International Journal of Business and Society, Vol. 20 S1, 2019, 91-106

DECOMPOSITION ANALYSIS OF DECOUPLING OF MANUFACTURING CO_2 EMISSIONS IN INDONESIA

Zaekhan
Universitas Indonesia

Nachrowi Djalal Nachrowi♣
Universitas Indonesia

Andi Fahmi Lubis
Universitas Indonesia

Widyono Soetjipto
Universitas Indonesia

ABSTRACT

This study aims to identify ways to effectively reduce CO_2 emissions from Indonesia's manufacturing industry sector. We use the log mean decomposition index method to decompose CO_2 emissions from this sector in the period 2010–2014. Then, we apply a decoupling index method to analyze the correlation between CO_2 emissions and manufacturing industry growth. The findings indicate that growth in the manufacturing industry was the main driver of increasing CO_2 emissions, whereas reduction in energy intensity and energy consumption structure played an important role in limiting these emissions. Relative decoupling was observed in 2012–2013, implying that the manufacturing industry grew while decreasing CO_2 emissions during that limited period. However, no decoupling was identified in the other years of the study period. The novelty of this study relative to others in the literature stems from the combination of these methods. Although many studies have focused on energy consumption and CO_2 emissions, no extant study is devoted to decomposing CO_2 emissions and decoupling them from manufacturing industry growth in Indonesia.

Keywords: CO_2 emissions; Manufacturing industry; Decomposition; Decoupling

1. INTRODUCTION

Climate change is regarded as an urgent global environmental problem (Akbostanci, Tunç, & Asık, 2011; Wang, Liu, Zhang, & Li, 2013; Zhang & Da, 2015). Climate change is occurring because of a significant increase in greenhouse gas (GHG) emissions resulting from the accelerated consumption of fossil fuels and land use changes (Akbostanci et al., 2011; Francey, Trudinger, van der

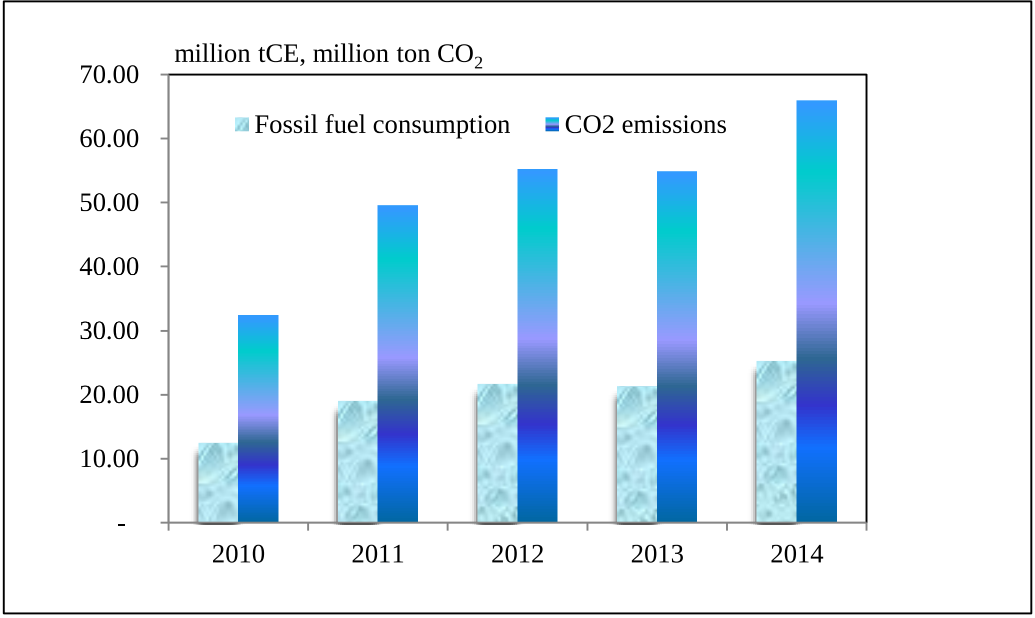
---

♣ Corresponding author: Graduate Program in Economics, Faculty of Economics and Business, Universitas Indonesia, Depok 16424, West Java, Indonesia; e-mail: nachrowi@ui.ac.id.

Schoot, Law, Krummel, Langen-felds, … Rödenbeck, 2013). The World Resources Institute estimates that approximately 61.4% of global GHG emissions derive from fossil fuel consumption. Of principal concern is CO_2, which accounts for 60% of the total GHGs (Ozturk & Acaravci, 2010; Akbostanci et al., 2011; Zhang & Da, 2015). In addition, other GHGs include methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFC).

The manufacturing industry is responsible for almost a third of fossil fuel consumption in the world and 36% of global CO_2 emissions (Yan & Fang, 2015). According to the Handbook of Energy and Economic Statistics of Indonesia (Ministry of Energy and Mineral Resource, 2016), the manufacturing industry accounts for the largest share of fossil fuel energy use in the country at 42% in 2014. The high fossil fuel consumption in the energy mix of the manufacturing industry sector causes high CO_2 emissions in the sector (Ministry of Industry, 2012). Figure 1 plots the fossil fuel consumption and CO_2 emissions of the Indonesian manufacturing industry in 2010–2014. During this period, CO_2 emissions increased by 104%. This drastic increase is alarming from the perspective of environmental sustainability. Therefore, reducing CO_2 emissions from manufacturing is important for Indonesia and other countries. Increased productivity, energy efficiency, energy conservation, and minimization of waste generation (CO_2 emission mitigation) should be on the agenda of the Indonesian manufacturing sector.

Figure 1: Fossil Fuel Consumption and CO_2 Emissions of Indonesian Manufacturing Industry



Data Source: Indonesian Large and Medium Industry Statistics, Statistics Indonesia (2017), Authors' calculations

Considering the aforementioned facts, as well as pressure from the increasingly vocal international community, the Indonesian government committed during the G-20 meeting in Pittsburgh to reduce greenhouse gas emissions by 26% by 2020, and possibly to 41% if international assistance is received. Given its geographical position, Indonesia is vulnerable to the impacts of climate change;

thus, mitigation efforts are necessary (Presidential Decree, 2011). The Indonesian government has sought to address environmental concerns by strengthening economic policies through pro-growth, pro-job, pro-poor, and pro-environment strategies. Presidential Decree No. 61 in 2011 on the National Action Plan for GHG Emissions Reduction is a pertinent example of such policies. The Ministry of Industry (2012), through its Master Plan for Green Industry Development (MPGID), implemented one of these action plans; one focus is to mitigate the CO_2 emissions from the manufacturing sector. To this end, we have identified the relative effects of the factors that lead to increased CO_2 emissions while analyzing the decoupling of CO_2 emissions and manufacturing industry growth in Indonesia.

In the literature, several studies have examined the correlation between economic activity, energy consumption, and environmental pollution. One method often used to identify and analyze the correlation of economic activity and energy consumption on CO_2 emissions is decomposition analysis. Improved understanding from applications of decomposition analysis in this context can be applied to inform policy decisions by addressing the most relevant driving forces of CO_2 emissions (IEA, 2014). Decomposition analysis is defined as the separation of the identity of a variable into its components. The changes in the components of this variable may explain the change in these variables (Rose & Miernyk, 1989). Decomposition analysis may be simple or complex depending on data availability and the purpose of the analysis.

Two well-known decomposition analysis methods are index decomposition analysis (IDA) and structural decomposition analysis (SDA) (Zhang, Mu, Ning, & Song, 2009). The fundamental difference these two methods is IDA uses the concept of index numbers, whereas SDA uses the input-output model (Ma & Stern, 2008; Zhang et al., 2009). In practical implementation, the IDA method is better able to analyze time and country dynamics in detail because of the availability of data (Lim, Yoo, & Kwak, 2009). Ang and Zhang (2000) introduced two IDA techniques, namely, Laspeyres IDA and Divisia IDA. In decomposing CO_2 emissions, the Divisia IDA method has an advantage over the Laspeyres variant (Ang, 2005; Cahill & Gallach, 2012) because the former is able to accommodate zero-values data. The Divisia IDA method is divided further into Arithmetic Mean Divisia Index and Logarithmic Mean Divisia Index (LMDI) methods. The benefit of the LMDI method is that it is easy to use, and complete decomposition is possible without residuals; furthermore, it is amenable to both additive and multiplication decomposition, and can be applied to short time series (Su & Ang, 2012).

The LMDI method is widely used in numerous studies quantitatively to identify the relative impact of various factors on energy consumption and CO_2 emissions. A number of studies on CO_2 emissions have been conducted in China. These studies concentrate primarily on overall trends and factors that affect CO_2 emissions according to the LMDI decomposition method, proceeding from aggregate national-scale analyses using Kaya identities (Wang, Chen, & Zou, 2005; Freitas & Kaneko, 2011; Xu, He, & Long, 2014; Zhang & Da, 2015; Shahiduzzaman & Layton, 2015; Moutinho, Au-Yong-Olivera, Coelho, & Manso, 2015) to manufacturing sector investigations using IDA identities developed by Ang (Liu, Fan, Wu, & Wei, 2007; Shao, Yang, Yu, Mingbo, & Yu, 2011; Wang & Nie, 2012; Zhu, 2012; Hammond & Norman, 2012; Chang, Mu, & Li, 2013; Ren, Yin, & Chen, 2014; Yan & Fang, 2015). Some of these studies are summarized in Table 1.

Table 1: Literature on CO_2 Emission Decomposition in Manufacturing Industry

Author	Research Objective	Country/Regional
Liu et al. (2007)	Changes of CO_2 emissions in Chinese industrial sectors	China
Shao et al. (2011)	Estimates energy-related industrial CO_2 emissions (ICE) and summarizes ICE's characteristics	Shanghai, China
Wang and Nie (2012)	Estimate of economic growth contribution, economic structure, energy intensity, and energy mix on CO_2 emissions	China
Zhu (2012)	Analysis of changes in CO_2 emissions in Chinese manufacturing industry	China
Hammond and Norman (2012)	Decomposition analysis method on carbon emissions in UK manufacturing	UK manufacturing
Chang et al. (2013)	Decomposition of CO_2 emissions in Chinese manufacturing industry	China
Ren et al. (2014)	Explores factors of CO_2 emissions in Chinese manufacturing industry	China
Yan and Fang (2015)	Investigates influencing factors on changes of CO_2 emissions by using LMDI method	China

Based on the above literature, the LMDI method (Ang, 2005) is used to identify the main factors causing CO_2 emissions in the Indonesian manufacturing industry. Ang (2004) provides a useful summary of the advantages and disadvantages of various methods and concludes that the LMDI method is the most preferred because of its superior theoretical foundation, adaptability, ease of use, and interpretability.

In addition, this study invokes the decoupling concept, which is important in the field of environmental–economic integration (Enevoldsen, Ryelund, & Andersen, 2007). This decoupling concept has gained global recognition and the Organization for Economic Cooperation and Development (OECD, 2010) developed it as an environmental indicator. For example, Climent and Pardo (2007) examined the correlation of GDP and energy consumption in Spain with respect to specific decoupling factors. Diakoulaki and Mandaraka (2007) adopted the concept to evaluate the progress in reducing CO_2 emissions from industrial growth in 14 European Union countries. Freitas and Kaneko (2011) examine the decoupling of CO_2 emissions and economic activity growth in Brazil in 2004–2009. Several concepts of and methods for measuring the decoupling exist, but no consensus has been reached on their relative strengths and weaknesses (Zhong, Huang, Han, & Wang, 2010). Therefore, the decoupling index analysis method is more effective when combined with other analytical methods such as decomposition analysis (Freitas & Kaneko, 2011).

For an improved understanding of how CO_2 emissions have evolved in the Indonesian manufacturing industry, this study serves as an initial effort to implement a combination of LMDI methods with the decoupling index method to analyze the contribution of factors that affect CO_2 emissions in this industry in 2010–2014. The novelty of this study relative to others in the literature stems from its combination of both of these methods. In addition, although many studies focus on energy consumption and CO_2 emissions, no extant study is devoted to decomposing CO_2 emissions and its decoupling from manufacturing industry growth in Indonesia.

The rest of this paper is organized as follows. Section 2 presents the research methods and describes the empirical data. Section 3 documents and explores the analytical results. Finally, Section 4 provides conclusions and policy implications.

2. RESEARCH METHODS

2.1. Data

The fundamental data used in this study refers to fuel consumption and industrial output values taken from statistics and surveys of large and medium manufacturing industries and prepared by the Statistics Indonesia. Data are organized on the various types of fuel used in different manufacturing companies. The data include all firms that consume fuel in aggregated form. Based on the large and medium industry statistics, fuels that are consistently consumed in the Indonesian manufacturing industry are gasoline, diesel oil, kerosene, coal, natural gas, liquefied petroleum gas (LPG), and electricity. These fuel types are considered in this study. Data are collated (Table 2) on fuel consumption and output (2000 constant prices) for each manufacturing industry in 2010–2014. Then, CO_2 emissions data are calculated from fossil fuel energy consumption data based on the Intergovernmental Panel on Climate Change (IPCC) method described in sub-chapter 2.2.

Table 2: Related Energy Data (10^3 tce) and Output (10^9 Rp)

	Gasoline	**Diesel oil**	**Kerosene**	**Coal**	**Natural gas**	**LPG**	**Electricity**	**Output**
2010	503	4713	95	3971	377	329	2519	2208
2011	571	6474	75	8334	543	168	2844	2618
2012	781	9681	121	7102	492	129	3400	2870
2013	804	6801	125	8268	1035	219	4049	3289
2014	1388	8070	252	6783	1253	237	7324	3624

Sources: Indonesian Large and Medium Industry Statistics, Statistics Indonesia (2017)

2.2. Estimation of CO_2 emissions

The method used to estimate CO_2 emissions is that recommended by the IPCC Guidelines for National Greenhouse Gas Inventories. This calculation method is based on fossil fuel consumption and carbon emission factors (IPCC, 2006). According to the IPCC, CO_2 emissions can be estimated using Equation 1.

$$C = \sum_{ij} C_{ij} = \sum_{ij} E_{ij}.\eta_j.O_j.\frac{44}{12} = \sum_{ij} E_{ij}.f_{ij} \tag{1}$$

where subscript *i* denotes sector, subscript *j* is fuel type, *C* indicates CO_2 total emissions, C_{ij} is CO_2 emissions sector *i* derived from fuel consumption *j*, E_{ij} indicates fuel consumption *j* in sector *i*, η_j indicates fuel carbon emissions factor *j*, O_j indicates carbon oxidation fraction of fuel *j*, 44/12 is the relative molecular weight ratio of carbon dioxide (CO_2) and carbon, and f_{ij} indicates fuel-type CO_2 emission factor j in sector i after conversion into standard coal equivalent units.

The coefficient of carbon emission factors for all fuels changes over time due to the advancement of energy efficiency or energy grade changes. As CO_2 emission factors to fuel are assumed constant, we can estimate this emission factor using the average net calorific value parameter, CO_2 conversion coefficient, carbon–oxygen efficiency, and conversion value to convert fuel consumption units to coal equivalent standards (IPCC, 2006). Table 3 shows the results.

Table 3: CO_2 Emission Factor of Fuel Type

Fuel type	**CO_2 emissions factor (*f*) (tCO_2/tce)**
Gasoline	2.029
Diesel oil	2.168
Kerosene	2.104
Coal	2.769
Natural gas	1.642
LPG	1.846
Electricity	3.249

Sources: IPCC (2006) and Ministry of Energy and Mineral Resource (2016)

Notes:

1. Unit of tCO_2/tce indicates 1 ton of CO_2 generated by 1 tce of fuel source
2. CO_2 emission factor of fuel type (*f*) =
(average net calorific × η × O × (44/12)) / conversion value to transform coal equivalent standards

2.3. CO_2 Emission Changes: Decomposition

This study uses the Log Mean Decomposition Index (LMDI), to determine the main factors that contribute to CO_2 emissions in the Indonesian manufacturing industry (Ang, 2005). Some of the practical advantages of the LMDI method are the following: it perfectly decomposes in a mathematical sense, leaving no residuals (IpekTunç, Türüt-As & Akbostancı, 2009) and the zero value in the data set can be replaced with a small positive constant value (Liu et al., 2007). Furthermore, LMDI is the most preferred method in the context of index decomposition analyses (Shao et al., 2011) being adopted widely because of its ease of formulation. LMDI is also consistent in aggregation (Ang & Liu, 2007). Other advantages of this method are its strong theoretical foundations, adaptability, and interpretability (Ang, 2004).

Based on the LMDI method, the CO_2 total emissions in the manufacturing industry (denoted by C) can be decomposed into the following five determinants:

(1) effect of industrial economic activity (denoted by *Q*), which represents the total output of the Indonesian manufacturing industry;
(2) effect of industrial economic structure (denoted by *S*), which represents the relative share of industrial output in the total output of the Indonesian manufacturing industry;
(3) effect of energy intensity (denoted by *I*), which represents the ratio of industrial fossil energy consumption and the value of industrial output;

(4) effect of energy mix (denoted by M), which represents the composition of fossil energy in the energy consumption total of the Indonesian manufacturing industry;
(5) effect of emission coefficient (denoted by *U*), which represents the average emission factor of fossil energy use; this factor describes an energy mix used in electric and heat utilities due to constant emission factors for conventional fuels.

The manufacturing CO_2 emissions decomposition model is as follows:

$$C = \sum_{ij} C_{ij} = \sum_{ij} Q.\frac{Q_i}{Q}.\frac{E_i}{Q_i}.\frac{E_{ij}}{E_i}.\frac{C_{ij}}{E_{ij}} = \sum_{ij} Q.S_i.I_i.M_{ij}.U_{ij} \qquad (2)$$

where *i* indicates sector, *j* indicates fuel type, *C* is CO_2 total emissions, and C_{ij} indicates CO_2 emissions from fuel consumption *j* in sector *i*; Q_i indicates the output in sector *i*, Q $(= \Sigma_i Q_i)$ indicates the total output of industrial economic activity, and S_i $(= Q_i/Q)$ indicates the proportion of sector economic activity *i*; E_i indicates the total fuel consumption in sector *i*, and I_i $(= E_i/Q_i)$ indicates the energy intensity in sector *i*; E_{ij} indicates fuel consumption *j* in sector *i* $(E_i = \Sigma_j E_{ij})$; M_{ij} $(= E_{ij}/E_i)$ indicates energy mix in total fuel consumed by sector *i*; and U_{ij} $(= C_{ij}/E_{ij})$ indicates the CO_2 emission factor of fuel consumption *j* in sector *i*.

In general, the decomposition method can be expressed as follows:

$$V = \sum_i V_i = \sum_i x_{1,i} x_{2,i} \ldots x_{n,i} \qquad (3)$$

In the additive decomposition method, the change is decomposed as follows:

$$\Delta V_{tot} = V^T - V^0 = \Delta V\, x_1 + \Delta V\, x_2 + \ldots + \Delta V\, x_n \qquad (4)$$

where subscript *tot* refers to total change, superscripts *T* and *0* respectively refer to periods *T* and *0*, and the term of the right-hand segment is the factor effects. The general equation for the *k*th factor effect in Equation (4) in the LMDI approach can be generalized as follows:

$$\Delta V_{xk} = \sum\nolimits_{\mathrm{i}} L(V_i^T, V_i^0) \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right) = \sum\nolimits_{\mathrm{i}} \frac{(V_i^T - V_i^0)}{(\ln V_i^T - \ln V_i^0)} \times \ln\left(\frac{x_{k,i}^T}{x_{k,i}^0}\right) \qquad (5)$$

Specifically, the additive decomposition of CO_2 emissions becomes its component parts (Ang, 2005) as shown in the following equation:

$$\Delta C_{tot} = C^T - C^0 = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{mix} + \Delta C_{emf} \qquad (6)$$

The subscripts *act*, *str*, *int*, *mix*, and *emf* on the right side of Equation 6 show the effects related to industrial economic activity, industrial economic structure, industrial energy intensity, industrial energy mix, and emission coefficient factors. These components are presented in the following equations:

$$\Delta C_{act} = \sum\nolimits_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(\ln C_{ij}^T - \ln C_{ij}^0)} \ln\left(\frac{Q^T}{Q^0}\right) \qquad (6a)$$

$$\Delta C_{str} = \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(\ln C_{ij}^T - \ln C_{ij}^0)} \ln\left(\frac{S_i^T}{S_i^0}\right) \tag{6b}$$

$$\Delta C_{int} = \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(\ln C_{ij}^T - \ln C_{ij}^0)} \ln\left(\frac{I_i^T}{I_i^0}\right) \tag{6c}$$

$$\Delta C_{mix} = \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(\ln C_{ij}^T - \ln C_{ij}^0)} \ln\left(\frac{M_{ij}^T}{M_{ij}^0}\right) \tag{6d}$$

$$\Delta C_{emf} = \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(\ln C_{ij}^T - \ln C_{ij}^0)} \ln\left(\frac{U_{ij}^T}{U_{ij}^0}\right) \tag{6e}$$

Using the decomposition components defined in (6a), (6b), (6c), (6d), and (6e), we describe the total of change in CO_2 emissions for the Indonesian manufacturing industry in 2010–2014.

2.4. Decoupling Index Formulation

We combine the LMDI method approach and the decoupling index method to analyze the decoupling of CO_2 emissions and Indonesian manufacturing industry growth. Based on the definitions given by Diakoulaki and Mandaraka (2007), efforts include measures to reduce energy intensity (lower energy intensity), switching to clean fuel alternatives (cleaner energy consumption), and a shift toward industries with less energy use (upgrading of industrial structures); these efforts refer to any action that directly or indirectly induces reductions in energy-related CO_2 emissions. Thus, the total absolute effort (ΔF^T) during the period from 0 to T can be explained as the difference between the total change in CO_2 emissions and change in CO_2 emissions due to the effect of industrial economic activity or as the sum of CO_2 emissions from the four effect factors in Equation (6). Therefore, we use ΔF^T to represent total CO_2 emission-inhibiting effects as follows:

$$\Delta F^T = \Delta C_{tot}^T - \Delta C_{act}^T = \Delta C_{str}^T + \Delta C_{int}^T + \Delta C_{mix}^T + \Delta C_{emf}^T \tag{7}$$

If the sum of the change in CO_2 emissions from the four effect factors is negative, then ΔF^T becomes negative, which means that it results in CO_2 emission reduction. To assess the extent to which this effort is effective in separating CO_2 emissions from growth in industrial economic activity, we define the D^T decoupling index during the period from base year 0 to target year T as follows:

$$\text{If } \Delta C_{act}^T \geq 0\text{, then } D^T = -\frac{\Delta F^T}{\Delta C_{act}^T} \tag{8}$$

$$\text{If } \Delta C_{act}^T < 0\text{, then } D^T = \frac{\Delta F^T - \Delta C_{act}^T}{\Delta C_{act}^T} \tag{9}$$

As Equation (8) refers to the effect of positive industrial economic activity, the decoupling index can be determined for each effect of the equation, and the value obtained can assist in identifying the relative contribution of each of the effect factors to the overall decoupling process. Thus, the decoupling index of the overall process becomes equal to the sum of the partial decoupling indices in the following:

$$D^T = -\frac{\Delta F^T}{\Delta C_{act}^T} = -\frac{\Delta C_{str}^T}{\Delta C_{act}^T} - \frac{\Delta C_{int}^T}{\Delta C_{act}^T} - \frac{\Delta C_{mix}^T}{\Delta C_{act}^T} - \frac{\Delta C_{emf}^T}{\Delta C_{act}^T} = D_{str}^T + D_{int}^T + D_{mix}^T + D_{emf}^T \quad (10)$$

where D^T is the manufacturing decoupling index; D_{str}^T, D_{int}^T, D_{mix}^T, and D_{emf}^T are the influences of industrial economic structure, industrial energy intensity, fuel consumption structure (industrial energy mixture), and emission factors, respectively. If $D^T \geq 1$, which indicates an absolute decoupling effect, then we can say that the sum of the effect factors inhibiting CO_2 emissions is greater than the effect factors of industrial economic activity. If $0 < D^T < 1$, then relative decoupling is apparent and we can conclude that the effect of CO_2 emission reduction appears weaker than the effect factors of industrial economic activity. Finally, if $D^T < 0$, then no decoupling occurs and we can conclude that the sum of the effect factors inhibiting CO_2 emissions is not prominent enough to significantly reduce CO_2 emissions. If the value of D_{str}^T, D_{int}^T, D_{mix}^T, and $D_{emf}^T > 0$, then we can say that the CO_2 emission-inhibiting factors such as industrial economic structure, industrial energy intensity, fuel consumption structure, and emission coefficient factors are substantive enough to contribute toward decoupling. Conversely, if the result is less than 0, then these factors do not contribute to decoupling (Wang et al., 2013; Zhang & Da, 2015).

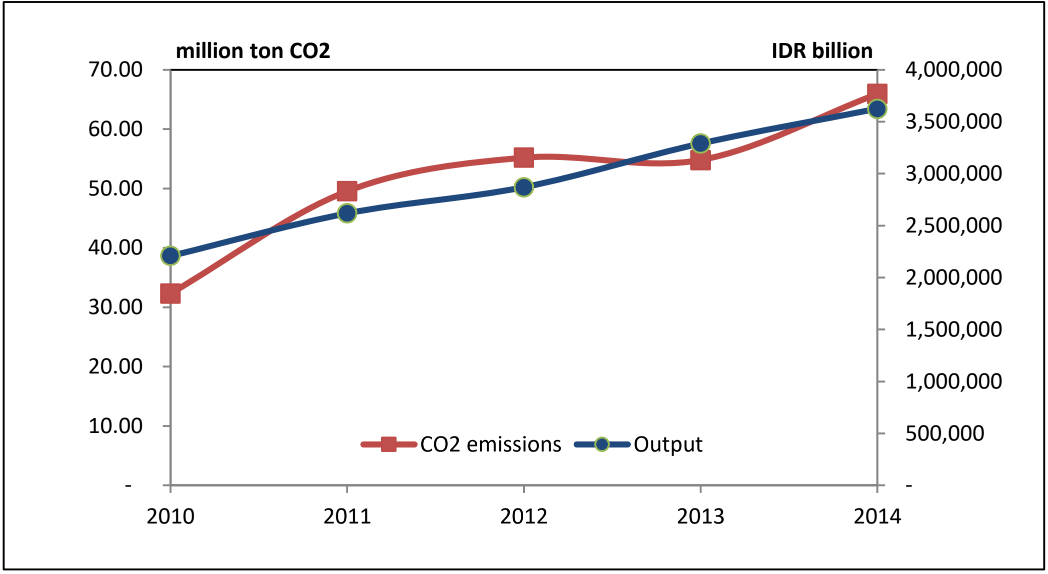
3. RESULTS AND DISCUSSION

3.1. Analysis of Energy-Related CO_2 Emissions

In this section, we consider the major descriptive statistical aspects of energy consumption data on the Indonesian manufacturing industry and estimated CO_2 emissions. Figure 1 plots the CO_2 emissions and energy consumption in the industry during 2010–2014. Not surprisingly, both data series appear co-integrated given that direct CO_2 emissions are derived from the energy consumption data. The calculation of the corresponding CO_2 emissions from fossil energy in the Indonesian manufacturing industry for 2010–2014 used the method presented in the estimation of CO_2 emissions. From 2010 to 2014, CO_2 emissions in the Indonesian manufacturing industry increased by 104% with an average annual growth of approximately 21%. If observed at annual time steps, changes in CO_2 emissions fluctuate but tend to increase continuously. In 2010–2012, a significant increase was initially observed, and then a slight decrease occurred in the period 2012–2013 before the upward trajectory was restored in 2013–2014.

Figure 2 presents a comparison between CO_2 emissions and real output of the Indonesian manufacturing industry in 2010–2014. In 2010–2012, CO_2 emissions increased at a rate that exceeded the increase in real output, leading to an increase in CO_2 emission intensity in the sector. However, in 2012–2013, CO_2 emissions declined despite further increases in real output; thus, CO_2 emission intensity decreased. Finally, in 2013–2014, CO_2 emissions increased, again resulting in intensified CO_2 emissions. In a broad sense, the intensity of CO_2 emissions in 2010–2014 increased despite fluctuating IDR.

Figure 2: Indonesian Manufacturing Industry CO_2 Emissions and Real Output



3.2. Decomposition Analysis

Tables 4 and 5 present the decomposition analysis results. Table 4 shows the contribution of each component described in Equations (6a)–(6e) in million tons of CO_2 emissions, while Table 5 presents the percentage contribution of each component to the total of change in CO_2 emissions. These results show that the main drivers of the dynamics of total CO_2 emissions are changes in industrial economy activity (ΔC_{act}) and industrial energy intensity (ΔC_{int}). According to the table, total CO_2 emissions increased sharply in 2010–2011, increased slightly in 2011–2012, decreased in 2012–2013, and then increased again in 2013–2014. These findings are consistent with the CO_2 emission data presented in Figures 1 and 2.

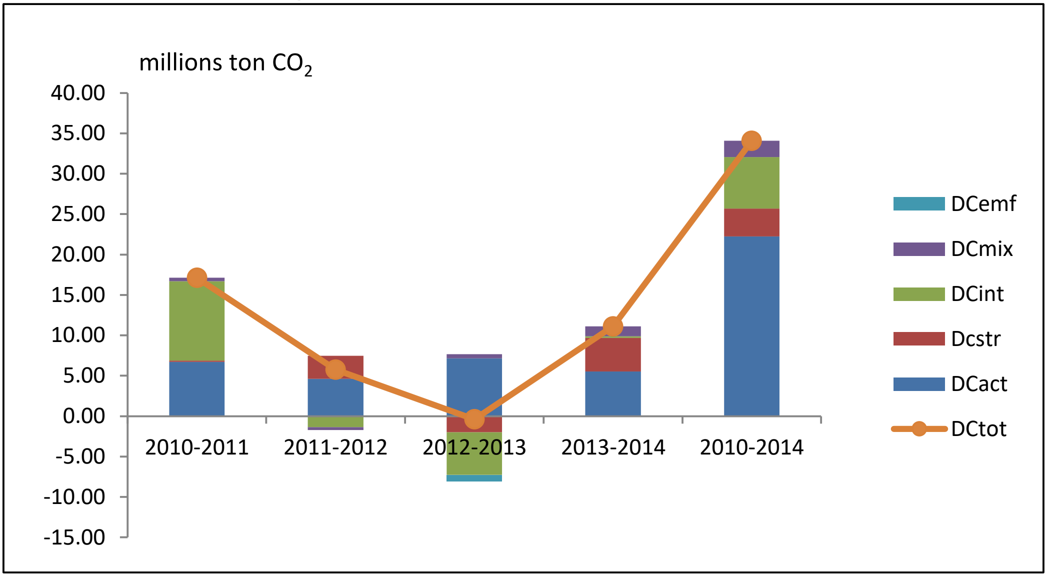
Table 4: Decomposition Analysis Results (million tons of CO_2)

Period	ΔC_{act}	ΔC_{str}	ΔC_{int}	ΔC_{mix}	ΔC_{emf}	ΔC_{tot}
2010–2011	6.61	0.21	9.66	0.45	0.00	16.93
2011–2012	4.57	2.75	-1.26	-0.25	0.00	5.81
2012–2013	7.12	-1.98	-5.27	0.34	0.00	0.21
2013–2014	5.54	4.16	0.18	1.25	0.00	11.12
2010–2014	22.24	3.47	6.37	1.99	0.00	34.07

Table 5: Results of Decomposition Analysis (percentage)

Period	ΔC_{act}	ΔC_{str}	ΔC_{int}	ΔC_{mix}	ΔC_{emf}	ΔC_{tot}
2010–2011	39.06	1.23	57.05	2.49	0.00	100.00
2011–2012	51.76	31.14	14.27	2.83	0.00	100.00
2012–2013	48.40	13.46	35.83	2.31	0.00	100.00
2013–2014	49.83	37.38	1.58	11.21	0.00	100.00
2010–2014	65.27	10.19	18.71	5.84	0.00	100.00

Figure 3: Component of CO_2 Emission Change



The overarching finding of the annual component decomposition analysis is that none of the results shows a stable pattern over the entire 2011–2014 period. As shown in Table 5 and Figure 3, the increase in CO_2 emissions during 2010–2011 is mainly due to increases in industrial energy intensity and industrial economic activity, which amounted to 9.66 million tons of CO_2 and 6.61 million tons of CO_2, respectively. The slight increase in CO_2 emissions in 2011–2012 can be explained by the increase in industrial economic activity and is offset by a slight decrease in industrial energy intensity of 4.57 million tons of CO_2 and 1.26 million tons of CO_2, respectively. The decrease in CO_2 emissions from Indonesia's manufacturing industry, as observed in 2012–2013, is due to the continuing decline in industrial energy intensity, which is becoming more pronounced than the increase in industrial economic activity. Changes in industrial economic structure also contributed to the mitigation of CO_2 emissions in this period. Over 2013–2014, the increase in CO_2 emissions was mainly due to increased industrial economic activity, changes in industrial economic structure, industrial energy intensity, and industrial fuel mix structure. In general, the largest contributors to CO_2 emission change during 2010–2014 are industrial economic activity (65.27%) and industrial energy intensity (18.71%).

3.3. Decoupling Analysis

Tables 6 and 7 present the decoupling effect analysis results between CO_2 emissions and growth of the Indonesian manufacturing industry as well as the effect of industrial economic structure, industrial energy intensity, and changes in industrial energy mix structure on the decoupling index or decoupling effect.

Table 6: Results of Decoupling Effect Analysis

Period	D_{str}	D_{int}	D_{mix}	D_{emf}	D_{tot}	Decoupling effect
2010–2011	-0.03	-1.46	-0.07	0.00	-1.56	No decoupling
2011–2012	-0.60	0.28	0.05	0.00	-0.27	No decoupling
2012–2013	0.28	0.74	-0.05	0.00	0.97	Relative decoupling
2013–2014	-0.75	-0.03	-0.23	0.00	-1.01	No decoupling
2010–2014	-0.16	-0.29	-0.09	0.00	-0.53	No decoupling

Table 7: Factor Contribution to Decoupling Effect (percentage)

Period	D_{str}	D_{int}	D_{mix}	D_{emf}	D_{tot}
2010–2011	2.02	93.62	4.36	0.00	100.00
2011–2012	64.52	30.11	5.38	0.00	100.00
2012–2013	26.17	69.16	4.67	0.00	100.00
2013–2014	74.51	3.14	22.35	0.00	100.00
2010–2014	29.33	53.86	16.80	0.00	100.00

The total decoupling index revolves around negative values (<0) for most of the study period, indicating the absence of decoupling effect between CO_2 emissions and the growth of the Indonesian manufacturing industry. The CO_2 emission reduction derived from the inhibiting effect factors is less robust than the driving effect factors caused by the growth of industrial economic activity. That is, as industrial economic activity grows, CO_2 emissions also increase. Inhibiting factors, such as industrial economic structure, industrial energy intensity, and changes in the energy mixture structure, have no role to play in reducing CO_2 emissions and instead contribute to increased CO_2 emissions along with manufacturing industry growth. In particular, in the 2010–2011, 2011–2012, and 2013–2014 periods, the CO_2 emission growth rates were 53%, 11%, and 20%, respectively, with a mean of 21% over the entire 2010–2014 study period.

However, the decoupling index in 2012–2013 was 0.97 ($0 < D^T < 1$), indicating a relative decoupling effect in this period, which means that growth in industrial economic activity accompanies CO_2 emission reduction. However, the CO_2 emission reduction derived from the inhibiting effect factors such as industrial energy intensity appears to be weaker than the driving effect of industrial economic activity. This result is mainly due to the Indonesian government's commitment to reduce CO_2 emissions by issuing Presidential Decree No. 61 in 2011 concerning the National Action Plan for Greenhouse Gas Emission Reduction, which was implemented by the Ministry of Industry with a focus on CO_2 emission mitigation in the manufacturing industry. The application of this commitment was only temporary because in 2013–2014, the decoupling index again became negative.

The effect of changes in industrial energy intensity on decoupling (D_{int}) was negative in 2010–2014, thereby implying that separation between CO_2 emissions and manufacturing industry growth has not occurred. Overall D_{int} accounted for 53.86% of the decoupling index total (D_{tot}) in 2010–2014. In particular, the contribution of industrial energy intensity fluctuates on the decoupling process, appearing significant in the 2011–2012 and 2012–2013 periods with the effect of relative separation over other periods. For example, in 2012–2013, relative decoupling occurred with a reduction in industrial energy intensity to 5.27 million tons of CO_2 (Table 4). This result means that industrial energy intensity, as the most important inhibiting factor of CO_2 emissions, is the largest contributor to the decoupling process.

The effect of changes in industrial economic structure on decoupling (D_{str}) was always negative during the study period except in 2012–2013. This finding suggests that the industrial economic structure does not contribute to the separation between CO_2 emissions and manufacturing industry growth except in 2012–2013. In 2012–2013, the effect of changes in the industrial economic structure on decoupling contributed 26.17% to the total decoupling index. The effect of changes in the industrial economic structure on decoupling was weaker relative to the effect of industrial energy intensity, accounting for only 29.33% of the decoupling index total in 2010–2014.

The effect of changes in the energy mixture structure of final energy consumption on decoupling (D_{mix}) tended to be negative during the study period except in 2011–2012. Thus, changes in the energy consumption structure do not contribute to the separation between CO_2 emissions and manufacturing industry growth. In 2011–2012, its contribution was too trivial to have an impact on decoupling. Based on the literature, changes in the energy consumption structure should contribute to the decoupling effect because it is similar to industrial energy intensity, which mainly contributes to the CO_2 emission reduction effect in the clean energy consumption structure. This result means that the Indonesian government and the manufacturing industry have not significantly harnessed low-carbon energy sources.

Finally, relative decoupling effect occurred between CO_2 emissions and the Indonesian manufacturing industry growth in 2012–2013, although no such decoupling was observed in other periods (Table 6). This result shows that industrial growth affected decoupling from time to time. Therefore, the target factors contributed to the separation of CO_2 emissions and the manufacturing sector growth. These results suggest that the Indonesian government must take effective measures to reduce energy intensity, change the industrial structure and support an economy-wide transition to low-carbon energy sources.

4. CONCLUSIONS

Our findings show that the main drivers of the changes in CO_2 emissions in the Indonesian manufacturing industry in 2010–2014 were the changes in industrial economic activity and industrial energy intensity. In the 2012–2013 periods, the change in industrial energy intensity was the driving force behind the reduction of CO_2 emissions. However, in other periods, the components of industrial economic activity appeared to dominate the changes in CO_2 emissions. Another important finding is that the differences in fuel type and fuel mixture structure are the decisive factors behind the changes in CO_2 emissions in 2011–2012. Furthermore, no decoupling effect was observed between CO_2 emissions and manufacturing industry growth in 2010–2014, whereas a relative decoupling effect was observed in 2012–2013. The relative decoupling effect shows that although the decrease in industrial energy intensity and changes in industrial economic structure played an important role in promoting decoupling with significant progress during that period, no decoupling effect was observed in other periods such that promotion appeared weak due to ineffective growth in the manufacturing industry.

This finding suggests the need for strategic policy interventions to reduce CO_2 emissions without affecting the growth of the Indonesian manufacturing industry. Thus, to decouple the CO_2 emissions and the Indonesian manufacturing industry growth, we can utilize the target factors that contribute to the separation. Furthermore, the Indonesian government must take effective measures to reduce industrial energy intensity by modifying the industrial economic structure and changing the industrial energy mix structure. To achieve energy savings and solve environmental problems, specifically to curb CO_2 emissions in the Indonesian manufacturing industry, Presidential Decree No. 61 in 2011 can help improve energy efficiency and cope with CO_2 emissions, although this policy may be insufficient to realize important changes in reducing energy consumption and CO_2 emissions. Indonesia should also reduce its dependence on fossil energy sources in the long term and focus on cleaning up its energy sources. In general, we can conclude that using clean energy sources and new energy-efficient technologies in the Indonesian manufacturing industry will be an important step to reduce CO_2 emissions.

As sustainable development has become an important global topic, the Indonesian government should not only pursue economic efficiency but also improve energy conservation and environmental quality. Based on the findings of this study, the strategic measures for sustainable development should aim to (1) decrease the intensity of energy consumption, especially in the energy-intensive manufacture sector; (2) promote the shift of industrial economic structure to industries with less intensive energy use; (3) promote access to low-carbon energy sources in the energy mix structure; and (4) encourage the import of energy-intensive products.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support provided by Universitas Indonesia. We also thank the anonymous referees and other parties involved for their helpful suggestions and corrections to improve the quality of this manuscript.

REFERENCES

Akbostanci, E., Tunç, G. I., & Asık, S. T. (2011). CO_2 emissions of Turkish manufacturing industry: A decomposition analysis. *Applied Energy*, *88*(6), 2273–2278.

Ang, B., & Zhang, F. (2000). A survey of index decomposition analysis in energy and environmental analysis. *Energy*, *25*(12), 1149-1176.

Ang, B. (2004). Decomposition analysis for policymaking in energy: Which is the preferred method. *Energy Policy*, *32*(9), 1131-1139.

Ang, B. (2005). The LMDI approach to decomposition analysis: a practical guide. *Energy Policy*, *33*(7), 867-871.

Ang, B., & Liu, N. (2007). Handling zero values in the logarithmic mean divisia index decomposition approach. *Energy Policy*, *35*(1), 238-246.

Cahill, C. J., & Gallach, B. P. O. (2012). Combining physical and economic output data to analyze energy and CO_2 emissions trends in the industry. *Energy Policy, 49*, 422-429.

Chang, L., Mu, H. L., & Li, H. N. (2013). Decomposition of energy-related CO_2 emissions over 2001 and 2011 in the manufacturing industry of China. *Advanced Material Research, 807-809*, 927-935.

Climent, F., & Pardo, A. (2007). Decoupling factors on the energy-output linkage: The Spanish case. *Energy Policy, 35*(1), 522–528.

Diakoulaki, D., & Mandaraka, M. (2007). Decomposition analysis for assessing the progress in decoupling industrial growth from CO_2 emissions in the EU manufacturing sector. *Energy Economics, 29*(4), 636–664.

Enevoldsen, M. K., Ryelund, A. V., & Andersen, M. S. (2007). Decoupling of industrial energy consumption and CO_2 emissions in energy-intensive industries in Scandinavia. *Energy Economics, 29*(4), 665–692.

Francey, R. J., Trudinger, C. M., van der Schoot, M., Law, R. M., Krummel, P. B., Langen-felds, R.L., … Rödenbeck, C. (2013). Atmospheric verification of anthropogenic CO_2 emission trends. *Nature Climate Change, 3*, 520–524.

Freitas, L. C., & Kaneko, S. (2011). Decomposing the decoupling of CO_2 emissions and economic growth in Brazil. *Ecological Economics, 70*(8), 1459–1469.

Hammond, G., & Norman, J. (2012). Decomposition analysis of energy-related carbon emissions from UK manufacturing. *Energy, 41*(1), 220-227.

Intergovernmental Panel on Climate Change (IPCC). (2006). *IPCC Guidelines for national greenhouse gas inventories.* Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2006). *IPCC guidelines for national green-house gas inventories*. Japan: IPCC.

International Energy Agency (IEA). (2014). CO_2 emissions from fuel combustion. Paris: IEA.

Ipek Tunç, G., Türüt-As¸ K, S., & Akbostancı, E. (2009). A decomposition analysis of CO_2 emissions from energy use: Turkish case. *Energy Policy, 37*(11), 4689-4699.

Lim, H., Yoo, S., & Kwak, S. (2009). Industrial CO_2 emissions from energy use in Korea: A structural decomposition analysis. *Energy Policy*, *37*(2), 686-698.

Liu, L. C., Fan, Y., Wu, G., & Wei, Y. M. (2007). Using LMDI method to analyze the change of China's industrial CO_2 emissions from final fuel use: an empirical analysis. *Energy Policy*, *35*(11), 5892-5900.

Ma, C., & Stern, D. I. (2008). China's changing energy intensity trend: a decomposition analysis. *Energy Economics*, *30*(3), 1037-1053.

Ministry of Energy and Mineral Resouce (MEMR). (2016). *Handbook of energy and economic statistics of Indonesia* (HEESI). Indonesia.

Ministry of Industry (MI). (2012). Master plan for *green industry development* (MPGID). Indonesia.

Moutinho, R., Au-Yong-Olivera, M., Coelho, A., Manso, J. P. (2015). Beyond th**e** "Innovation's Black-Box": Translating R & D outlays into employment and economic growth. *Socio-Economic Planning Sciences, 50,* 45-58.

Organisation for Economic Co-operation and Development (OECD). (2010). Indicators to measure decoupling of environmental pressure from economic growth. *Sustainable Development*. OECD publications.

Ozturk, I., & Acaravci, A. (2010). CO_2 emissions, energy consumption and economic growth in Turkey. *Renewable Sustainable Energy Reviews, 14*(9), 3220–3225.

Presidential Decree (PD) . (2011). *Presidential Decree No. 61 of 2011*: *National action plan for greenhouse gas emission reduction*. Indonesia.

Ren, S., Yin, H., & Chen, X. H. (2014). Using LMDI to analyze the decoupling of carbon dioxide emissions from China's manufacturing industry. *Environmental Development, 9,* 61–75.

Rose, A., & Miernyk, W. (1989). Input-output analysis: The first fifty years. *Economic System Research, 1*(2), 229–271.

Shahiduzzaman, M., & Layton, A. (2015). Changes in CO_2 emissions over business cycle recessions and expansions in the United States: A decomposition analysis. *Applied Energy, 150,* 25-35.

Shao, S., Yang, L., Yu, M, & Yu, M. (2011). Estimation, characteristics, and determinants of energy-related industrial CO_2 emissions in Shanghai (China), 1994-2009. *Energy Policy, 39*(10), 6476-6494.

Statistics Indonesia (SI). (2017). *Indonesian large and medium industry statistics* (ILMIS). Jakarta: SI.

Su, B., & Ang, B. W. (2012). Structural decomposition analysis applied to energy and emissions: Some methodological developments. *Energy Economics*, *34*(1), 177-188.

Wang, C., Chen, J., & Zou, J. (2005). Decomposition of energy-related CO_2 emission in China: 1957-2000. *Energy*, *30*(1), 73-83.

Wang, D., & Nie, R. (2012). The empirical study of Chinese manufacturing industry's carbon emission status and its influence factors. *Journal of Arid Land Resources and Environment, 26*(9), 132-136.

Wang, W., Liu, R., Zhang, M., & Li, H. (2013). Decomposing the decoupling of energy-related CO_2 emissions and economic growth in Jiangsu Province. *Energy for Sustainable Development*, *17*(1), 62-71.

Xu, S., He, Z., & Long, R. (2014). Factors that influence carbon emissions due to energy consumption in China: Decomposition analysis using LMDI. *Applied Energy, 127*, 182-193.

Yan, X., & Fang, Y. (2015). CO_2 emissions and mitigation potential of the Chinese manufacturing industry. *Journal of Cleaner Production, 103*, 759-773.

Zhang, M., Mu, H. L., Ning, Y. D., & Song, Y. C. (2009). Decomposition of energy-related CO_2 emission over 1991–2006 in China. *Ecological Economics*, *68*(7), 2122–2128.

Zhang, Y., & Da, Y. (2015). The decomposition of energy-related carbon emission and its decoupling with economic growth in China. *Renewable and Sustainable Energy Reviews, 41*, 1255-1266.

Zhong T. Y., Huang, X. J., Han, L., & Wang, B. Y., (2010). Review on the research of decoupling analysis in the field of environments and resource. *Journal Natural Resource*, *25*, 1400–1412.

Zhu, L. (2012). Analysis on the energy-related CO_2 emissions of Chinese manufacturing industry. Fudan University, Shanghai, China.