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DECOMPOSITION ANALYSIS OF CO_2 EMISSION IN INDONESIA'S ENERGY-INTENSIVE INDUSTRIES

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Abstract

The growth of the industrial sector through industrialization greatly affects the increase in CO_2 emissions. Energy conservation and diversification policies need to be carried out to reduce CO_2 emissions, especially in energy-intensive industries. This study aims to decompose and analyze the factors that cause changes in CO_2 emissions using the LMDI method. The data used in this study was sourced from large and medium industry surveys during the period 2010-2015. The results show that the effects of changes in economic activity, industrial economic structure and energy intensity are the main factors that contribute to the increase in CO_2 emissions in the cement, food, pulp & paper, chemical and textile industries. The structural effects of energy composition and emission coefficients have not shown a significant contribution to the increase or decrease of CO_2 emissions. Policy recommendations to reduce CO_2 emissions in energy-intensive industries are to encourage energy efficiency and transition through the use of energy-saving and low-carbon technologies, as well as revitalize old and inefficient technologies.

Keywords: ***CO_2 Emission, Energy Intensive Industries, Decomposition Analysis, LMDI***

INTRODUCTION

Global warming is a serious issue and has been a topic of frequent discussion by researchers and policymakers since the 1980s (Wu, Zhu, & Zhu, 2018; Zhang, Liu, Wang, & Zhou, 2013). This issue certainly raises deep concerns for the wider community, because it will affect the quality of health and the environment. From 1990 to 2015 greenhouse gas (GHG) emissions from energy use increased by 27%, with about 90% of emissions produced coming from CO_2 and developing countries accounting for almost 50% of the world's total CO_2 emissions (International Energy Agency, 2019; Martínez-Zarzoso & Maruotti, 2011; Nair, Arvin, Pradhan, & Bahmani, 2021).

Indonesia as a developing country produces quite high CO2 emissions, which based on the report *Climate Watch (2024)* in 2010 Indonesia produced a total CO2 emission of 703.41 MtCO2, increasing to 1,060.49 MtCO2 in 2021. The increase in CO2 emissions in Indonesia is caused by the increase in energy use in the industrial and transportation sectors. The existence of the industrial sector, especially the manufacturing industry, has an important role for economic growth in Indonesia (Budiono, Nurcahyo, & Habiburrahman, 2021; Harahap, Qadri, Harahap, Situmorang, & Wulandari, 2023; Hartono, Irawan, & Achsani, 2011; Putri, Chetchotsak, Ruangchoenghum, Jani, & Hastijanti, 2016; Tadjoeddin, 2016).

The burning of fossil fuels and the removal of large amounts of smoke from the industrial sector in Indonesia are directly responsible for environmental degradation in both the short and long term (Kahouli, Miled, & Aloui, 2022; Ponce & Khan, 2021; Suparmoko, 2015; S. Wang, Li, Fang, & Zhou, 2016; Xin et al., 2021). Efforts to mitigate CO2 emissions need to be realized through reducing fossil fuel consumption in the industrial sector (Martinho, 2016). However, reducing the use of fossil fuels in reducing CO2 emissions will have a negative impact on economic development, especially in developing countries such as Indonesia that still rely on fossil energy sources (Ali, Gong, Ali, Wu, & Yao, 2021). Therefore, a dilemma arises for policymakers in adjusting between economic growth and environmental degradation (Bradshaw, 2010; Liu et al., 2015).

To address the dilemma between economic growth and environmental degradation in Indonesia's manufacturing sector, policymakers must take immediate action (Anwar & Elfaki, 2021) through effective and targeted energy conservation and diversification policies in realizing CO2 emission reduction in the manufacturing industry sector in Indonesia, especially energy-intensive industries (Rosita, Zaekhan, Estuningsih, & Widharosa, 2021; Zaekhan, Nachrowi, Hartono, & Rosita, 2022). According to Ministry of Energy and Mineral Resources (MEMR) (2016) Industries that are included in the energy-intensive industry group (High Energy Intensity) consist of the food and beverage industry, fertilizer industry and chemical industry, rubber industry, glass and ceramic industry, cement industry, textile industry, pulp and paper industry, basic metal industry and steel. In particular, energy-intensive industries contribute 59% to the final energy consumption of the manufacturing industry sector in Indonesia. Considering that industrialization in Indonesia has resulted in a rapid increase in energy consumption and demand for building materials (cement, steel, and others) which can significantly increase CO2 emissions through energy consumption in related industries. Therefore, it is necessary to identify the factors that affect changes in CO2 emissions in energy-intensive industries in Indonesia to reduce CO2 emissions and achieve sustainable economic development (Meng, Fu, & Wang, 2018).

Based on the above analysis, the contribution of this article lies in the following aspects: (1) identifying the driving factors that contribute to changes in CO2 emissions in energy-intensive industries in Indonesia using the Logarithmic Mean Division Index (LMDI) method during the period 2010-2015. (2) conduct a comparison of each sector of energy-intensive industries and analyze the main driving factors in changes in CO2 emissions in energy-intensive industries. (3) presents several policy recommendations focused on energy-intensive industries to achieve CO2 emission reductions and maintain their economic value.

This article is organized into four sections, namely: section 1 introduction, section 2 describes the methodology and data used, section 3 shows the results of the decomposition of LMDI CO2 emissions in energy-intensive industries by industry sub-sector and section 4 focuses on conclusions and presents policy recommendations.

METHOD

Data

This study uses CO2 emission data converted from energy consumption and output data measured from total production in rupiah based on constant prices in 2010 in each energy-intensive industry during the period 2010-2015. Data was obtained from survey statistic large and medium industries published by Statistic Indonesia (Badan Pusat Statistik). This study uses the manufacturing industry sub-sector up to 5-digit based on the 2009 Indonesian Standard Business Field Classification. After going through the screening and cleaning process, the number of energy-intensive industries includes more than 8,000 firms every year. Energy consumption in the manufacturing industry consists of gasoline, diesel, kerosene, coal, natural gas and liquefied petroleum gas (LPG). The study also considers electricity consumption as an indirect CO2 emission generated by thermal power because most of the electricity consumption in the manufacturing industry is converted from fossil energy (M. Wang & Feng, 2017). The available energy consumption data has different unit forms from each other, so to obtain the total fuel energy consumption of a company, the unit needs to be standardized first into the form of barrel oil equivalent (BOE) based on the Ministry of Energy and Mineral Resources and then converted into tons of coal equivalent (TCE).

Estimation of Emission CO_2

CO2 emission data can be calculated based on energy consumption data used by each company based on the *Intergovernmental Panel on Climate Change* (IPCC) 2006, Energy-related CO2 emissions from the industrial sector i are calculated using the following equation:

$$CO_2 = \sum_{ij} E_{ij} \times f_{ij}$$

Where i shows the industrial sector, j shows the different types of energy sources. E_{ij} shows that fuel consumption j from the industrial sector i and f_{ij} is a type of fuel CO2 emission factor in sector i after being converted into tons of coal equivalent (TCE). The CO2 emission factors of each fuel in the industrial sector are listed in (Table 1).

Table 1. CO2 Emission Factors by Fuel Type

Fuel type	**CO_2 emission factors (*f*)**
	(tCO_2/TCE)
Gasoline	2.029
Diesel	2.168
Kerosene	2.104
Coal	2,769
Natural Gas	1.642

LPG	1.846
Electricity	3.249

Source: IPCC (2006) and Rosita dkk. (2021)

Decomposition model

This study uses the decomposition approach of Index Decomposition Analysis (IDA) as carried out by Diakoulaki & Mandaraka (2007). The basic concept of an IDA is to break down a single variable into several combinations of factors or effects and then determine how much contribution each factor or effect makes in influencing the outcome of the variable (Tu et al., 2019). LMDI is the most perfect decomposition method because it has several practical advantages and is easy to apply in decomposition analysis, both additive and multiplication versions (Ang, 2004). In estimating decomposition using the IDA method, it is estimated that there are five effects on changes in CO2 emissions, namely (Carmona & Collado, 2016; Duran, Aravena, & Aguilar, 2015; Su, Wang, Li, & Guo, 2020; H. Wang, Ang, & Su, 2017):

a) Activity effect (economic activity), this effect considers changes in the scale of economic activity or the overall output level assuming that the increase in output level that occurs is due to an increase in energy consumption.
b) Structural effects (economic structure), these effects take into account changes in the structure of economic activity. This change assumes that the change has an impact on the level of energy consumption because each economic activity has a different energy intensity from each other.
c) Intensity effect (energy intensity), this effect considers the impact of changes in energy intensity on energy consumption. This effect is considered a good proxy for energy efficiency changes.
d) Energy composition effect (energy composition structure), this effect shows the distribution of fossil energy consumption to total energy consumption. This effect is also often called the mix effect because it indicates the amount of fossil fuel consumption consumed.
e) The emission coefficient effect, this effect reflects changes in emission reduction and fuel quality as well as fuel switching due to changes in the technology used. This effect is also known as the emission factor effect.

The calculation of the total decomposition of CO2 emissions can be presented in the following equation:

$$C=\sum_{ij} C_{ij}=\sum_{ij} Q\cdot\frac{Q_i}{Q}\cdot\frac{E_i}{Q_i}\cdot\frac{E_{ij}}{E_i}\cdot\frac{C_{ij}}{E_{ij}}=\sum_{i} Q.S_i.I_i.M_{ij}.U_{ij}$$

where C is total CO2 emissions in energy-intensive industries; $Q(=\sum_i Q_i)$ is total CO2 emissions in energy-intensive industries; $S_i(=Q_i/Q)$ is the share of economic activity of energy-intensive industries; $I_i(=E_i/Q_i)$ is the energy intensity of sub-category *i*; $M_{ij}(=E_{ij}/E_i)$ indicates the composition of energy consumed in the sector *i*; and $U_{ij}(=C_{ij}/E_{ij})$ shows the CO2 emission coefficient from fuel consumption *j* in sector *i*. This study uses an additive IDA in describing the difference in CO2 (C) emissions between two periods (0, T), so that the equation is as follows:

$$\Delta C_{tot}=C^T-C^0=\Delta C_{act}+\Delta C_{str}+\Delta C_{int}+\Delta C_{mix}^T+\Delta C_{emf}^T$$

where the components of the change in CO2 emissions (C) are the economic activity effect (C_{act}), the economic structural effect (C_{str}), the energy intensity effect (C_{int}), the energy composition effect (C_{mix}) and the emission coefficient effect (C_{emf}). The effects contained in the equation above can be estimated each of the effects through the following equation:

$$\Delta C_{act}=\sum_{ij}\frac{(C_{ij}^T-C_{ij}^0)}{(\ln C_{ij}^T-\ln C_{ij}^0)}\ln\left(\frac{Q^T}{Q^0}\right)$$

$$\Delta C_{str}=\sum_{ij}\frac{(C_{ij}^T-C_{ij}^0)}{(\ln C_{ij}^T-\ln C_{ij}^0)}\ln\left(\frac{S_i^T}{S_i^0}\right)$$

$$\Delta C_{int}=\sum_{ij}\frac{(C_{ij}^T-C_{ij}^0)}{(\ln C_{ij}^T-\ln C_{ij}^0)}\ln\left(\frac{I_i^T}{I_i^0}\right)$$

$$\Delta C_{mix}=\sum_{ij}\frac{(C_{ij}^T-C_{ij}^0)}{(\ln C_{ij}^T-\ln C_{ij}^0)}\ln\left(\frac{M_{ij}^T}{M_{ij}^0}\right)$$

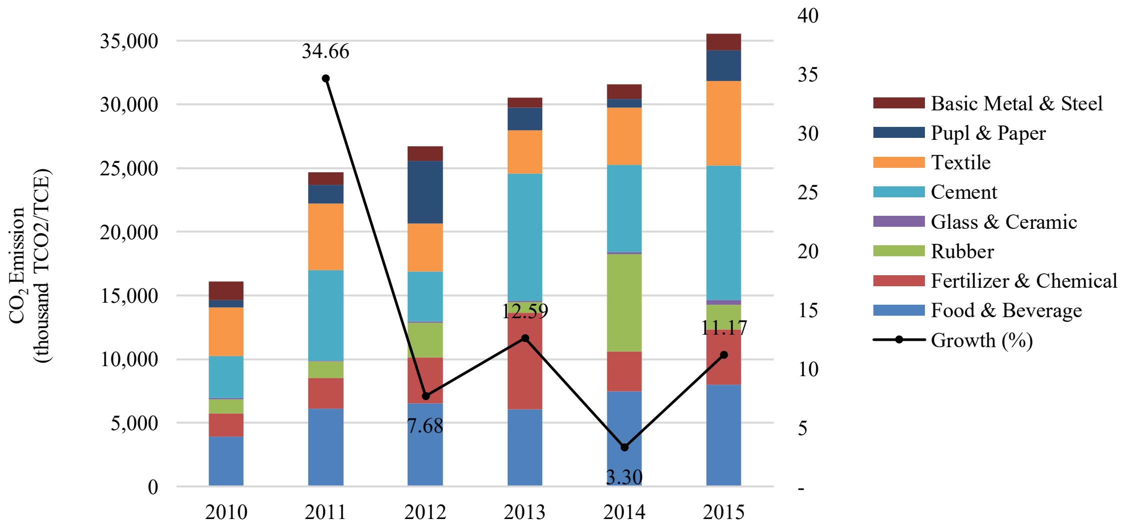
$$\Delta C_{emf}=\sum_{ij}\frac{(C_{ij}^T-C_{ij}^0)}{(\ln C_{ij}^T-\ln C_{ij}^0)}\ln\left(\frac{U_{ij}^T}{U_{ij}^0}\right)$$

Furthermore, the LMDI method is used to decipher the factors affecting CO2 emissions in each industry and evaluate the contribution of each factor to changes in CO2 emissions sectorally.

RESULTS AND DISCUSSION

CO2 emissions in energy-intensive industries trends

CO2 emissions in energy-intensive industries in Indonesia during the period calculated based on (Equation 1). Figure 1 shows that emissions generated from energy-intensive industries have increased from 19,383.78 thousand tons of CO2 in 2010 to 35,572.39 thousand tons of CO2 in 2015 with an average annual growth of 13.9%. The contribution of CO2 emissions from energy-intensive industries to total CO2 emissions. The highest growth rate of CO2 emissions in energy-intensive industries occurred in 2011 reaching 34.66%, the rapid growth during the period 2010-2011 occurred because the Indonesian government encouraged the rapid growth of the manufacturing industry through increasing the industrial business population, strengthening the industrial sector and increasing productivity with the aim of making the industrial sector a growth driver national economy as stated in the National Medium-Term Development Plan (RPJMN) for 2010-2014. Sectorally, the cement industry accounted for the largest CO2 emissions of around 24.71% of the total CO2 emissions in energy-intensive industries and was followed by the food and beverage industry (23.17%) and the chemical industry (13.64%) during the period 2010-2015.



Source: BPS (processed), 2010-2015

Figure 1. Growth of CO2 emissions in energy-intensive industries

Analysis of CO2 emission decomposition in energy-intensive industries

This section will present the results of the analysis of the decomposition of CO2 emissions in energy-intensive industries. Based on the LMDI method, the driving factors for CO2 emissions from energy-intensive industries in Indonesia consist of industrial economic activity, industrial economic structure, energy intensity, energy composition structure and emission coefficient. Considering the heterogeneity in the industrial sub-sectors that are quite diverse, this study divides the energy-intensive industrial sector into 11 sub-sectors in accordance with the 2009 Industrial Business Field Standard Classification (KBLI) ranging from 2-digit to 5-digit consisting of the food industry (10), beverage (11), fertilizer industry (2012), chemical industry (2011), rubber (221), glass industry (2311), ceramics (2393), cement industry (23941), textile industry (13), pulp & paper industry (1701), base metals & steel industry (2410) to present clearer, concise and more accurate results.

Table 2. Results of CO2 emission decomposition by industrial sub-sector (Million TCO2)

Industrial Sub-sector	ΔC_{act}	ΔC_{str}	ΔC_{int}	ΔC_{mix}	ΔC_{emf}	ΔC_{tot}

Food (10)	2.81	0.10	1.15	-0.21	-0.04	3.81
Beverage (11)	0.11	0.01	-0.06	-0.11	0.00	-0.04
Fertilizer (2012)	0.16	-0.17	0.64	0.38	-0.10	0.90
Chemical (2011)	1.33	2.65	-2.26	-0.30	0.27	1.69
Rubber (221)	0.78	-0.58	0.71	-0.28	-0.08	0.55
Glass (2311)	0.06	0.03	0.17	0.17	-0.02	0.40
Ceramic (2393)	0.02	0.03	0.02	0.04	0.00	0.10
Cement (23941)	3.21	4.16	-0.15	2.35	0.02	9.59
Textile (13)	2.64	0.67	-0.62	-1.32	0.13	1.51
Pulp & Paper (1701)	0.66	-1.07	2.07	0.66	0.12	2.43
Basic Metal & Steel (2410)	0.72	-0.99	0.21	-1.15	-0.05	-1.26
Total	**12.51**	**4.82**	**1.88**	**0.22**	**0.25**	**19.68**

Source: BPS (processed). 2010-2015

The results of the decomposition of changes in CO2 emissions in energy-intensive industries during the period 2010-2015 can be seen in (Table 2). Changes in CO2 emissions due to the effect of economic activity resulted in an increase in CO2 emissions in all energy-intensive industrial sectors, where the highest effects occurred in the cement, food, textile and chemical industries of 3.21 million tons of CO2, 2.81 million tons of CO2, 2.64 million tons and 1.3 million tons of CO2, respectively. Meanwhile, in other sub-sectors, the increase in CO2 emissions due to the effect of economic activity was below 1 million tons of CO2. This occurred because industrial economic activity was measured by the value of production of all sub-sectors of energy-intensive industries in Indonesia based on constant prices in 2010. During the period 2010 to 2015, real production from energy-intensive industries has increased from 898.92 trillion rupiah to 1,504.01 trillion rupiah or an increase of around 40.23% and experienced fairly stable growth every year.

The increase in CO2 emissions due to changes in the industrial economic structure occurred in the food, beverage, chemical, glass, ceramics, cement and textile industries. However, in some sub-sectors, changes in the economic structure of the industry show a decrease in CO2 emissions such as in the fertilizer, rubber, pulp & paper as well as base metals and steel industries. This shows that there has been a change in the structure of energy-intensive industries to low energy intensive during the period 2010-2015 which is in line with the decrease in the proportion of production output of the four industries.

The energy intensity effect also shows positive value in most energy-intensive industries except for the beverage, chemical, cement and textile industries. A negative value on the effect of energy intensity indicates a change in CO2 emissions through a reduction in energy consumption required to produce one unit of industrial output, it shows that efforts to mitigate CO2 through energy efficiency have begun to be applied to some of these industries. This is in line with the issuance of Peraturan Presiden Nomor 61 Tahun 2011 Tentang Rencana Aksi Nasional Penurunan Emisi Gas Rumah Kaca (GRK) which regulates energy conservation and audit policies, one of which is in the cement industry sector which is the highest contributor to CO2 emissions among other energy-intensive industries. Although the effect caused has not been significant enough in reducing CO2 emissions in the cement industry because the cement production process requires high temperatures and involves a lot of energy (Barbhuiya, Bhusan Das, & Adak, 2024). However, energy efficiency policies in the cement industry are the right first step to reduce CO2 emissions in energy-intensive industries.

The negative value of the effect of energy composition structure in energy-intensive industries indicates a decrease in CO2 emissions due to changes in the structure of energy composition) such as those in the food, beverage, chemical, rubber, textile and base metals and steel industries. However, the positive value of the effect of energy composition structure in several industries shows that fossil energy consumption in energy-intensive industries is still quite high, this is in line with research Ali et al. (2021) which states that fossil energy is still an option in economic activities, especially in developing countries. Meanwhile, the effect of emission coefficients has not shown a significant impact on reducing CO2 emissions in energy-intensive industries, even showing a considerable increase in emissions in the chemical, textile and pulp & paper industries. Therefore, the effect of emission coefficients needs to be driven through the energy transition of the energy transition that initially uses high-carbon energy (coal, gasoline and diesel) to lower carbon (gas and LPG) or clean energy (zero carbon).

CONCLUSION

CO2 emissions in energy-intensive industries during the period 2010-2015 increased in almost all sectors. Based on the results of the decomposition analysis using the LMDI method, industries that have experienced a fairly high increase, namely the cement, food, pulp & paper, chemical and textile industries. The effects of changes in economic activity, industrial economic structure and energy intensity are the main factors that contribute to the increase in CO2 emissions in the industry. The structural effect of energy composition has a considerable contribution to the increase in CO2 emissions in the cement industry and the decrease in CO2 emissions in the textile and base metals & steel industries. Meanwhile, the effect of emission coefficients has not shown a significant contribution to the increase or decrease in CO2 emissions. Therefore, the recommended policy recommendations to reduce CO2 emissions in energy-intensive industries. First, encouraging clean production activities through the use of energy-efficient and low-carbon technology and revitalizing inefficient and energy-intensive production machines in energy-intensive industries. Second, the development of Artificial Intelligence (AI) and Internet of Things (IoT) in the production process such as smart meters (electricity, water and others) in order to control energy use and CO2 emissions produced so that they become considerations in the implementation of efficiency policies and energy transition.

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