DECOMPOSITION ANALYSIS OF DECOUPLING OF MANUFACTURING CO₂ EMISSIONS IN INDONESIA

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ABSTRACT

This study aims to identify ways to effectively reduce CO₂ emissions from Indonesia’s manufacturing industry sector. We use the log mean decomposition index method to decompose CO₂ emissions from this sector in the period 2010–2014. Then, we apply a decoupling index method to analyze the correlation between CO₂ emissions and manufacturing industry growth. The findings indicate that growth in the manufacturing industry was the main driver of increasing CO₂ 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 CO₂ 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 CO₂ emissions, no extant study is devoted to decomposing CO₂ emissions and decoupling them from manufacturing industry growth in Indonesia.

Keywords: CO₂ emissions; Manufacturing industry; Decomposition; Decoupling

1. INTRODUCTION

Climate change is regarded as an urgent global environmental problem (Akbo, 2011; Wang, 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 (Akbo et al., 2011; Francey, Trudinger, van der...
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Schoot, Law, Krummelfelds, … Rödenbeck, 2013). The World Resources Institute estimates that approximately 61.4% of global GHG emissions derive from fossil fuel consumption. Of principal concern is CO₂, which accounts for 60% of the total GHGs (Ozturk & Acaravci, 2010; Akbostanci et al., 2011; Zhang & Da, 2015). In addition, other GHGs include methane (CH₄), nitrous oxide (N₂O), and chlorofluorocarbons (CFC).

The manufacturing industry is responsible for almost a third of fossil fuel consumption in the world and 36% of global CO₂ 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 CO₂ emissions in the sector (Ministry of Industry, 2012). Figure 1 plots the fossil fuel consumption and CO₂ emissions of the Indonesian manufacturing industry in 2010–2014. During this period, CO₂ emissions increased by 104%. This drastic increase is alarming from the perspective of environmental sustainability. Therefore, reducing CO₂ emissions from manufacturing is important for Indonesia and other countries. Increased productivity, energy efficiency, energy conservation, and minimization of waste generation (CO₂ emission mitigation) should be on the agenda of the Indonesian manufacturing sector.

**Figure 1:** Fossil Fuel Consumption and CO₂ Emissions of Indonesian Manufacturing Industry

![Figure 1](image_url)

*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 CO₂ Emission Decomposition in Manufacturing Industry

<table>
<thead>
<tr>
<th>Author</th>
<th>Research Objective</th>
<th>Country/Regional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liu et al. (2007)</td>
<td>Changes of CO₂ emissions in Chinese industrial sectors</td>
<td>China</td>
</tr>
<tr>
<td>Shao et al. (2011)</td>
<td>Estimates energy-related industrial CO₂ emissions (ICE) and summarizes ICE’s characteristics</td>
<td>Shanghai, China</td>
</tr>
<tr>
<td>Wang and Nie (2012)</td>
<td>Estimate of economic growth contribution, economic structure, energy intensity, and energy mix on CO₂ emissions</td>
<td>China</td>
</tr>
<tr>
<td>Zhu (2012)</td>
<td>Analysis of changes in CO₂ emissions in Chinese manufacturing industry</td>
<td>China</td>
</tr>
<tr>
<td>Chang et al. (2013)</td>
<td>Decomposition of CO₂ emissions in Chinese manufacturing industry</td>
<td>China</td>
</tr>
<tr>
<td>Ren et al. (2014)</td>
<td>Explores factors of CO₂ emissions in Chinese manufacturing industry</td>
<td>China</td>
</tr>
<tr>
<td>Yan and Fang (2015)</td>
<td>Investigates influencing factors on changes of CO₂ emissions by using LMDI method</td>
<td>China</td>
</tr>
</tbody>
</table>

Based on the above literature, the LMDI method (Ang, 2005) is used to identify the main factors causing CO₂ 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 CO₂ emissions from industrial growth in 14 European Union countries. Freitas and Kaneko (2011) examine the decoupling of CO₂ 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 CO₂ 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 CO₂ 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)

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel oil</th>
<th>Kerosene</th>
<th>Coal</th>
<th>Natural gas</th>
<th>LPG</th>
<th>Electric-ity</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>503</td>
<td>4713</td>
<td>95</td>
<td>3971</td>
<td>377</td>
<td>329</td>
<td>2519</td>
<td>2208</td>
</tr>
<tr>
<td>2011</td>
<td>571</td>
<td>6474</td>
<td>75</td>
<td>8334</td>
<td>543</td>
<td>168</td>
<td>2844</td>
<td>2618</td>
</tr>
<tr>
<td>2012</td>
<td>781</td>
<td>9681</td>
<td>121</td>
<td>7102</td>
<td>492</td>
<td>129</td>
<td>3400</td>
<td>2870</td>
</tr>
<tr>
<td>2013</td>
<td>804</td>
<td>6801</td>
<td>125</td>
<td>8268</td>
<td>1035</td>
<td>219</td>
<td>4049</td>
<td>3289</td>
</tr>
<tr>
<td>2014</td>
<td>1388</td>
<td>8070</td>
<td>252</td>
<td>6783</td>
<td>1253</td>
<td>237</td>
<td>7324</td>
<td>3624</td>
</tr>
</tbody>
</table>

*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.

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

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 $i$, $\eta_j$ 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 (CO₂) and carbon, and \( f_j \) indicates fuel-type CO₂ 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 CO₂ emission factors to fuel are assumed constant, we can estimate this emission factor using the average net calorific value parameter, CO₂ 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>
<thead>
<tr>
<th>Fuel type</th>
<th>CO₂ emissions factor ((f)) (tCO₂/tce)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>2.029</td>
</tr>
<tr>
<td>Diesel oil</td>
<td>2.168</td>
</tr>
<tr>
<td>Kerosene</td>
<td>2.104</td>
</tr>
<tr>
<td>Coal</td>
<td>2.769</td>
</tr>
<tr>
<td>Natural gas</td>
<td>1.642</td>
</tr>
<tr>
<td>LPG</td>
<td>1.846</td>
</tr>
<tr>
<td>Electricity</td>
<td>3.249</td>
</tr>
</tbody>
</table>


Notes:
1. Unit of tCO₂/tce indicates 1 ton of CO₂ generated by 1 tce of fuel source
2. CO₂ emission factor of fuel type \((f) = \) (average net calorific \( \times \eta \times O \times (44/12) \) / conversion value to transform coal equivalent standards

2.3. CO₂ Emission Changes: Decomposition

This study uses the Log Mean Decomposition Index (LMDI), to determine the main factors that contribute to CO₂ 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 CO₂ 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:

$$C = \sum_{ij} c_{ij} = \sum_{ij} q_i \cdot \frac{q_i}{Q} \cdot \frac{E_{ij} \cdot c_{ij}}{E_i} = \sum_{ij} q_i \cdot S_i \cdot I_i \cdot M_{ij} \cdot U_{ij}$$  \hspace{1cm} (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 $i$, $Q = \sum Q_i$ 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 $i$ ($E = \sum_i E_{ij}$); $M_{ij} = E_{ij} / E_i$ 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:

$$V = \sum_{i} V_i = \sum_{i} x_{1,i} x_{2,i} \ldots x_{n,i}$$  \hspace{1cm} (3)

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

$$\Delta V_{tot} = V^T - V^0 = \Delta V x_1 + \Delta V x_2 + \ldots + \Delta V x_n$$  \hspace{1cm} (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:

$$\Delta V_{xk} = \sum_{i} L(V_i^T, V_i^0) \ln \left( \frac{x_{k,i}^T}{x_{k,i}^0} \right) = \sum_{i} \frac{q_i^T - q_i^0}{(\ln V_i^T - \ln V_i^0)} \times \ln \left( \frac{x_{k,i}^T}{x_{k,i}^0} \right)$$  \hspace{1cm} (5)

Specifically, the additive decomposition of CO$_2$ emissions becomes its component parts (Ang, 2005) as shown in the following equation:

$$C^T - C^0 = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{mix} + \Delta C_{emf} \hspace{1cm} \Delta C_{tot} =$$  \hspace{1cm} (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:

$$\Delta C_{act} = \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0)}{(\ln C_{ij}^T - \ln C_{ij}^0)} \ln \left( \frac{q_{ij}^T}{q_{ij}^0} \right)$$  \hspace{1cm} (6a)
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\[ \Delta C_{str} = \sum_{ij} \frac{(c_{ij}^T - c_{ij}^0)}{(\ln c_{ij}^T - \ln c_{ij}^0)} \ln \left( \frac{s_i^T}{s_i^0} \right) \]  

(6b)

\[ \Delta C_{int} = \sum_{ij} \frac{(c_{ij}^T - c_{ij}^0)}{(\ln c_{ij}^T - \ln c_{ij}^0)} \ln \left( \frac{i_i^T}{i_i^0} \right) \]  

(6c)

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

(6d)

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

(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 (\(\Delta F^T\)) 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 \(\Delta F^T\) to represent total CO\(_2\) emission-inhibiting effects as follows:

\[ \Delta F^T = \Delta C_{tot}^T - \Delta C_{act}^T = \Delta C_{str}^T + \Delta C_{int}^T + \Delta C_{mix}^T + \Delta C_{emf}^T \]  

(7)

If the sum of the change in CO\(_2\) emissions from the four effect factors is negative, then \(\Delta F^T\) 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:

\[ \text{If } \Delta C_{act}^T \geq 0, \text{ then } D^T = -\frac{\Delta F^T}{\Delta C_{act}^T} \]  

(8)

\[ \text{If } \Delta C_{act}^T < 0, \text{ then } D^T = \frac{\Delta F^T - \Delta C_{act}^T}{\Delta C_{act}^T} \]  

(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:
\[ D^T = - \frac{\Delta P^T}{\Delta c_{\text{act}}} = - \frac{\Delta c_{\text{str}}^T}{\Delta c_{\text{act}}} - \frac{\Delta c_{\text{int}}^T}{\Delta c_{\text{act}}} - \frac{\Delta c_{\text{mix}}^T}{\Delta c_{\text{act}}} - \frac{\Delta c_{\text{emf}}^T}{\Delta c_{\text{act}}} = D_{\text{str}}^T + D_{\text{int}}^T + D_{\text{mix}}^T + D_{\text{emf}}^T \] (10)

where \( D^T \) is the manufacturing decoupling index; \( D_{\text{str}}^T, D_{\text{int}}^T, D_{\text{mix}}^T, \) and \( D_{\text{emf}}^T \) 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 \( D_{\text{str}}^T, D_{\text{int}}^T, D_{\text{mix}}^T, \) and \( D_{\text{emf}}^T > 0 \), 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.
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 ($\Delta C_{act}$) and industrial energy intensity ($\Delta C_{int}$). 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.

![Figure 2: Indonesian Manufacturing Industry CO$_2$ Emissions and Real Output](image_url)

### Table 4: Decomposition Analysis Results (million tons of CO$_2$)

<table>
<thead>
<tr>
<th>Period</th>
<th>$\Delta C_{act}$</th>
<th>$\Delta C_{str}$</th>
<th>$\Delta C_{int}$</th>
<th>$\Delta C_{mix}$</th>
<th>$\Delta C_{emf}$</th>
<th>$\Delta C_{tot}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010–2011</td>
<td>6.61</td>
<td>0.21</td>
<td>9.66</td>
<td>0.45</td>
<td>0.00</td>
<td>16.93</td>
</tr>
<tr>
<td>2011–2012</td>
<td>4.57</td>
<td>2.75</td>
<td>-1.26</td>
<td>-0.25</td>
<td>0.00</td>
<td>5.81</td>
</tr>
<tr>
<td>2012–2013</td>
<td>7.12</td>
<td>-1.98</td>
<td>-5.27</td>
<td>0.34</td>
<td>0.00</td>
<td>0.21</td>
</tr>
<tr>
<td>2013–2014</td>
<td>5.54</td>
<td>4.16</td>
<td>0.18</td>
<td>1.25</td>
<td>0.00</td>
<td>11.12</td>
</tr>
<tr>
<td>2010–2014</td>
<td>22.24</td>
<td>3.47</td>
<td>6.37</td>
<td>1.99</td>
<td>0.00</td>
<td>34.07</td>
</tr>
</tbody>
</table>
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 CO₂ 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 CO₂ and 6.61 million tons of CO₂, respectively. The slight increase in CO₂ 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 CO₂ and 1.26 million tons of CO₂, respectively. The decrease in CO₂ 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 CO₂ emissions in this period. Over 2013–2014, the increase in CO₂ 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 CO₂ emission change during 2010–2014 are industrial economic activity (65.27%) and industrial energy intensity (18.71%).
Tables 6 and 7 present the decoupling effect analysis results between CO₂ 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.

The total decoupling index revolves around negative values (<0) for most of the study period, indicating the absence of decoupling effect between CO₂ emissions and the growth of the Indonesian manufacturing industry. The CO₂ 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, CO₂ 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 CO₂ emissions and instead contribute to increased CO₂ emissions along with manufacturing industry growth. In particular, in the 2010–2011, 2011–2012, and 2013–2014 periods, the CO₂ 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™<1), indicating a relative decoupling effect in this period, which means that growth in industrial economic activity accompanies CO₂ emission reduction. However, the CO₂ 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 CO₂ 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 CO₂ 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 ob-
served between CO₂ 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 CO₂ emissions without affecting the growth of the Indonesian manufacturing industry. Thus, to decouple the CO₂ 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 CO₂ emissions in the Indonesian manufacturing industry, Presidential Decree No. 61 in 2011 can help improve energy efficiency and cope with CO₂ emissions, although this policy may be insufficient to realize important changes in reducing energy consumption and CO₂ 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 CO₂ 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.

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