

Carbon Emissions, Energy Consumptions, and Production Activity: Now and Future

Dwiputra Ahmad Ramdani
Center of Policy Analysis
Ministry of National Development Planning
Jakarta, Indonesia
dwiputra.ramdani@gmail.com

Gisty Ajeng Septami
Center of Policy Analysis
Ministry of National Development Planning
Jakarta, Indonesia
agiseptami@gmail.com

Abstract—Most of the countries in the world, including Indonesia, have agreed to take action of keeping global warming below 2° Celsius in this century, as ratified in the Paris Agreement. Indonesia is committed to reduce their greenhouse gasses (GHG) emissions by 29% in 2030 without any international support. This study aims to analyze the nexus between carbon emission, energy consumption, and economic productivity; and moreover, identifies which factor in Kaya identity that affects more to the carbon emission. By employing energy and emission data from International Energy Agency (IEA), and macroeconomic data of 34 Provinces from Central Bureau of Statistics (BPS), three dynamic models confirm that there is causality between those three variables.

Decomposition results of Kaya identity showed that during 1993-2014, there was an increasing trend of carbon emissions mostly affected by carbon efficiency (ratio of CO₂ emitted per energy consumption) and economic productivity. On the other hand, energy intensity of economy showed a promising decline trend over this period, indicating that less energy was needed to get a rupiah of GDP. Assuming the growth rate of GDP per capita is steady at 3% per year, Indonesia needs to further reduce its carbon content of energy at 4.5% per year and energy intensity at 2% per year, so that the INDC target in 2030 can successfully be achieved.

Keywords—economic growth; energy consumption; carbon emissions; kaya identity; dynamic panel data

I. INTRODUCTION

Indonesia commits in reducing carbon emission by implementing the issuance of the National Energy Policy (KEN) in Presidential Decree No. 79/2014. In March 2017, President Joko Widodo signed a presidential regulation on the General Planning for National Energy (RUEN) elaborating the action plan of national energy policy. In this policy, the renewable energy is still targeted to account for 23 percent of Indonesia's total energy consumption. This target seems reasonable, considering renewable energy accounted for 23 percent of global electricity generation in 2015 [1], Indonesia still struggled to have a steady growth of renewable energy share in the past few years. In 2016, share of renewable energy in primary energy mix was only 6.51% or only increased 2 percentage points in 2 years [2].

The slow growth of renewable energy in Indonesia can be understood considering the economic condition of Indonesia

that is still growing in average of 5.3% per year for the past decade [3]. This situation is seemingly resembled the Environmental Kuznetz Curve (EKC) that said environmental degradation tend to get worse until the income per capita reaches a certain point, assuming Indonesia is still on the left-side of the inverted u-shape curve.

This study aims to analyze the nexus between GHG emissions represented by carbon emission, energy consumption, and economic productivity in Indonesia, while proving the existence of EKC in Indonesian economy. After obtaining the causality nexus between those three variables, the study uses Kaya identity in order to identify which identity has dominant impact on Indonesia's carbon emissions. At the end, a policy recommendation on how the government should act in order to reach the National Determined Contributions (NDC) target of 29% emission reduction by 2030 is proposed.

II. ANALYTICAL FRAMEWORK

An analysis on relationship between CO₂ emissions and GDP has been profoundly studied over the past decade. A previous study showed there is no causal relation between GDP and CO₂ emissions [4], meanwhile others said that there is a unidirectional relation between those variables (which only GDP affecting the emissions) [5]. A study testing UAE data during 1975-2011 showed the presence of EKC along with the similar relationship between financial development and CO₂ emissions [6]. Furthermore, a study in the Middle-East North-Africa (MENA) Net Oil Exporting Countries (NOEC) confirmed that there is bidirectional causality between energy consumption to economic growth [7].

A. The Review of Production Function and Traditional Economics Model

According to the economic theory, output, inputs and profits of a company (as well as, a country) are determined by the production function. Basically, a firm needs resources, equipment, supplies, and other inputs to produce something. A production function is a way of measuring what comes out of production to what has gone into it. In macroeconomics, the factors of production are classified into 4 (four) categories which are: (i) Capital Stock (K), or tangible assets that are created to use in the production process. This includes machines, vehicles, buildings, and other equipment; (ii) Labor (L), or all human efforts in order to produce goods and services;

(iii) Land (P), that includes natural resources, raw materials and energy sources; and (iv) Entrepreneurship (H), or the quality of the business intelligence to develop, organize, and manage a production process with any risks in order to make a profit.

Therefore, the production function is principally expressed in the formula of $Q = f(K, L, P, H)$, where the amount produced is a function of the assembled input quantities of each factor. Another basic formula of this calculation is $Q = f(K, L)$, in which capital and labor are the two main factors of production with the greatest impacts on the output. This function is then known as the Cobb-Douglas production function. This equation would need to have the property that $F(K, L) = A K^\alpha L^{(1-\alpha)}$ where A is a productivity parameter explaining the advancement of technology, and α is a constant representing capital's share of income.

B. Kaya Identity

The Kaya identity is a formula expressing the total carbon emission level that can be stated in four inputs: human population, GDP per capita, energy intensity, and carbon intensity. This study uses a simplified version of Kaya identity that rules out the population factor as just part of the GDP, considering the growth of population in Indonesia is relatively constant at 1.5% per year [3]. The equation then can be expressed as follows:

$$CO_2 = \frac{CO_2}{Energy} \times \frac{Energy}{GDP} \times GDP \quad (1)$$

In most Kaya identity analysis, the numbers of population and GDP are not really a useful way to limit the negative impacts on climate change because normally people still want their economy to grow. The proposal to discuss the effects on climate change then remains on the energy intensity of the economy and carbon content of energy.

III. DATA AND METHODS

In general, this study comprises of two methods: causality analysis using dynamic panel data and decomposition of Kaya identity. Three dynamic panel models are built by employing energy and emission data from IEA and macroeconomic data of 34 Provinces from BPS. The descriptive summary of the variables used can be seen in Table 1. Due to some regional expansion and/or segregation, some data could not perfectly cover all provinces in Indonesia.

A. Estimation Methodology and Procedure

An extended production function, adapted from Omri's model, is used as the main framework to develop three-way linkages model between CO₂ emissions, economic growth, and energy consumption in Indonesia. The three models can be expressed as follows:

$$\ln(Y_{it}) = \alpha_0 + \alpha_{1i} \ln(E_{it}) + \alpha_{2i} \ln(C_{it}) + \alpha_{3i} \ln(K_{it}) + \alpha_{4i} \ln(L_{it}) + \pi_{it} \quad (2)$$

$$\ln(E_{it}) = \beta_0 + \beta_{1i} \ln(Y_{it}) + \beta_{2i} \ln(C_{it}) + \beta_{3i} \ln(K_{it}) + \beta_{4i} \ln(L_{it}) + \beta_{5i} \ln(CR_{it}) + \varepsilon_{it}$$

TABLE I. SUMMARY OF VARIABLES

Variable / Units	Obs.	Mean	Std. Dev.	Min.	Max.
Gross Regional Domestic Product* (in Billion Rp)	671	176,063.1	242,093.7	7,814.7	1,373,390
CO₂ Emission** (Kiloton CO ₂)	671	11,584.58	14,911.49	363.4	82,640.83
Energy Consumption* (Kiloton Oil Equivalent—TOE)	671	4,210.896	5,879.769	210.81	27,993.76
Gross Fixed Capital Formation** (in Billion Rp)	671	44,835.65	77,488.93	240.9505	638,377.7
Trade Openness* (Export and Import Ratio to GRDP)	671	0.6787	0.3897	0.0015	1.9477
Population* (in Thousand)	670	7,025.252	9,804.58	551.017	46,029.6
Labor Force* (in Thousand)	655	3,192.959	4,519.264	226.3531	19,306.51
Loan Ratio to GRDP*	656	0.1326	0.1324	00.0049	0.8622

Source: *) Central Bureau of Statistics, **) International Energy Agency

$$\ln(C_{it}) = \psi_0 + \psi_{1i} \ln(Y_{it}) + \psi_{2i} \ln(E_{it}) + \psi_{3i} \ln(TO_{it}) + \psi_{4i} \ln(POP_{it}) + \lambda_{it} \quad (4)$$

Equation (2) shows that economic growth can be influenced by the energy consumption (E), CO₂ emission (C), capital stock (K), and total labor (L) [8] [9]. Equation (3) states that the energy consumption is derived from economic growth (Y), CO₂ emission, capital stock, total labor, and ratio of total credit per GDP (CR) [8] [9] [10]. Equation (4) postulates that environmental degradation has a relationship between economic growth, energy consumption, trade openness (TO), and population (POP) [9] [10] [11].

In order to get the empiric estimation, this study employs dynamic simultaneous-equation models in (2), (3), and (4) by utilizing the one-period lagged levels of the three dependent variables—economic productivity, energy consumption per capita, and CO₂ emissions per capita—with assumption that the current levels of each dependent variables are somewhat depend on each previous condition. This study adapts the dynamic models with panel data using the Arellano and Bond Generalized Method of Moments (GMM) estimator [12]. This approach averts the biases as well as the endogeneity problem of the regressors by using a set of Instrumental Variables (IV). The GMM has also been proven robust to arbitrary heteroskedasticity. Furthermore, this study analyses those equations by using the ordinary least squares (OLS) method.

B. Decomposition Analysis

According to (1), the changes of carbon emissions from base year to a certain year can be expressed as follows:

$$\Delta CO_{2T} = CO_{2T} - CO_{20} = \Delta C_{cnt} + \Delta E_{int} + \Delta GDP \quad (5)$$

where ΔC_T denotes the total effects of carbon emission changes, ΔC_{cnt} denotes the carbon content of energy. In order to identify the impacts on total carbon emissions from those three factors, the decomposition of simplified Kaya identity utilizes Logarithmic Mean Divisia Index (LDMI) that can be formulated as follows:

$$L(CO_{2T}^T, CO_{20}^0) = \frac{CO_{2T} - CO_{20}}{\ln(\frac{CO_{2T}}{CO_{20}})} \quad (6)$$

$$\Delta C_{cnt} = \sum_{i=1}^{34} L(CO2_i^T, CO2_i^0) \times \ln\left(\frac{C_i^T}{C_i^0}\right) \quad (7)$$

$$\Delta E_{int} = \sum_{i=1}^{34} L(CO2_i^T, CO2_i^0) \times \ln\left(\frac{E_i^T}{E_i^0}\right) \quad (8)$$

$$\Delta GDP = \sum_{i=1}^{34} L(CO2_i^T, CO2_i^0) \times \ln\left(\frac{GDP_i^T}{GDP_i^0}\right) \quad (9)$$

IV. RESULTS

A. Dynamic Panel Data Results

The summary of the regression results for the three models is stated in Table 2. The first model indicates that carbon emission positively and significantly (by 5%) affects the economic growth; an increase of 1% in carbon emissions increases the GRDP by 0.15%. This relationship shows that provinces in Indonesia are still in the early phase of EKC hypothesis—economic growth is still the main priority and environmental degradation tends to worsen as its by product [9]. On the other hand, the rising of emissions shows the increasing level of production activity in a region, which also leads to higher GRDP [5]. In Model 1, the Gross Fixed Capital Formation (GFCF), as a proxy of capital stock, statistically has significant positive relation with the GRDP. As mentioned above, in the Cobb-Douglas equation, capital is one of the main important determinants of the output—beside labor [13].

TABLE II. REGRESSION RESULTS

Independent Variables	Model 1 GDP per Capita	Model 2 Energy Consumption per Capita	Model 3 CO ₂ Emission per Capita
Gross Regional Domestic Product		0.3003*** (0.99)	0.4162 (0.368)
Gross Regional Domestic Product (-1)	0.5838*** (0.112)		
CO ₂ Emission	0.1491** (0.065)	0.2204*** (0.076)	
CO ₂ Emission (-1)			0.0504 (0.088)
Energy Consumption	0.1290 (0.091)		0.916** (0.483)
Energy Consumption (-1)		0.4176*** (0.06)	
Gross Fixed Capital Formation	0.0356** (0.016)	0.0409 (0.025)	
Trade Openness			0.0929 (0.092)
Population			1.2724*** (0.497)
Labor Force	0.0059 (0.006)	0.0054 (0.006)	
Loan Ratio to GRDP		-0.7432*** (0.155)	
Constant	1.2321*** (0.371)	-1.4142*** (0.277)	-10.8743*** (2.914)
Obs	552	544	636
Prob>chi ²	0.0000	0.0000	0.0000
Arrelano-Bond test	0.0178	0.0012	0.0078

*) indicates significant at 10% level, **) indicates significant at 5% level, and ***) indicates significant at 1% level.

In Model 2, the result shows that GRDP, environmental degradation and loan ratio to GRDP are statistically significant to the energy consumption per capita. The GRDP shows a positive relationship—1% increase of GRDP tends to increase energy consumption by 0.3%. Carbon emissions also show a positive relation with energy consumption and this conjugates well with the fact that some carbon emissions are derived from energy consumption. On the other hand, loan ratio to GRDP has a negative association with the energy consumption. The coefficient demonstrates that there is 0.47% reduction of energy consumption per capita for every 1% increase in loan. This relation implies that financial development, represented by the loan ratio, promotes the usage of efficient energy since the fund is used to purchase newest appliances, so that the energy consumption becomes more efficient [14] [15].

In the last model, it can be seen that variables of energy consumption and population statistically give significant influence to the carbon emissions. The result shows that an increase of 1% on energy consumption per capita makes almost a 1% increase in carbon emissions. In addition, the regression result also indicates that as population continues to grow, energy use and carbon emissions in most regions do the same.

B. Decomposition Results

As seen in Fig. 1, Indonesia mostly had a steady economic growth, after the downfall of Indonesia’s economy caused by 1998 Asian Crisis, in average amounting to 5.3% per year. As for its energy intensity, the finding revealed a negative growth of 1% per year, which means that less of energy is needed in order to produce a rupiah of GDP. This indicates a good sign of Indonesia’s energy becoming greener at a constant rate. As for carbon content of energy, its high fluctuation rate plays a significant role in influencing the total carbon emitted per year.

The detailed year-by-year decomposition results from LDMI are presented in Table 3. The accumulated effects for four periods are also shown in the lower section of Table 3. Based on these results, even though in the last few years there were fluctuations of carbon emission, but in general, from 2008 to 2014, Indonesia emitted 30 million tons more carbon each year. As shown in Table 3, economic productivity and carbon content of energy plays a significant role in emitting more carbon emissions. Energy intensity, on the other hand, is the most significant factor in decreasing carbon emissions in Indonesia’s

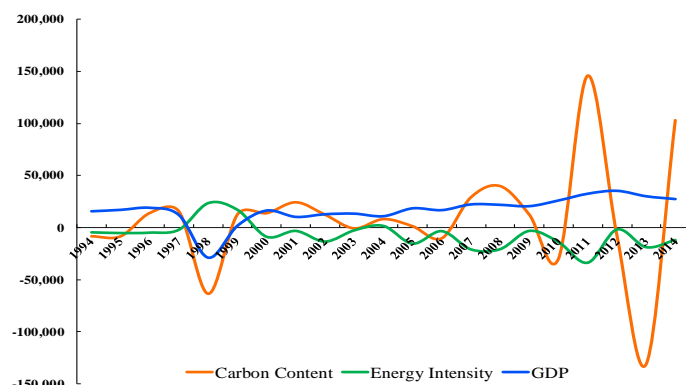


Fig. 1. Proportion of Kaya identity in total carbon emissions

TABLE III. DECOMPOSITION RESULTS

Year	ΔC_{tot}	ΔC_{ent}	ΔE_{int}	ΔGDP
1993 - 1994	2,812.58	-8,218.74	-4,473.36	15,504.68
1994 - 1995	3,527.66	-8,187.03	-5,157.32	16,872.01
1995 - 1996	28,349.55	14,290.25	-4,772.91	18,832.21
1996 - 1997	25,368.35	15,434.01	-1,850.50	11,784.84
1997 - 1998	-68,448.22	-63,432.46	23,801.05	-28,816.81
1998 - 1999	31,787.44	12,824.43	17,262.34	1,700.67
1999 - 2000	21,410.39	13,983.27	-8,767.19	16,194.31
2000 - 2001	31,509.57	24,479.88	-3,114.69	10,144.38
2001 - 2002	11,819.00	12,542.02	-13,397.39	12,674.36
2002 - 2003	10,075.49	-605.55	-2,564.15	13,245.19
2003 - 2004	20,822.65	8,311.04	1,716.91	10,794.70
2004 - 2005	4,367.15	1,464.49	-15,422.48	18,325.14
2005 - 2006	3,127.36	-10,126.70	-3,339.85	16,593.92
2006 - 2007	30,404.34	29,304.47	-20,977.22	22,077.09
2007 - 2008	41,014.12	40,036.41	-20,716.75	21,694.46
2008 - 2009	29,861.29	12,542.63	-3,076.41	20,395.07
2009 - 2010	-17,660.65	-29,605.44	-13,880.91	25,825.70
2010 - 2011	144,630.50	146,177.84	-33,824.74	32,277.40
2011 - 2012	26,145.02	-7,196.98	-1,708.40	35,050.40
2012 - 2013	-120,159.55	-131,195.68	-18,815.84	29,851.97
2013 - 2014	118,621.40	103,326.50	-11,886.86	27,181.75
1993 - 1997	60,058.14	10,852.47	-17,415.37	66,621.04
1998 - 2002	96,526.40	61,730.30	-3,563.78	38,359.89
2003 - 2007	58,721.50	28,185.42	-37,334.39	67,870.47
2008 - 2014	181,438.01	95,998.90	-83,770.12	169,209.23

current situation.

In order to promote growth, economic productivity represented by GDP is expected to have a steady growth at 5.3% per year. So, the government's controls in carbon emission reduction are only possible in maintaining energy intensity of economic and carbon content of energy. Although the rate of energy intensity has already been declining, Indonesia needs to further intensify its greener growth. Assuming that 2% of decline rate each year can be successfully achieved, by 2030 there will be 28% carbon emission reduction from energy intensity. This means that, to reach the NDC target, the carbon content of energy reduction needs to be accelerated until 4.5% each year. Thus, in previous years this carbon content of energy can be reduced up to more than 20% in one year. This assumption is possible to be achieved; by 2030, the carbon emissions will reduce by 29.5%.

V. CONCLUSION AND POLICY IMPLICATIONS

Even though the studies on economic growth, carbon emissions, and energy consumption have improved over last few years, there is no study investigating the relationship of these

variables using simultaneous equation models for 34 provinces in Indonesia. The regressions are based on time data panel from 1993 to 2014. This study divides the global panel analysis into three specifications with the dependent variables are economic growth, carbon emissions, and energy consumptions. The empirical results show that carbon emissions and GFCF have significant relationship with GDP per capita. It implies that the economic activities and capital is the key for each local government to boost local income. In addition, variables that influence per capita energy consumption in Indonesia are GRDP, carbon emissions, and loan ratio to GRDP. Consequently, in pursuance of lowering the environmental degradation, the government should control the usage of energy. The government should promote the usage of efficient renewable energy.

Based on the decomposition results of Kaya identity, carbon content of energy plays an important role in contributing to Indonesia total carbon emissions. On contrary, energy intensity of economic over the past decade showed a significant impact in reducing total carbon emissions. Using the average growth rate of GDP, in order to successfully achieved NDC target, Indonesia needs to reduce their carbon content of energy by 4% per year and further improve the reduction of energy intensity into 2% reduction per year. By then, in 2030, Indonesia's total carbon emissions are expected to be 29.5% lower than the current situation.

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