpha_4 \Delta lnoil_{t-1} + \sum_{i=1}^{n1} \alpha_5 \Delta lnhydro_{t-1} + \delta_1 lnCO_{2_{t-1}} + \delta_2 growth_{t-1} + \delta_3 fdi_{t-1} + \delta_4 lnoil_{t-1} + \delta_4 lnhydro_{t-1} + \mu_t \qquad (3)$$

Where parameter _t,i = 1, 2, 3, 4, 5 as long-term multiplier, while function parameter _1,α_2,α_3,α_4,α_5 as short-term coefficient of ARDL model. The cointegration test on the ARDL model is to test the value of F-statistics. The initial hypothesis (null hypothesis) states that there is no cointegration or is described (H0:δ1 = 2 = δ3 = δ4 = 5 = 0), while the alternative hypothesis is that there is cointegration between variables. If there is cointegration, the next step is to estimate the long-run and the short-run adjustment.

The next step is classical assumption tests. Classical assumption test should be performed to avoid bias in regression result [30]. Further, classical assumptions are also important because it examines whether the model is valid as an estimator [31]. This study employs normality test, autocorrelation test, and heteroscedasticity test.

The following step is model stability. (Narayan & Smyth (2005) in Kuncoro et al, 2021) explained that there are changes over time in time series regression that makes the parameters unstable and undetected which leads to the potential of bias result. Thus, CUSUM and CUSUM of Square further can be performed to estimate the stability of the model. If the graphs are within the critical value of 5%, then the model is considered stable.

3. RESULT AND DISCUSSION

The first stage in estimating ARDL model is to ensure that the data is stationary at any level except at 2nd difference. Stationarity test is necessary to conduct to avoid false the result from regression estimation. This study employs ADF to test the stationery. The p-values of I(1) of lnco2, growth, fdi, lnoil, and lnhydro are 0.000, 0.000, 0.000, 0.0001, and 0.0000 respectively. The Unit Root Test reveals that the independent variables are stationery at 1st difference or I(1) except growth that stationary at I(0) and I(1).

Table 2 Stationarity Test

Variables	I (O)		I (I)	
	t-stat	p-value	t-stat	p-value
lnco2	0.879	0.992	5.928	0.000
growth	-4.320	0.001	7.556	0.000
fdi	-1.398	0.572	7.598	0.000
lnoil	-1.797	0.375	5.648	0.000
lnhydro	1.443	0.998	6.438	0.000

Source: estimation results, 2024.

Further, the bound test is performed to test the existence of the long-run relationship. The F-test showed the value of 12.2494 which is greater than the lower and upper bounds at 5%. Thus, there is a long run cointegration

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among CO_2, economic growth, FDI inflows, oil consumption, and hydroelectricity generation.

Table 3. Bound Test Cointegration Result

Indicator	Result
Lag optimum	(3,1,4,4,4)
F-test	12.2494
Critical value	5%
Lower bounds I(0)	2.56
Upper bounds I(1)	3.49

Source: estimation results, 2024.

The result of short run estimation is displayed by Table 4. In the short run, economic growth affects CO_2 positively but not significant. The increasing 1% in economic growth will boost CO_2 emissions by 0.0031%. The result aligns with study by Kaya et al. (2017) and Adebayo & Akinsola (2020). However, in the long run, economic growth affects CO_2 negatively but not significant. Further, the second independent variable, FDI inflows, affects CO_2 negatively but also not significant at the short and the long run. But, at the short run, FDI inflows (-4) shows negative and significant effect on CO_2. The increasing FDI inflows in 1% will decline CO_2 by 5%. The results are align with [5]. Further, Oil consumption affects CO_2 emissions positively and significantly both in short and long run. The 1% increase on oil consumption will generate CO_2 by 0.7375% and 0.7318% in the short and long run respectively. The increasing oil combustion will generate CO_2. The results are align with [34], [35], [36]. The increasing Hydroelectricity generation as the proxy of renewable energy affects CO_2 emissions negatively but not significant in the short run. The 1% increase in hydropower generation will decline the CO_2 emissions 0.0007% in the short run. The negative relationship between hydroelectricity and CO_2 is also shown by [37], [38] and [39]. However, in the long run, the hydroelectricity shows positive effect on CO_2 positively but not significant.

The results implies that the relationship between economic growth and CO_2 emissions in short and long run confirms that the EKC hypothesis exist. At the short run, economic growth will generate CO_2 emissions, but at the long run, the effect is vice versa. The results from the effect of FDI inflows in the short and long run confirm halo effect hypothesis. The FDI inflows from home countries utilize greener technology that leads to the decreasing CO_2 in the host country. Further, the increasing oil consumption will lead to the increasing CO_2 emissions. It confirms the chemical theory which oil combustion from fossil fuel will generate greenhouse gases such as carbon dioxide (CO_2). Indonesia is one of the countries that still have high utilization of fossil fuel especially oil. Moreover, the negative relationship between hydroelectricity generation and CO_2 emission confirms that hydroelectricity is a renewable energy source that able to decrease CO_2 emissions by producing relatively minimum waste and environmentally-friendly. Further, the positive impact of hydroelectricity generation on CO_2 in long run explains that in Indonesia, the utilization of green energy relatively low compare to the fossil energy such as oil and coal. It is explained by the data reported by Jakarta Globe, that the capacity of new and renewable energy power plants only reached 13% of the total energy mix in 2023 which the target is 19.49% in 2024 [40]. British Petroleum reported that the growth of hydroelectricity consumption from 1986 to 2022 is only 13.8% while coal and oil consumption are 192,8% and 7,34 % respectively.

The Error Correction Term (ECT) showed the value of -2.6098 which is negative and significant value of 0.000. The ECT value explains the speed of adjustment towards the equilibrium point. The results showed that the equilibrium will exist 2 years and 7 months after the model experience disequilibrium. The next estimation is conducting the classical assumption test or residual diagnostic. The results are presented in Table 5.

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Table 4. ARDL Estimation Result

Short Run Estimation Result			
Variable	Coefficient	t-stat	Prob
D(lnco2)t-1	-0.7064	-4.3400	0.0012
D(lnco2)t-2	-0.3985	-2.3648	0.0375
D(lnco2)t-3	-0.5048	-3.0473	0.0111
growth	0.0031	1.3389	0.2076
growth t-1	-0.0041	-1.7433	0.1091
D(fdi)	-1.2332	-0.7749	0.4547
D(fdi)t-1	2.1269	1.3593	0.2013
D(fdi)t-2	1.1039	0.8311	0.4236
D(fdi)t-3	-7.0981	-0.4358	0.6714
D(fdi)t-4	-5.0019	-2.6843	0.0212
D(lnoil)	0.7375	5.7030	0.0001
D(lnoil)t-1	0.6382	4.5082	0.0009
D(lnoil)t-2	0.4379	2.5566	0.0267
D(lnoil)t-3	0.4292	2.2965	0.0423
D(lnoil)t-4	-0.3331	-1.578	0.1427
D(lnhydro)	-0.0007	-0.0150	0.9883
D(lnhydro)t-1	0.0471	0.8917	0.3916
D(lnhydro)t-2	0.0978	2.0537	0.0646
D(lnhydro)t-3	0.0710	1.3747	0.1966
D(lnhydro)t-4	-0.0461	-1.0167	0.3311
ECT	-2.6098	-10.3394	0.0000
Long Run Estimation Result			
Variable	Coefficient	t-stat	Prob
growth	-0.0003	-0.3930	0.7017
D(fdi)	-1.4231	-0.8432	0.4170
D(lnoil)	0.7318	9.9959	0.0000
D(lnhydro)	0.0648	1.2216	0.2473
Diagnostic Test			
R^2			0.9369
Adjusted R^2			0.8223
F-Statistic			8.1774

Source: authors' estimation, 2024

Table 5. Residual Diagnostic Results

Normality		Serial Correlation		Heteroskedasticity Test	
Jb Stat	Prob	Obj R2	Prob	Obj R2	Prob
5.954	0.0509	2.0562	0.1516	18.5835	0.5490

Source: Authors' estimation, 2024

The Jarque-Bera p-value is greater than critical value 5%. It means that the residual is normally distributed. There is no serial correlation in the model. It explained by the p-value of serial correlation that greater than 5% critical value. The residual is also homoscedastic due to the p-value that greater thn 5% critical value which is 0.5490.

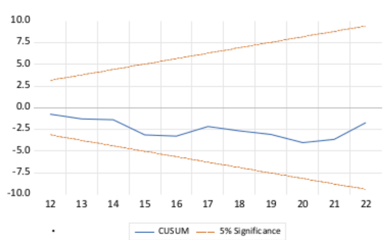

Figure 2. CUSUM Graph

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The stability test of CUSUM and CUSUM of Square (CUSUMQ) are employed to check the stability of the model. Both CUSUM and CUSUM of Square are in the 5% critical value. It means that the model is stable.

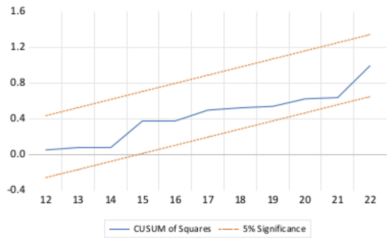

Figure 3. Cusum of Square Graph

4. CONCLUSSION

This study estimates the effect of economic growth, FDI inflows, oil consumption, and hydroelectricity generation on CO2 in Indonesia from 1986 to 2022. The data generated from statistic Indonesia. This study employs ARDL to estimate the data. The results showed that there is a positive relationship between economic growth and CO2 emissions in short run while in the long run is negative. This pattern confirms the EKC hypothesis which explained that in the long run, economic growth makes environmental degradation become worsen. It is because the utilization of cheaper input factor during production process which is relatively contains harmful substance that leads to the environmental degradation. The FDI inflows shows negative effect on CO2 but not significant in short and long run respectively.

The utilization of oil as non-renewable energy shows positive and significant effect on CO2 both in short and long run. It implies that the utilization of non-renewable energy cause environmental degradation. The results also found that the short run relationship between hydroelectricity and CO2 emissions are negative but not significant. It means that in Indonesia, specifically, the utilization of renewable energy should be escalated in order to gain the maximum impact. It is because the renewable energy tends to produce minimum waste and not endanger the environment. Furthermore, the innovation of renewable energy utilization should be supported by the government. In Indonesia, the utilization of renewable energy is not yet maximum compare to non-renewable energy such as coal and oil.

This study contributes to the literature regarding the issue about environment and climate change as one of the mitigation processes to deal with inevitable climate change. Finding the factors that affect CO2 emissions helps government to construct policies in order to slower the negative impact of the CO2. The policies can be in a form of the tighter policies in running a business, utilize greener technology and resources, and support from government in order to evolving the renewable energy.

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