Determinants of CO_2 emission intensity: Manufacturing firm-level evidence in Indonesia

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Melisa Constantia

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Members of the Examining Committee:

Elissaios Papyrakis

Lorenzo Pellegrini

The Hague, The Netherlands

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Disclaimer:

Inquiries:

International Institute of Social Studies
P.O. Box 29776
2502 LT The Hague
The Netherlands

t: +31 70 426 0460
e: info@iss.nl
w: www.iss.nl
fb: http://www.facebook.com/iss.nl
twitter: @issnl

Location:

Kortenaerkade 12
2518 AX The Hague
The Netherlands

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Contents

List of Tables

List of Figures

List of Appendices

List of Acronyms

AFOLU	Agricultural, Forestry and Other Land Use
IPCC	Intergovernmental Panel on Climate Change
IPPU	Industrial Processes and Product Use
ISIC	Indonesian Standard of Industrial Classification Code

Abstract

Using a firm-level dataset from the Indonesian large and medium manufacturing sector, this paper investigates the energy usage performance and the main factors that are related to carbon dioxide emission intensity of manufacturing firms, from 2011 to 2014. Although food, beverages; fabricated metal and machinery; and non-metallic mineral are three primary energy-intensive sectors, only the latter had high energy intensity. Meanwhile food industry and fabricated metal and machinery show low energy intensity due to their high value-added. This paper also presents an estimation of carbon dioxide emission due to fuels consumption of firms. During the period of study, the trend of carbon emission has increased, but the carbon emission intensity has shown improvement. Performing panel data framework, this study uses OLS, 2SLS, and fixed effect model in analysing the determinants of CO_2 intensity. The result of the FE regressions suggests that larger firms are emission efficient compared to small sized firms. Similarly, capital and labor intensive firms are less-carbon intensive. Furthermore, firms that spend more on maintenance have emitted more. This perhaps due to the adoption of high maintenance equipment by emission-intensive firms that requires for more expanses.

Relevance to Development Studies

Fossil fuels are the most important natural resource that human use for everyday life. On the one side, the non-renewable energy can boost economic growth and human development. On the other side, the excessive consumption of natural energy can cause global climate change, natural disasters, air pollution, and regional disparities. These issues have become global challenges for many years, yet the effect has been worsening. As a matter of fact, the emerging countries that rely on industrial development to keep their economy growing, undeniably, needs fossil fuels as an energy source. However, the fossil fuel combustion generates CO_2 emission which will cost highly on human and animal health, environment damage, food supply changes, and poverty. As economic development must be achieved in environmental sustainability way, the study related to economic sector and emissions is important to be conducted. This paper tries to examine energy consumption, energy intensity, and CO_2 emission intensity in Indonesian manufacturing sector, as the country is being acknowledged as one of the highest contributors of CO_2 emission. The results of this study may provide information and insight to the policymakers to formulate and impose regulations related to energy, emissions, and manufacture.

Keywords

Fossil fuels, coal, energy intensity, CO_2 intensity, Indonesia, manufacturing, panel data, fixed effect.

CHAPTER 1. INTRODUCTION

1.1 Background

Climate change has become an issue of concern for humanity in many years. According to World Health Organization (2018), climate change is projected to cause 250.000 deaths per year between period 2030 and 2050. Also, it is estimated would cost to health around US$ 2-4 billion per year by 2030. On environment side, the increase of heat in atmosphere is associated with sea level rise, flooding, forest fires, drought, and even species extinction (Intergovernmental Panel on Climate Change-IPCC, 2018). Indonesia also faces the climate change threat which have impacts on various aspect of its economy and development. As an archipelagic country with thousands small islands and low-lying area, Indonesia is the most vulnerable countries affected by global warming. The losing of small islands because of the increasing of sea level, the tidal flooding in big cities such as Jakarta and Semarang and the increasing of sea surface temperature in Java and Eastern Indonesia's seas are just a few examples of the real consequences of global warming. Certainly, these conditions have cost highly. Based on Indonesia Long-Term Strategy report (2021), the increase of sea level rises up to 0.8 m affecting several kilometres in Cirebon area causes losses more than IDR 1.29 trillion per ha/year. Similarly, the tidal flooding in Semarang and Jakarta is estimated will cost more than IDR 6.1 trillion and IDR 4.7 trillion, respectively. Not only those, the threats will affect the people's livelihoods as their work capacity decreases which further increase the people living in poverty.

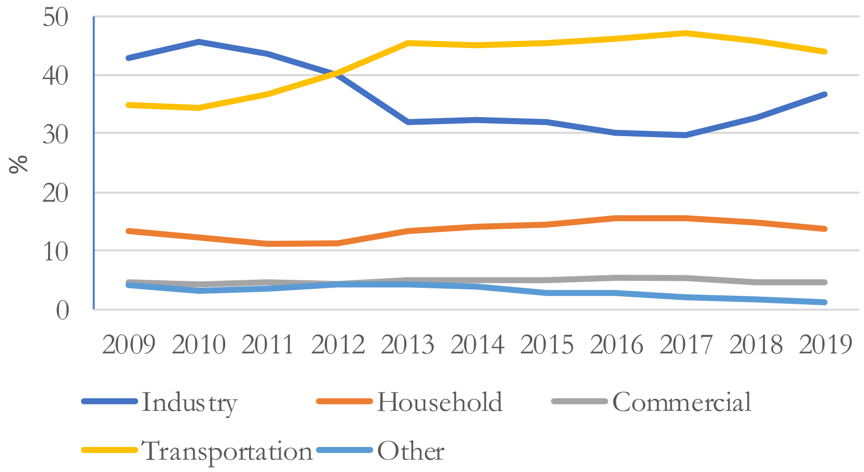
Global warming is primarily caused by carbon dioxide emissions. The IPCC reports that human activities have caused global warming of approximately 1.0^{0}C above pre-industrial levels with increasing at 0.2^{0}C per decade. These activities such as, manufacture operation, heating, transportation operation, and electricity generation, are mostly using fossil fuels as their energy sources. Yet, fossil fuels combustion that release carbon dioxide emissions are accounted for the largest share of climate change. International Energy Agency (IEA) in 2017 claimed that the use of energy was the largest source of emissions by estimated share of 68%, followed by large-scale biomass burning, agriculture, and industrial processes at 14%, 12% and 7%, respectively. The global demand of fossil fuels (coals, oils, and natural gas) is undeniably still high, although there has been shifting to renewable energy in some European countries. Germany, as the leading country of renewable energy consumer, has shifted to using renewable energy at 12.74% of their total energy consumption. United Kingdom, Sweden, Spain, and Italy also has replaced its fossil fuels with renewable energy at 11.95%, 10.96%, 10.17%, and 8.8%, respectively (Gordon, 2019). However, the global demand for fossil fuels is also expected to increase 6.2% (oil), 4.5% (coal), 3.2% (natural gas) in 2021, with the growth concentrated in emerging markets (IEA, 2021)[a].

Many studies show that the high fossil energy consumption coincides with the rapid economic growth in developing countries which result in the increase of carbon emission level (Vo, et. al., 2019; Hwang and Yoo, 2012; Sahu and Narayanan, 2010). However, some literature suggests that economic growth cause deterioration in the initial stage, but after the adoption of high technologies, it might lead to environmental improvement. International Energy Agency (IEA) recently states that emerging markets now account for over two thirds of carbon emission globally and its levels in 2021 is predicted to increase as the world economic gradually recover from Covid-19 pandemic. Indonesia, as the largest economy in Southeast Asia, also faces the issue of the accumulation of carbon dioxide to the environment.

The Indonesian economy has grown rapidly after economic reform in trade and investment in the mid-1980s. The reform boosted the manufacturing sector as the primary growth-driver that pushed GDP grew at an average of 8% per year (Kuncoro, 2018). Now, Indonesia is one of the emerging markets in the world, and is ranked at 16th as the biggest economy with a GDP of US$ 1.12 trillion as of 2019 (World Bank, 2021). In addition, the manufacturing industry contributes to 19.7% of GDP in the same year (Statistics Indonesia, 2020). Along with the rapid economic development, Indonesia inevitably faces excessive energy demand and environmental issues such as pollutions. **Figure 1.1** presents the share of final energy consumption with two sectors, industry and transportation, as the largest energy consumers. From 2009 to 2012, industrial sector was dominating the energy usage, while from 2012 onward, transportation sector took over with the consumption reaching 414.98 million BOE (*barrel oil equivalent*) in 2019. This is also followed by the increasing of carbon emission level in Indonesia. IEA (2017) states that Indonesia is one of the largest contributors of emission in Asia, after China and India. Emissions grew at 230% faster than the global level at 56.5% in 1990-2015 (Hastuti et al., 2020).

Figures 1.1

Share of final energy consumption by sector (own construction)



Source: Ministry of Energy and Mineral Resources (2020)

One of ways to develop low carbon strategy in energy sectors is to improve energy efficiency. Feng et al. (2009) argue that energy intensity can be considered as an indicator of energy efficiency and development of economic in certain area. Energy intensity is defined as the ratio of energy consumption to gross domestic products (IEA, 2017)[b]. A study by Setyawan (2020) provides a result that the value-added from manufacturing sector has grown continuously with average of 5% per year along with the lower rate of growth in energy consumption. This means that energy intensity of this sector has improved over time. IEA (2021)[b] also reveals that between 2014-2018, the growth of energy consumption in Indonesia has followed by improvements of energy intensity due to shifting of economy activities from energy-intensive industrial sector to less-intensive manufacturing and service sectors. However, the trend of carbon emission level from manufacture sector has increased in the last seven year (Kementerian Energi dan Sumber Daya Mineral, 2020).

As those findings interesting, therefore, it is important to identify which sub-sectors of manufacturing have energy intensity improvement, so that this study provides evidence and information for policymakers to conduct regulation related to energy consumption and energy intensity in the manufacturing sector. Moreover, the concerning fact of increasing carbon emissions pushes author to investigate the driving forces affecting CO_2 emission level in Indonesian manufacturing, with concentrating on firm characteristics. Thus, this paper tries to examine whether foreign ownership affects the emissions intensity; whether larger enterprises benefit from its economies of scale and thus release less emissions per unit of output than smaller enterprises; whether firms with higher export intensity are less emission intensive; whether levels of maintenance expenditure affect pollution intensity; and whether capital intensive and labor intensive firms emit less per unit of output.

A previous study in Indonesia examining pollution- haven and halo hypothesis by Brucal, et al. (2017) shows that for the period 1983-2001, firms with foreign shareholders increases total energy consumption and CO_2 emissions due to the increasing production scale or expansion, thus, it decreases the energy intensity and emissions intensity of the firms. This implies that the firms improve its efficiency in using energy inputs to produce unit of output in lower energy and carbon content. Meanwhile Ramstetter and Narjoko (2014) argue that the correlation between plant ownership and total energy intensity was generally weak. Soytas et al. (2007) examine the association between carbon dioxide emissions, energy consumption, and level income in the US. They found that energy use is the prominent contributor of emissions, but the association between income and carbon emissions is not significant. Furthermore, other existing literature using a standard OLS approach suggests that exports activity has significant negative relation to CO_2 emission intensity, meaning exporters firms appear to have better environmental performance than non-exporters (Cole et al., 2013).

Since the study on a panel approach at the firm level in Indonesia is very limited, it is important to conduct research on the impact of firm characteristics on CO_2 emissions using plant-level data. The unavailability of carbon dioxide emission data at the plant level might be one of the reasons why there is no recent study in this literature at firm level, particularly in Indonesia. As the best of our knowledge, this paper is the first study in Indonesia which use data survey of manufacturing firms to calculate carbon emissions and further use it to analyse determinants of carbon dioxide emissions intensity. Besides, the micro level data might generate more reliable findings than the macro level data since the macro data are conducted from the supply side of the energy, and hence it may not represent the actual consumption of the firm. Thus, this research presents the results of estimation of the CO_2 emission from firm by comparing OLS, 2SLS, and fixed effects (FE) models over 2011-2014 by following bottom-up sectoral approach by IPCC Guidelines and associate it with the firm characteristics.

1.2 Contribution

The contribution of this study:

1. This study provides analysis of the energy consumption and energy intensity by calculating total energy use from firm's fuel consumption data in manufacture sectors. Since the data fuels usage are based on survey to the firms, therefore, it may provide more reliable data for their actual fuel consumption. Comparing energy intensity across sectors is important for understanding the production and consumption of the energy needs of the country. This analysis provides valuable information which may add to the literature of energy use in Indonesia. Also, the results might help policymakers to understand which sectors have energy intensity improvement and which sectors have inefficient in energy use.

2. The study of carbon emissions at the micro level is rare, especially in Indonesia. This is mostly due to unavailability of data which requires estimation of firm level emissions. Many studies have been conducted at the macro levels, such as at country or province levels, while only few studies provide calculation of CO_2 emissions from fossil fuels' firm data (Priambodo and Kumar, 2000; Brucal, Javorcik, and Love, 2017). However, Priambodo and Kumar used period of study 1993 and focused on small-medium enterprises without analysing the determinants of carbon intensity. Meanwhile Brucal, Javorcik, and Love analysed the impact of foreign shareholder acquisition on firm's performance in emitting pollution during period of 1983-2001. They calculated carbon emission using conversion factors from US energy institutions, unlike this study which follows the IPCC approach. For these reasons, to comprehensively identify the firm characteristic that affecting carbon emissions level with recent data and different method, this study attempts to perform analysis of large and medium enterprises in manufacture sector using panel data regression in the period of 2011-2014.

1.3 Research objectives and questions

The objective of this research is to provide information on energy intensity performance in across manufacturing sectors and fill the gap in the literature to empirically examine the determinants that associated with carbon dioxide emissions in Indonesia's manufacturing sectors.

Given the background and objectives above, this research tries to address the following research questions:

a. What was the performance of energy intensity of the firms in Indonesian manufacturing sectors during 2011-2014?
b. What are the determinants of carbon dioxide emissions of firms consuming different type of fuels in the Indonesian manufacturing sector?

1.4 Scope and Limitation

This research is conducted to examine the determinants of carbon emission intensity in Indonesian manufacturing sector on plant level data. Due to the lack of availability data in recent years, the study only covers the period of data analysis of the year 2011-2014. The latest annual data survey has been conducted in 2017. However, in 2016 Indonesia held Economic Census, thus; the country did not conduct annual survey manufacturing which the variables between census and survey are different. For reasons of compatibility of variables and consistency of time, this research uses data from 2011-2014. Also, this paper uses data of large and medium firms in manufacturing sectors due to this group accounts for 90% value added of aggregate manufacturing. The emission intensity analysis is based on the IPCC bottom-up approach by using data of the fuel consumption with different types of fossil fuel such as gasoline, diesel oil, kerosene, coal, coal briquettes, natural gas, LPG, and lubricants. Therefore, this study only considers the fossil fuels consumed by the firms. Furthermore, this study only focuses on one type of pollutant, carbon dioxide, as it is the most important greenhouse gas for global warming.

1.5 Structure of research paper

This paper is designed by six chapters. Chapter 1 provides the introduction of the study by presenting background, contribution, research objectives and research questions, scope and limitation. Chapter 2 reviews the relevant literature related to energy consumption, energy intensity, carbon emission intensity, and empirical study. Chapter 3 introduces the data collection and research methodology: estimation of energy intensity and CO_2 intensity, OLS estimation approach, 2SLS estimation, and fixed effects (FE) and fixed effects-instrumental variable (FE-IV). Chapter 4 reports the empirical results and its discussions. Lastly, Chapter 5 provides some conclusions.

CHAPTER 2. LITERATURE REVIEW

2.1. Energy sources – Fossil fuels

Fossil fuels are energy resources that are formed from living organism buried deep by sediments. They are also known as non-renewable since it takes long time to form them (Curley, 2012). As oil, coal, and natural gas are primary sources of energy that essential for human's life, both developed and developing countries' energy systems relies heavily on fossil fuels. IEA reported that fossil fuels account for 80% of all primary energy globally. Manufacture of goods and services needs the energy to support the production activity. Vehicles and electrical power generation also require fossil fuels for heating and converted to energy (Casper, 2010). However, the combustion of fossil fuels has many negative impacts to the environment. Since fossil fuels contain of high carbon content, when they are burned, they will release large quantities of carbon dioxide in the atmosphere, which drive environmental issues such as greenhouse gas accumulation, water pollution, acidification, and damage to land surface.

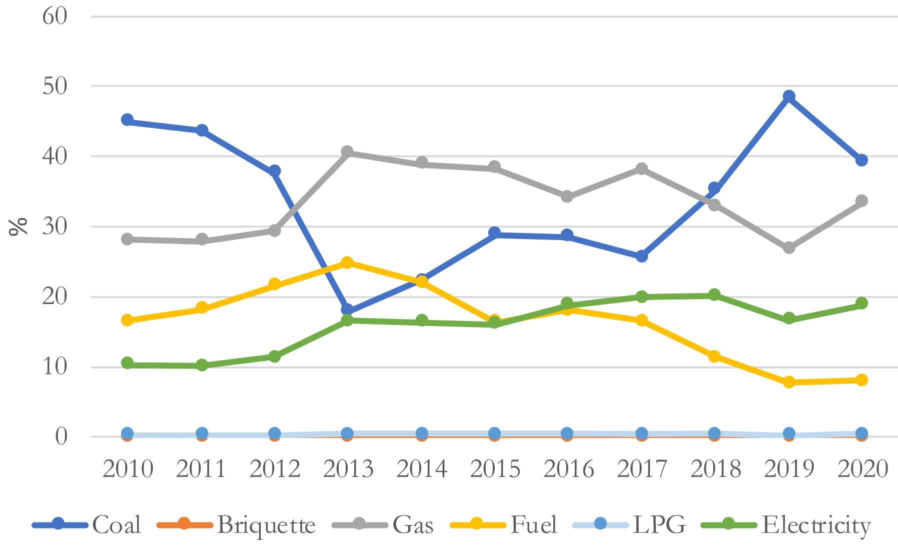
Casper (2010) states that for over 200 years, the fossil fuels combustion has caused more than 25% increase in the amount of carbon dioxide. In the combustion processes, different fuels produce different amounts of gas emissions. According to Enzler, about 30% of carbon dioxide emissions in the air is due to oil combustion, but the largest emissions are caused by coal burning. This because coal has high carbon content compared to other fossil fuels. On the other hand, natural gas only releases small amount of carbon dioxide with 43% less carbon emissions than coal and 30% fewer than oil (Casper, 2010).

According to bp's Statistical Review of World Energy report in 2020, the growth of global energy demand has slowed which coincide with weaker economic growth. However, countries such as China, India, and Indonesia show an increase in the primary energy consumption. China accounts for over three quarters of net global world, followed by India and Indonesia as the next biggest contributors. Interestingly, the report also shows that coal consumption declining with a shift of increase in natural gas and renewable energy consumption. Natural gas accounted 0.2% percentage point change in share from 2018 to 2019, while renewables energy reached 0.5%. In contrast, oil, coal, hydro, and nuclear experienced negative growth.

As already projected in 2025 National Mixed Energy Target, fossil fuels will become the main energy source and the largest share of energy portfolio of Indonesia (Ministry of National Development Planning, 2011). However, in 2014 the government has imposed Regulation 79/2014 on National Energy Policy to reduce coal use and renewable energy, and to achieve the efficiency of energy in all sectors. Compared to the consumption of renewable energy; coal and gas are dominating the share of energy use in industrial sector in Indonesia (see **Figure 2.1**). In 2020, the share of coal consumption at 39.38%, followed by gas at 33.47%. However, between 2013 and 2018, the consumption of gas was higher than coal (Ministry of Energy and Mineral Resources, 2021). Furthermore, according to National Energy Council (2019), gas and coal are predicted as the main energy sources in manufacturing until 2050. The consumption of gas would be dominated by metal, fertilizer, and ceramics industry with the total of 83% from the total gas demand in industry, while 90% of total demand of coal would be consumed by cement industry. On the other hand, food and paper industry is projected to increase the demand of renewable energy and biomass energy.

Figure 2.1.

Share of energy consumption in industrial sector (own construction)



Source: Ministry of Energy and Mineral Resources (2021)

As the fact that the world still relying on fossil energy, the issue of environmental is hard to be avoided. Climate change, global warming, and natural disasters caused by green-house gas emissions are closely associated with fossil fuels production and consumption. Environmentalists argued that to fight the climate change, it needs to reduce the use of fossil fuels. Casper (2010) suggested that regardless the innovative technologies are being developed to address environmental degradation, the practical way to decrease carbon dioxide emissions level is to improve its efficiency by produce more energy out of each weigh of fossil fuels which being measured by many researchers as energy intensity.

2.2. Energy intensity

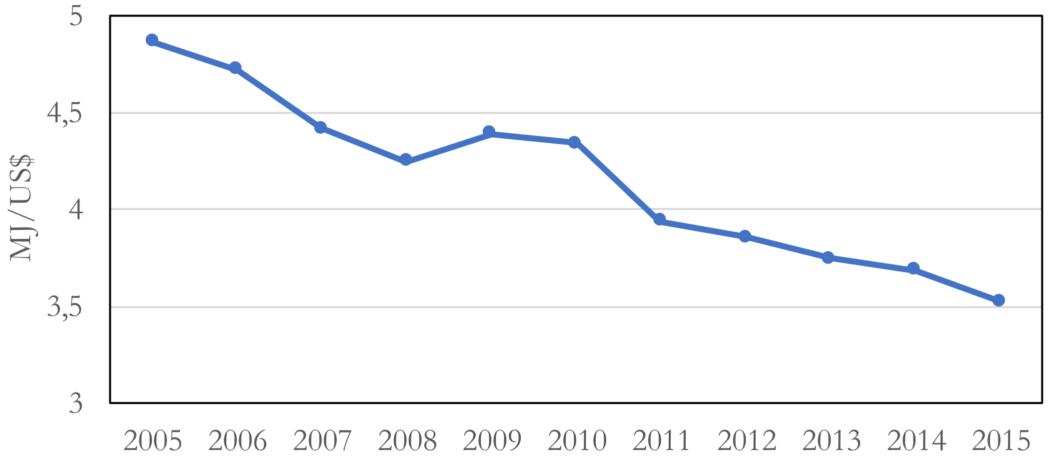
Energy intensity is defined as how much amount of energy is consumed to produce a dollar's worth of economic output (Rudenko and Tanasov, 2020). Furthermore, energy intensity indicator can be described energy use per production value, energy use per value added, energy use per passenger-km, etc. Meanwhile IEA (2018) defines energy intensity as the energy used per unit of GDP. The less energy use to produce a unit of GDP, the more competitive the economy's global, and provides an incentive for environmental sustainability. In other words, the improvement of energy intensity means reducing energy use without undermining economic output. The energy intensity is often used as a channel to estimate energy efficiency in the manufacturing sector (Dasgupta and Roy, 2017; Azhgaliyeva et al. 2020; Shen and Lin, 2020); however, Energy Information Administration (1995) states that energy intensity does not necessarily represent real energy efficiency since energy intensity is affected by many factors other than just energy efficiency, such as the economic structure and geographic characteristics.

Such a rapid economic development may lead to an increase in demand for energy. Indonesia's GDP at 2010 constant price per has climbed from 6,864 trillion rupiahs in 2010 to 10,949 trillion rupiahs in 2019 (Ministry of Energy and Mineral Resource, 2020). In the last decade, Indonesia's total primary energy supply also has increased from 1,075,175 thousand

BOE (2010) to 1,559,295 thousand BOE (2019). However, based on The World Bank data (**Figure 2.2),** the trend of energy intensity in Indonesia from 2005 to 2015 was decreasing indicates that there was an improvement in energy efficiency throughout the years. This estimation based on Indonesian total energy supply and gross domestic product measured in 2011 US$ purchasing power parity (PPP).

Figure 2.2.

Energy intensity level of primary energy (own construction)



Source: World Bank[b] (2021)

The manufacture process primarily uses heat to convert raw materials into finished goods which cause manufacturing as an energy intensive sector. Rudenko and Tanasov (2020) also state that in most cases the manufacture sector is more energy intensive meaning a higher level of industrial base result in an increase of energy demand and hence energy intensity. According to US Energy Information Administration-EIA (2016), there are three industry types: energy-intensive, nonenergy-intensive, and nonmanufacturing. Food and beverage, pulp and paper, chemical, refining, nonferrous metals, non-metallic minerals, and iron and steel, are considered as energy-intensive industries. Nonenergy-intensive industries are other chemicals (pharmaceuticals, paint and coating, detergent) and other industrials (computer and electronic products, fabricated metal products, machinery). Moreover, agriculture, forestry, fishing, mining, and construction are included as nonmanufacturing. IEA (2020) added that the most energy intensive within manufacturing sector is paper and printing and basic metal, while machinery is the least energy intensive sectors.

Energy intensity pattern across manufacture sectors in each country is varied. A study by Dasgupta and Roy (2017) in India shows that cement, aluminium, and fertilizer industries have improved energy intensity, on the other hand, steel and pulp and paper industries are energy intensive industries. Comparing energy intensity performance between Japan and China, Zhao et al. (2014) argue that the energy intensity of Japanese industry is much lower than Chinese industry with only subsector of textile industry which outperformed the Japanese industry. Vivadinar et al. (2012) found that the energy-intensive manufacture in Indonesia consist of food, textile, pulp and papers, steel, chemical, and cements-glass industries. They account around 80% of total energy consumption in the energy demand structure of the manufacturing sector.

Moreover, National Energy Council (2019) reported that six subsectors: metal, cement, fertilizer, food and beverage, ceramics, and paper industry, are the largest energy consumers with total of energy demand at 87% of the total energy consumption within industry manufacturing.

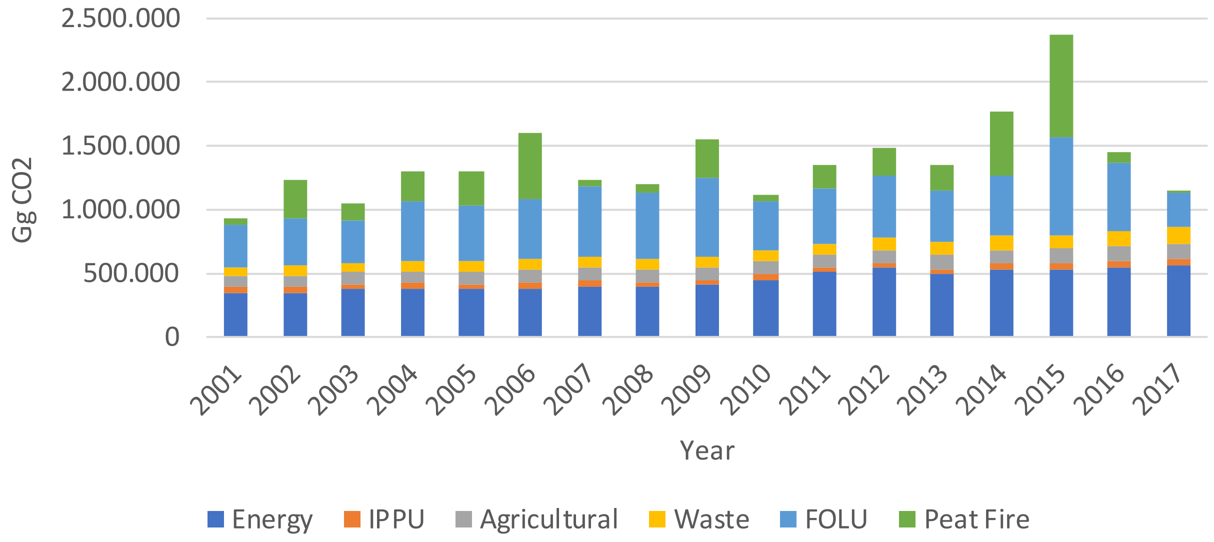
2.3. Carbon dioxide emissions

The IPCC guideline divides greenhouse gas emission into five main sectors related processes, sources and sinks: energy; Industrial Processes and Product Use (IPPU); Agricultural, Forestry and Other Land Use (AFOLU); waste; and other sectors. Energy sector which largely caused by the fossil fuels combustion is the most responsible sector in producing greenhouse gas emissions. Fossil fuel combustion is the process of conversion of carbon and hydrogen of fossil fuel into CO_2 and H_2O, at the same time releasing the chemical energy as heat that used to produce mechanical energy or generate electricity. IPPU is a sector which covers emissions from industrial activities that chemically or physically convert materials. Emissions that come from non-energy uses of fossil fuels are also included in IPPU sectors. The main sources of carbon dioxide in IPPU sector are the release of carbon dioxide as a by-product of lime, glass, cement, steel, and aluminium. For the AFOLU sector, on the other hand, greenhouse gas emissions are produced by human intervention on managed land to perform production, ecological, or social functions. For instance, emissions from livestock or cultivation. Lastly, waste sector covers emissions from solid disposal, biological activity, wastewater, incineration and open burning. Incineration and open burning are the most important sources of carbon emissions in this sector. In this study, we focus on energy sector on fuel combustion of manufacturing industries.

Carbon dioxide is a greenhouse gas, considered has the greatest anthropogenic global warming impact. The dominant source of carbon dioxide emissions is the burning of fossil fuels. Globally, the growth of energy demand from fossil fuels results in the upward trend in CO_2 emissions from almost zero in the Industrial Revolution period to over 33GtCO_2 in 2018 (IEA, 2020). By fuel type, coal represented 28% of total global primary energy share but contributed for 45% of the world carbon dioxide emissions in 2015. This caused by its high carbon content per unit of energy released. Furthermore, it was reported that in comparison to gas, coal is two-times as emission intensive on average. The increasing of CO_2 emission due to the rebound of coal demand is projected in 2021. Meanwhile based on sector, industry was the largest contributor of 40% of global emissions, after allocating electricity and heat emission across final sectors. While buildings and transportation account to over a quarter each (IEA, 2020).

Figure 2.3

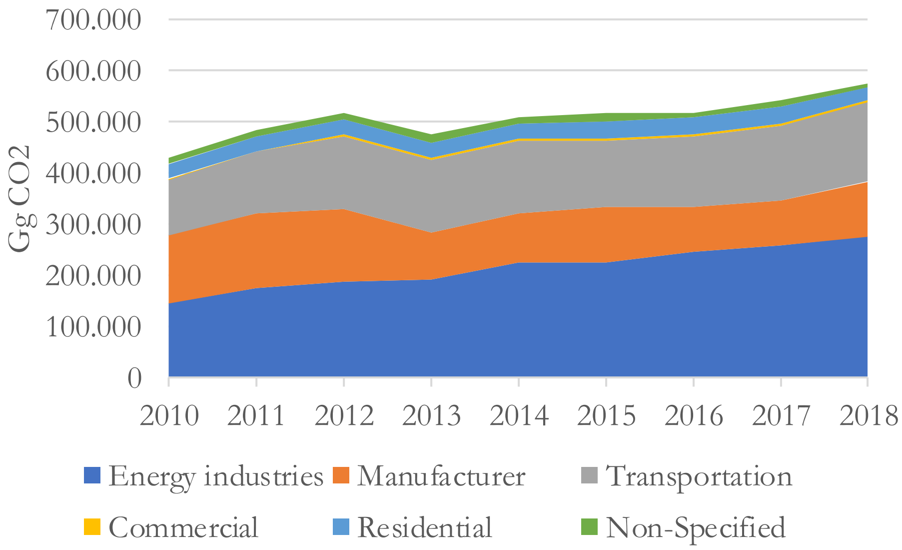
Carbon dioxide emission trend based on sector (own construction)



Source: Kementerian Lingkungan Hidup dan Kehutanan/Indonesian Ministry of Environment and Forestry (2018)

Figure 2.4

Carbon dioxide emissions based on sectoral (own construction)



*Energy industries (including electricity generation, oil and gas, and coal processing)
*Manufacturer (not including construction sector)

Source: Indonesian Ministry of Environment and Forestry (2020)

Statista Research (2021) reports that in 2017, Indonesia emitted 562 Gg CO_2eq from the energy sector, making it as the highest sector contributes in emit CO_2. This data also supported by Ministry of Environment and Foresty which shows that between 2001-2017, energy sector is consistent as the biggest contributor of CO_2 emissions (see **Figure 2.3**). This figure has increased by 140% between 1990 and 2017 and has projected would continue to increase by 2030. Meanwhile, the IPPU sector has emit the lowest emissions among others sources. Furthermore, **Figure 2.4** presents the total carbon emission in Indonesia for period 2010-2018 based on government calculation using total energy demand data. It shows that energy industries (electricity generation, oil and gas, and coal processing industries) has contributed as the largest emitter, followed by transportation and manufacture sector. This is not surprising since energy industries are energy-intensive sector which lead to higher emitter as well. Interestingly, there has been reduction of emissions level in manufacture sector from period 2012 until 2017, indicating there has been improvement in mitigating the increase of carbon emissions. However, for a year later the emission level in this sector has increased again.

2.4. Empirical evidences of CO_2 emission intensity

With the increase of concern in environmental degradation, a growing empirical literature has examined the cause of emissions level. Sahu and Mehta (2016) investigate the determinants of carbon dioxide emission intensities of manufacturing firms in India. At the firm level, data for carbon dioxide emissions is not available, thus they calculated the emission coefficient based on IPCC reference approach. They used fixed and random effects models and found that firms which allocate more expanses in research and development activities are more energy and emission efficient. A similar result also found by Cole et al. (2005) that emissions intensity is significantly negative to the firm's expanses on capital and research and development. In addition, Sahu and Mehta (2016) found that repair intensity is significantly positive to emission intensity. Intuitively, the higher firms spend money on machine maintenance, the better the quality of the machine, thus the production processes have become more efficient and will produce less waste. Moreover, without proper maintenance, it may cause the downgrade of the machine that cause a higher consumption of energy per unit product. From the arguments and some empirical studies, it can be expected that the increase in maintenance intensity will lower carbon dioxide emissions.

To pursue profit maximization, firms do not have allocation invested to reduce emissions. In accordance with pollution haven hypothesis, pollution-intensive industries which emit more pollution are likely to move out from strict regulated nations to less-regulated nations. Thus, foreign firm might emit more pollution compared to local firms. On the other hand, pollution halo hypothesis suggests that foreign firms have positive effect on environment due to their cleaner technologies than their local counterparts. Several studies, however, provide inconclusive results. In 2014, Jiang et al. examined the main factors of emission intensity level for three types of prominent pollutants in China which are sulphur dioxide, wastewater, and soot. They used firm-level dataset from manufacturing sector covering over 100 cities in China. The manufacturing pollution dataset is provided by China's Ministry of Environment Protection with 2862 (in 2006) and 4261 (in 2007) of firms as observations. This database in only a sample of all firms in China which for the emission data is conducted from the manufacturing plant self-report. They found that multinational enterprises have lower pollutant emission intensity than state owned enterprises (SOEs). Eskeland and Harrison (2003) also found similar result: multinational enterprises are more energy efficient than state-owned firms and apply superior technology. Also, foreign firms are more likely to avoid negative impression or perception in one country such as the image of polluting industries (Wang and Jin, 2002). Differently, a study in Ghana by Cole et al. (2008) suggested that foreign ownership have no influence in increasing fuel consumption and total energy use, but only increase the electricity use. However, since there are more evidences of pollution halo, this study expects that foreign ownership will lead to lower carbon dioxide intensity.

Firm size is believed as one of the components of firm heterogeneity in affecting the intensity of pollution emissions. Larger firms with bigger scale economies might consume more efficient fuel and generate low carbon emissions. Besides, compared to small firms, they have more flexibility to adopt new efficient technology without worrying about financial constraint. Cole et al. (2005) found that Japanese firm' pollutions are negatively correlated with firm size and productivity. A similar result also shown by Jiang et al (2014) larger firms with more educated worker tend to emit less. From the theory and empirical studies above, this study expects that firm size is negatively associated with carbon dioxide emissions.

Furthermore, Cole et al. (2005) suggested that firms that reliant on machinery tend to emit more than firms that rely on labor. This because capital intensive firms may engage in certain complex industrial sector which generate more emission per unit of energy. Moreover, capital intensity seems to have positive relationship to energy intensity (Papadogonas et al. 2007) which might be due to a positive association between capital intensity and pollution intensity. However, Sahu and Mehta (2018) found that capital intensity in Indian manufacturing firms have no association with emission intensity. However, the bigger firms, the more flexible for them to adopt new technology and do the research and development. Besides, big firms are likely to keep their positive image by being environmental-friendly enterprises. Since more evidences on positive relationship between capital intensity and CO_2 intensity, thus this study expects that an increase of capital intensity will increase the carbon dioxide intensity of the firm.

The argument of relationship between labor intensity and emission intensity is uncertain. On the one hand, firms with high skilled labor (to operate high technology) tend to be more efficient and less energy intensive compared to lower skill industries. On the other hand, it has been argued that low skilled industries could be more energy efficient because high skilled sectors typically emit more pollution due to their complex industrial processes. Cole et al. (2005) found that an increase in labor intensity will increase pollution intensity within an industry. On the other hand, Xie et al. (2018) suggested that labor intensity have not led to a significant boost in reduction of carbon dioxide emissions in China western region. However, this study expects that labor intensity has negative relationship with the carbon emissions intensity, meaning that labor intensive firms will emit less pollution.

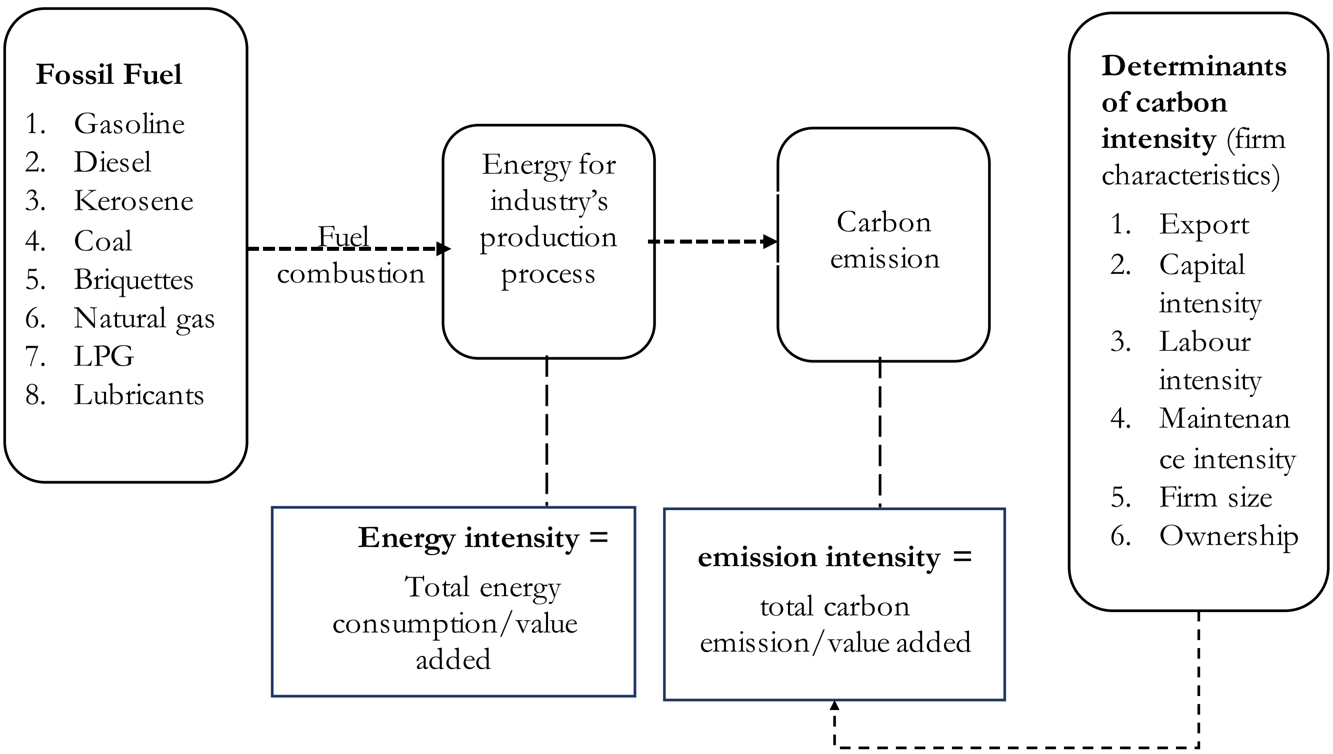
Richter and Schiersch (2017) examine carbon dioxide emission intensity with the focus on firms' exporting activity by using a unique panel dataset for manufacturing firms in Germany. From the dataset, they calculate CO_2 emission intensities and capital stocks for each firm. The data consist of information on the usage of fifteen different fuels type at the firm-level in unit kWh. From this data, they can calculate CO_2 emissions accurately by transforming fuel inputs to CO_2 emissions using the emissions factors for each fuel. The main finding suggests a negative relation between export intensity and emission intensity. Exporters can sell more product for the same amount of emitted carbon dioxide than non-exporting firms. A study by Holladay (2010) found that after controlling for productivity, exporting firms emit less pollution than their non-exporting enterprises in the same industry. This is because exporting leads to an increase number of production and hence lower emission intensity. A similar result also shown by Cole et al.

(2013), examining on Japanese manufacturing firms, they found that export activity negatively correlated to CO_2 emission intensity. It means that the more firms depend on exports, the lower its pollution intensity. In their study, export activity is measured as the share of product sold outside country. Based on empirical evidences, in this research, the expectation sign of correlation between export activity and emission intensity is negative.

There are several studies are analysing energy-related emission in Indonesia. However, very few studies examined the determinants of carbon emission at the plant level. First study which using plant level data was conducted by Priambodo and Kumar in 2001. They examined energy consumption and carbon dioxide emission in small- and medium- industries (SMI) in all 27 Indonesian provinces (during the period of study, Indonesia consists of 27 provinces) by using dataset statistics of SMI. They found that textile and fabricated metal industry were the largest contributors to CO_2 emission. They also found that the effect of liquid fuels to CO_2 emission was significant. However, they did not examine the determinants of energy intensity and carbon dioxide emissions. Brucal, et al. (2017) examine the effect of foreign acquisitions on environmental performance of the plant-level by using data from Manufacturing Census in Indonesia for the period 1983-2001. The analysis applies a difference-in-difference (DID) method and coarsened exact matching. In accordance with the literature, we expect that exporting firms will produce less carbon dioxide intensity. Based on literature reviews above, this figure below (**Figure 2.5**) is the conceptual frameworks of this study.

Figure 2.5

Conceptual framework (own construction)



CHAPTER 3. DATA AND METHODOLOGY

3.1 Data

This research uses secondary data from Indonesia Large and Medium-Scale Manufacturing Firms Annual Survey (LMM) conducted by Statistics Indonesia. The dataset with the period of 2011-2014 provides establishment level data for all manufacturing firms (foreign and domestic firms) with 20 or more workers annualy. Although the latest survey is LMM in 2017, this study could not use this period due to in 2016 Indonesia held Census Economy which its questionnaire survey is slightly different with annual survey. To set the consistency of period of the data, therefore, this study only covers four years period between 2011-2014. This classification of LMMs is not based on assets own or any other criteria of firm, but only based on the number of employees engaged. All firms with 20 workers or more are included in LMMs. The study is limited to only the large and medium manufacturing because this sector accounted almost 90% value-added of aggregate manufacturing.

The dataset is classified based on five digits Indonesian Standard of Industrial Classification Code (ISIC); however, in order to simplify analysis in energy intensity section, this study applied two digits ISIC which result in 23 sectors and then grouping again into 9 sectors based on similar industries. See **Table 3.1** for the list of classified manufacturing sectors. LMMs consist of 24 manufacturing sectors based on two digits ISIC. The advantage of using LMMs survey dataset is its comprehensiveness and its detailed data up to subsectors which gives advantage on manufacturing subsector analysis. Data based on questionnaire of LMMs have detailed information on energy consumption of fuels and electricity consumption in terms of money values and physical quantities, and other firm characteristics variables, such as ownership details, industry classification, workers wage, total workers, and value added. The dataset basically pools four cross-sectional, then we construct panel data by merging the dataset. However, the number of observations for each period might vary because it depends on the number of new firms and firms that do not continue their business. Therefore, this result in unbalanced panel dataset.

Table 3.1

The manufacturing sector list of the survey at two digits ISIC code

No	Sectors	ISIC	Description
1	Food, beverages, and tobacco	10	Manufacture of food products
		11	Manufacture of beverages
		12	Manufacture of tobacco products
2	Textile, wearing apparel and leather	13	Manufacture of textiles
		14	Manufacture of wearing apparel
		15	Manufacture of leather and of products of leather and footwear
3	Wood and wood products	16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials

		31	Manufacture of furniture
4	Paper and paper products	17	Manufacture of paper and paper products
		18	Printing and reproduction of recorded media
5	Chemical, petroleum, coal, rubber, and plastic products	19	Manufacture of coke and refined petroleum products
		20	Manufacture of chemicals and chemical products
		21	Manufacture of pharmaceuticals, medicinal chemical and botanical products
		22	Manufacture of rubber and plastics products
6	Non-metallic mineral products	23	Manufacture of other non-metallic mineral products
7	Basic metal industries	24	Manufacture of basic metals
8	Fabricated metal products, machinery, and equipment	25	Manufacture of fabricated metal products, except machinery and equipment
		26	Manufacture of computer, electronic and optical products
		27	Manufacture of electrical equipment
		28	Manufacture of machinery and equipment
		29	Manufacture of motor vehicles, trailers and semi-trailers
		30	Manufacture of other transport equipment
9	Other manufacturing industries	32	Other manufacturing
		33	Repair and installation of machinery and equipment

Source: BPS-Statistic Indonesia (2020)

3.2 Methodology

3.2.1. Estimation of energy intensity

Energy intensity is an indicator how energy is used in the economic activity. Following Priambodo and Kumar (2001), the energy analysis is calculated based on energy consumption used in the process and value-added data:

$$Energy\ Intensity\ (\frac{TJ}{US\$}) = \frac{total\ energy\ consumption\ in\ the\ plant\ during\ the\ year}{value\ added\ of\ the\ product\ during\ the\ year} \ \dots\dots\dots \ (1)$$

Total energy consumption at firm level is obtained is by adding all fossil fuels consumption with corresponding energy conversion values. Since the data available of fuel usage are in volume or mass units (kg, liter), then, it needs to be converted into energy units (e.g. Joules). To convert the unit into energy units, it requires calorific values. The IPCC Guideline use net calorific values (NCVs) in units of TJ/Gg. Default NCV values to convert to unit of terajoules are presented in **Table 3.2** The conversion formula is given by:

$$FC_{j,t}^{i}(TJ) = FC_{j,t}^{i}(physical\ unit) x\ NCV_{i} \ \dots\dots\dots\dots\dots\dots\dots\dots\dots \ (2)$$

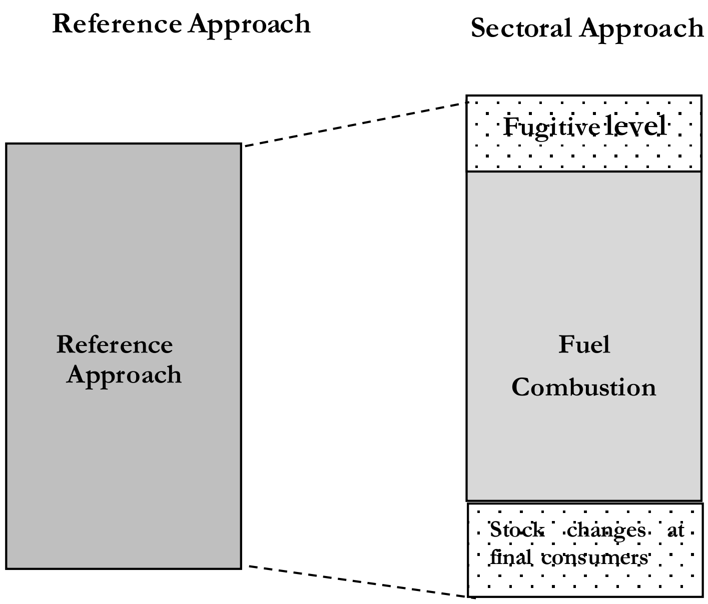
where $FC_{j,t}^{i}$ denotes the total energy consumption of fuel type i by firm j in year t. The total fuel consumption data in this study is the sum of fuel used for the processes of manufacturing. Meanwhile value addition data can be generated from LMM data set.

3.2.2. Estimation of CO_2 emission intensity

To calculate carbon dioxide emissions based on fossil fuels combustion, this study follows the methodologies of 2006 IPCC Guideline. There are some refinements of the 2006 IPCC Guideline which published in the 2019 IPCC Guidelines; however, no refinement has been made in section of methodological of stationary combustion estimation. Thus, the estimation of carbon dioxide emission still follows the 2006 IPCC Guidelines. There are two approaches in estimating carbon emission: sectoral and reference approach. The former approach is an approach which using surveyed fuel consumption to measure carbon dioxide emissions (bottom-up approach). Meanwhile, the reference approach is an approach which applied energy supply data of the country to derive carbon dioxide emissions (top-down approach). This means that the latter approach provides no information on how fuels are consumed by firm. Unlike the top-down approach, the bottom-up approach ignores emissions from non-energy uses such as fugitive emissions. Thus, it is possible to have different results between these two approaches, however, the gap results should not be wide, 5 per cent or less. Although the IPCC recommends using the top-down approach to calculate emission of the country, they believe that applying both approaches is a good practice with the intention to compare the estimations. Since this study uses surveyed fuel usage of the firms, therefore we follow bottom-up approach to estimate carbon dioxide emission. The difference graphic between reference and sectoral approach can be seen in **Figure 3.1.**

Figure 3.1

Comparison between reference approach and sectoral approach



Source: IPCC Guidelines (2006)

Fossil fuels consist of hydrogen and carbon atoms. Burning them result in oxidization of carbon to CO_2. For each fossil fuel has specific carbon content, the emissions factors also different across fuels (Richter and Schiersch, 2017). Carbon emission factors for each fuel are presented in **Table 3.2**. According to IPCC (2006), CO_2 emissions are not dependent to combustion technology; thus, carbon dioxide emissions can be calculated based on the averaged carbon content of the fuels and the total amount of fuels combusted.

Table 3.2.
The default net calorific value and carbon emission factors

Energy sources	NCV (TJ/Gg)	Carbon emission factors (kg/TJ)
Gasoline	44.3	69300
Diesel	43.0	74100
Kerosene	43.8	71900
Coal	26.44[1]	96920[1]
Coal briquettes	20.7	97500
Gas	48	56100
LPG	47.3	63100
Lubricants	40.2	73300

[1] The average value of NCV and carbon emission factor of anthracite, coking coal, other-bituminous coal, sub-bituminous coal, and lignite.

Source: IPCC Guideline (2006)

Since there is no data CO_2 emission on firm level, therefore, plant level data on fuel consumption has been converted into carbon dioxide emission using emission factors (equation 3). After that we estimate carbon emissions intensity by dividing the total CO_2 emissions for each plant with the total value added of each plant (equation 4).

$$CE_{j,t} = \sum_i FC^i_{j,t}\, x\, NCV_i\, x\, CF_i\, x\, COF_i x\, \left(\frac{44}{12}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$CEI_{j,t} = \frac{CE_{j,t}}{value\ added\, of\ the\, product\, during\, the\, year} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where i denotes the various fuels/electricity, t represents the time in years, $CE_{j,t}$ means total carbon emissions of firm j in year t, $FC^i_{j,t}$ denotes the total energy consumption of fuel type i by firm j in year t, NCV_i represents net calorific values of fuel type i. CF_i is the carbon emission factor of fuel type i, COF_i is the carbon oxidization factor with the default of equal 1 for all fuels, and $CEI_{j,t}$ is the carbon dioxide emission intensity of firm j in year t.

To calculate the total emissions from fossil fuel combustion, there are three tiers that we can adopt depending on the availability of specific data. Applying a Tier 1 approach requires data on the amount of fuel combusted and a default emission factor (*CF*) that provided in IPCC 2006 Guidelines. See **Table 3.2** for the default of carbon emission factors for each energy sources. Under Tier 2, default emission factors are not used, but being replaced by country-specific emission factors. It means that the emission factors for each energy be more applicable and precise to a given country's situation. While for Tier 3, the estimation must consider a specific emission factor for each technology used such as fuel type used, combustion and control technology, operating conditions, quality of maintenance and age of the machine used.

As Tier 1 applies the simplest calculation methods and requires the least data, the estimation results are the least accurate compared to Tier 2 and Tier 3 approach. However, IPCC (2006) states that using a Tier 3 approach is often not necessary because carbon dioxide emissions do not depend on the combustion technology. This study applied Tier 1 since in the case of Indonesia, not all types of fuels have the figures of country-specific emission factors. Therefore, the emission factors follow the default value provided in IPCC 2006 Guidelines. The computation of CO_2 would result in absolute value. On this issue, Sahu and Mehta (2006) states that to generate a better calculation, then the absolute value need to be normalized with output of the firm which known as carbon emission intensity. Therefore, for the regression computation, we use carbon emission intensity as the dependent variable.

3.2.3. Ordinary least squares (OLS) regression

After the first step of calculation energy intensity and CO_2 intensity, then I apply four econometrics methods: OLS, 2SLS, fixed effects and fixed effect-instrumental variable to answer the research questions of determinants of CO_2 emissions intensity. As the benchmark model, firstly, this study estimates the equation using OLS regression; however, the estimation might be biased due to endogeneity issues. The OLS regression model is as follow:

$$\ln(CEI)_{j,t} = \alpha + \beta_1 ln(fsize)_{j,t} + \beta_2 ln(export)_{j,t} + \beta_3 ln(cap)_{j,t} + \beta_4 ln(labor)_{j,t} + \beta_5 ln(maintenance)_{j,t} + \beta_6 (dummy\ ownership)_{j,t} + \delta_t + \varepsilon_{j,t} \quad \text{(5)}$$

$CEI_{j,t}$ denotes carbon emission intensity for firm j in at time t, and $(fsize)_{j,t}$ is firm size for firm j in at time j, $(export)_{j,t}$ is export intensity for firm j in at time t, $(cap)_{j,t}$ is capital intensity for firm j in at time t, $(labor)_{j,t}$ is labor intensity for firm j in at time t, $(maintenance)_{j,t}$ is maintenance for existing infrastructure intensity for firm j in at time t, $(dummy\ ownership)_{j,t}$ is binary dummy with 1 for foreign ownership, 0 otherwise, δ_t is year fixed effect, and $\varepsilon_{j,t}$ is the stochastic disturbance term. For the details definition and symbol can be seen in **Table 3.3**.

Furthermore, this study also tries to analyse how interaction between explanatory variables has a different effect on the outcome variable. I set two interaction term variables: ownership and export intensity; and maintenance intensity and capital intensity. The models estimation could look like in the following:

$$\ln(CEI)_{j,t} = \alpha + \beta_1 ln(fsize)_{j,t} + \beta_2 ln(export)_{j,t} + \beta_3 ln(cap)_{j,t} + \beta_4 ln(labor)_{j,t} + \beta_5 ln(maintenance)_{j,t} + \beta_6 (dummy\ ownership)_{j,t} + \beta_7 (dummy\ ownership)_{j,t} * ln(export)_{j,t} + \delta_t + \varepsilon_{j,t} \quad \text{(6)}$$

$$\ln(CEI)_{j,t} = \alpha + \beta_1 ln(fsize)_{j,t} + \beta_2 ln(export)_{j,t} + \beta_3 ln(cap)_{j,t} + \beta_4 ln(labor)_{j,t} + \beta_5 ln(maintenance)_{j,t} + \beta_6 (dummy\ ownership)_{j,t} + \beta_7 (maintenance)_{j,t} * ln(cap)_{j,t} + \delta_t + \varepsilon_{j,t} \quad (7)$$

3.2.4. Two-stage least squares (2SLS) regression

As the OLS estimates may suffer from endogeneity problems such as reverse causality, omitted variable bias and selection bias, which may cause inconsistent estimates and lead to misleading interpretations, I apply 2SLS regressions model with an instrumental variable. Although I predict that the relationship/causal link runs from firm characteristics to carbon emission intensity, there is a possibility of reverse causality occurrence. For instance, while large firm size is likely to emit less emission due to their features, the level of CO_2 intensity might affect firm size as well. As the firms release high emission to the atmosphere, the government forces them to reduce their emissions, hence, they need to spend more money on technology or hired skilled workers that can affect their profit thus their firm size. Moreover, the result estimations might be also affected by selection bias and unobserved heterogeneity such as firm culture. Therefore, to address these concerns, I employ an instrumental variable.

To find a useful instrument, some conditions must be met. First condition is the instrument should correlate with the treatment variable (firm size). Second, the instrument variable must be correlated to the outcome variable (CO_2 emissions intensity) through the suspected endogenous variable (firm size) and not correlate with error terms. A recent study by Kabir et al. (2021) uses 'signatories of the Kyoto protocol' as an instrumental variable to investigate the reverse causality of carbon emission and default risk. While finding a valid instrumental variable is challenging, in this study, I employ the compensation expenses (social allowance and pension for workers) as the instrumental variable. While the total compensation expenses are expected to have significant impact on firm size, the compensation itself is not expected to have direct effect on CO_2 intensity. Birindelli et al. (2019), in investigating the impact of women CEO on environmental performance, also use 2SLS random-effects methods and apply the log of the board member compensation as an instrument. A similar instrument also used by Nuber and Velte (2020) in examining board gender and carbon emissions. They used total pensions scaled to the number of employees as an instrument. In the first stage of 2SLS, I regress firm size on the compensation expenses along with other independent variables (equation 8). Then in the second stage, I regress CO_2 intensity with instrumental variable (equation 9).

$$\ln(fsize)_{j,t} = \alpha + \beta_1 ln(compensation)_{j,t} + \beta_2 ln(export)_{j,t} + \beta_3 ln(cap)_{j,t} + \beta_4 ln(labor)_{j,t} + \beta_5 ln(maintenance)_{j,t} + \beta_6 (dummy\ ownership)_{j,t} + \delta_t + \varepsilon_{j,t} \quad (8)$$

$$\ln(CEI)_{j,t} = \alpha + \widehat{\beta_1} ln(fsize)_{j,t} + \beta_2 ln(export)_{j,t} + \beta_3 ln(cap)_{j,t} + \beta_4 ln(labor)_{j,t} + \beta_5 ln(maintenance)_{j,t} + \beta_6 (dummy\ ownership)_{j,t} + \delta_t + \varepsilon_{j,t} \quad (9)$$

3.2.5. Fixed effects (FE) and Fixed effects - Instrumental Variable (FE-IV)

As applying individual fixed effect is useful to overcome the effects of the unobservable heterogeneity, this study tries to use the FE model and FE-IV model in analysing the determinants of CO_2 intensity. The aim of estimate the regression models using firm fixed-effects is to capture time-invariant unobservable of firm characteristics such as the culture of the firm. In addition, I add robust standard errors clustered at firm level. I also perform random effects models to compare the results; however, after applied Hausman test statistics to select the most appropriate model between FE model and RE model, the results indicate to reject null hypothesis which states that there is no correlation between the regressors and the effects (**Appendix 6.3**). Thus, fixed effects model is preferred over random effects model. The estimation of RE model can be seen in **Appendix 6.1**. Furthermore, as comparison to the FE model estimation, I also present FE-IV model by using instrument variable, compensation expenses. **Table 3.3** presents the definition for each variable.

Table 3.3

Definitions and units of variables involved in the study

No.	Variable	Symbol	Definition
1	Energy intensity	lnEI	Natural log of energy intensity
2	CO_2 emission intensity	lnCEI	Natural log of CO_2 emission/net sales
3	Firm ownership	ownership	This dummy takes value 1 if there is foreign share (FDI firms) and 0 if 100% domestic firm
4	Export intensity	lnexport	Natural log of total export/total sales
5	Capital intensity	lncap	Natural log of total fixed assets/total sales
6	Labour intensity	lnlabour	Natural log of total wages/total sales
7	Maintenance intensity	lnmaintenance	Natural log of total expenses on repairs or maintenance/total sales
8	Firm size	lnfsize	Natural log of total net sales

3.2.6. Descriptive analysis

Table 3.4 provides the desricptive statistics of the firm characteristics for period of study 2011-2014. With the total of 95.189 firm-year observations, the mean carbon intensity is calculated at 0.0123 with standard deviation of 2.3780. Capital intensity and export intensity have mean at 2.5810 and 12.623, with standard deviation of 57.6541 and 118.0618, respectively. The high figures of standard deviation means that the data range of capital intensity and export intensity are spread out. **Table 3.5.** depicts descriptive summary of dummy variable, firm ownership status, which classified into two groups: foreign firms and non-foreign firms. We can observe that there are more domestic firms (90.43%) than foreign firms (9.57%). On export activity, it can be concluded that foreign firms are export intensive compared to local firms. Further, we find that local firms are labor intensive, while multinational firms are more capital intensive. Interestingly, foreign firms spend less on maintenance activity compared to local firms. This probably because foreign enterprises are capital intensive that have already adopt higher quality of technology that lead to efficient energy-saving and less cost in maintenance. The variable firm size shows the value of firms' net sales, which can be seen that large or foreign firms (0.1497) have lower carbon intensity than domestic firms (0.1734).

Table 3.4

Descriptive statistics of variables

Firm characteristics	Mean	Standard Deviation	Min	Max
Carbon intensity	0.0123	2.3780	0	547.327
Energy intensity	13.8579	360.1097	0	48507.960
Capital intensity	2.5810	57.6541	0	5750
Export intensity	12.623	118.0618	0	34469.110
Labor intensity	0.2827	0.8904	0	56.999
Maintenance intensity	0.0610	0.5041	0	97.869
Firm size	5.61e+07	5.79e+08	1004	5.38e+10
Number of observations		95,189		

Source: Own calculation from the Large and Medium Manufacturing Survey dataset

Table 3.5

Descriptive statistics disaggregated per firm ownership

Firm characteristics	Domestic Firms				Foreign Firms			
	Mean	Std Deviation	Min	Max	Mean	Std Deviation	Min	Max
Carbon intensity	0.1734	2.5426	0	547.327	0.1497	1.1228	0	52.852
Energy intensity	11.211	314.145	0	40041.75	38.859	649.458	0	48507.96
Capital intensity	2.3809	53.9933	0	5092.698	4.4713	84.7460	0	5750
Export intensity	9.8340	123.2569	0	344469.1	33.1125	40.0740	0	195.521
Labor intensity	0.2971	0.8924	0	53.399	0.1463	0.8600	0	56.999
Maintenance int	0.5489	0.2450	0	40.288	0.1191	1.4436	0	97.869
Firm size	3.73e+07	4.46e+08	1004	4.90e+10	2.33e+08	1.26e+09	7415	5.38e+10
Number of observations		86,077				9112		

Source: Own calculation from the Large and Medium Manufacturing Survey dataset

3.2.7 Correlation matrix and multicollinearity test

Table 3.6 presents the pairwise correlation matrix. As can be seen, all the correlation coefficients between variables are less than 0.5 which means the correlation in the estimations is small. In addition, all variables show statistically significant correlation at 5%, providing preliminary finding for further analysis. The variable carbon intensity has negative significant correlations with export intensity, firm size, labor intensity and ownerships. This indicates that firms with export activity are emitting less carbon emissions. Similarly, larger firms release less pollution. In addition, labor intensive firms are more environmental-friendly compared to capital intensive firms which has positive relationship with carbon intensity. The positive association is also found between carbon intensity and maintenance intensity, indicating that firm with spending more machinery maintenance are emitting more emissions. These significant relationship between carbon dioxide intensity and other independent variables suggest the importance to control the variables choosen in regression models.

Table 3.6

Pairwise correlation matrix for the panel data

	Carbon intensity	Capital intensity	Export intensity	Maintenance intensity	Labor intensity	Firm size	Ownership
Carbon intensity	1.0000						
Capital intensity	0.0082*	1.0000					
Export intensity	-0.0350*	-0.0699*	1.0000				
Maintenance intensity	0.0771*	0.1269*	0.0517*	1.0000			
Labor intensity	-0.1160*	0.1624*	-0.0594*	0.0328*	1.0000		
Firm size	-0.1550*	-0.1136*	0.2359*	0.0883*	-0.4371*	1.0000	
Ownership	-0.0392*	-0.0133*	0.2754*	0.1089*	-0.1196*	0.3433*	1.0000

Notes: All variables's data in natural logs, except for variable dummy ownership
* Indicates correlation coefficients significant at 5%

Furthermore, we check the possibility of multicollinearity. Multicollinearity is a condition when there is a highly intercorrelated among explanatory variables. Although the estimators would be unbiased and consistent, the effect of multicollinearity will generate coefficient with large standard errors, making the estimation less precise. Besides, due to high standard errors, the coefficients may appear insignificant, in a consequence, important variables may be eliminated. **Table 3.7** displays the result of collinearity diagnostic which show that the variance inflation factors (VIF) of all explanatory variables are less than the standard threshold of 10, indicating that there is no serious multicollinearity with other predictors. Thus, we can include all independent variables in regression models.

Table 3.7

Collinearity diagnostics

Variable	**VIF**	**SQRT VIF**	**Tolerance**	**R-Squared**
Capital intensity	1.05	1.03	0.9515	0.0485
Labor intensity	1.27	1.12	0.7904	0.2096
Firm size	1.43	1.20	0.6981	0.3019
Export intensity	1.12	1.06	0.8965	0.1035
Maintenance intensity	1.04	1.02	0.9629	0.0371
Ownership	1.20	1.09	0.8360	0.1640
Mean VIF	1.18			

CHAPTER 4. RESULTS AND DISCUSSIONS

4.1. Energy intensity in Indonesia

The first section of this chapter will discuss the energy intensity of the manufacturing firms across sectors. The estimation of energy consumption is based on firm survey dataset. **Table 4.1** describes energy consumption structure of different type of fuels which shows that the percentage of coal consumption in manufacturing sectors reached the highest percentage by over 66% in 2011, however, it decreased to 54.2% in 2014 yet it has still become the prominent fuel source in manufacturing sector. After coal, diesel oil was the second highest fuel consumed by firms with the range of consumption at 25.7% (2011) to 32.4% (2014). The decrease in coal consumption was followed by an increase in gasoline and natural gas which accounted from 3.2% and 2.9% in 2011 to 5.4% and 4.0% in 2014, respectively. This decrease might be due to the Government Regulation 79/2014 on National Energy Policy which focuses on reducing coal use and renewable energy, and optimising the use of gas. Gas energy is generally needed by the industry which use boiler as its processes, especially in ceramics and glass industry. The government has required plant adopting the efficient technology such as regenerative burner, reheating furnace and waste heat recovery boiler. To achieve the goal of the shifting to gas consumption, the government set the government's economic policy package, President Regulation No 40/2016 on Natural Gas Pricing. In this regulation, the allocation of lower gas prices offered to seven sectors: fertilizer, petrochemical, steel, rubber glove, glass, oleo-chemical, and ceramic. These regulations were set to achieve the optimalisation and efficiency of energy in all sectors.

Table 4.1

Fuel type share in manufacturing (own calculation)

Fuel Types	2011 (%)	2012 (%)	2013 (%)	2014 (%)
Gasoline	3.2	4.2	4.4	5.4
Diesel	25.7	32.7	28.0	32.4
Kerosene	0.4	0.6	0.7	0.8
Coal	66.1	59.2	57.0	54.2
Coal briquette	0.0	0.1	1.7	0.9
Natural gas	2.9	3.0	6.6	4.0
LPG	0.6	0.6	0.8	0.8
Lubricants	0.9	1.2	0.9	1.4

Source data: LMM dataset

Appendix 2.2 presents the consumption of energy for each sector. The three sectors with the largest energy consumption are food, beverages, and tobacco; non-metallic mineral products (cement and lime); and chemical, petroleum, coal, rubber, and plastic products. This aligns with the National Energy Council report that food, chemicals, and non-metal sectors are the highest energy consumers (National Energy Council, 2019). The total energy demand in these three sectors contributes 65% of the total fuels usage in industry.

Energy intensity is an indicator of the energy efficiency of an economy. With the calculation as units of energy per value added, it indicates how efficient the economy converts energy into output. However, lower energy use does not always imply more efficient energy efficient. The trends of energy consumption are driven by changes in output level or activity level in the industry, change in intensity effect and change in structural change or product mix (Reddy and Ray, 2010). The expectation of the energy improvement is the low ratio of energy intensity. **Table 4.2** shows the energy intensity of firms per sector based on energy consumption and value added in TJ/US$. Although food, beverages, and tobacco have high energy usage, its energy intensity was quite low compared to other sectors. This because the value added of this sector was impressive. On the other hand, non-metallic mineral industries have the highest energy intensity among other sectors for all period which its energy intensity fluctuates at range 0.016 to 0.036 TJ/US$. Glass, ceramic products, baked clay, and cement are included in non-metallic industry. Referring to Yin and Wang (2021), ceramic production processes typically require high energy consumption since it use kiln as its combustion. Further US Energy Information Administration claimed that the cement industry is the most energy-intensive among other manufacturing sectors which rely heavily on petroleum coke and coal. While the energy consumption of non-metallic mineral industries is high, the added value of these two is low compared to other sectors (see **Appendix 3** for value added per sector). This causes its energy intensity is quite high. This initial analysis concludes that non-metallic mineral industry needs to improve energy efficiency so that their contribution to the economy and environment can be significant.

Table 4.2

Energy intensity of manufacturing sectors in Indonesia

NO	Sector	Energy Intensity (TJ/US$*)			
		2011	2012	2013	2014
1	Food, beverages, and tobacco	0.004	0.017	0.003	0.003
2	Textile, wearing apparel and leather	0.008	0.005	0.003	0.004
3	Wood and wood products	0.005	0.006	0.005	0.003
4	Paper and paper products	0.006	0.013	0.006	0.007
5	Chemical, petroleum, coal, rubber, and plastic products	0.006	0.006	0.005	0.003
6	Non-metallic mineral products	0.031	0.019	0.036	0.016
7	Basic metal industries	0.009	0.007	0.003	0.004
8	Fabricated metal products, machinery, and equipment	0.023	0.003	0.001	0.002
9	Other manufacturing industries	0.004	0.014	0.003	0.002

Source: own calculation based on the LMM survey dataset

Figure 4.1. presents the trend of the value added and energy consumption of the Indonesian manufacturing from 2011 to 2014. It can be seen that the total energy consumption was decreasing from about 750,000 TJ in 2011 to 430,000 TJ in 2013, but slightly increasing again to about 450,000 TJ in 2014. The industry value-added shows increasing trend from year to year, 70 million US$ (2011) to 119 million USD (2014). **Figure 4.2.** illustrates the graphs of energy consumption and energy intensity. Since the trend of value-added increases, and energy usage decreases except for the year of 2013 to 2014, the energy intensity shows decreasing trend from 2011 to 2013, but slightly increasing in the last year. The increase of energy intensity indicates that the share of energy-intensive manufacturing in Indonesia increases during the period 2013-2014. **Appendix 4** provides the energy intensity of the manufacturing sub-sectors.

Figure 4.1

Energy consumption and value-added of the Indonesian manufacturing industry

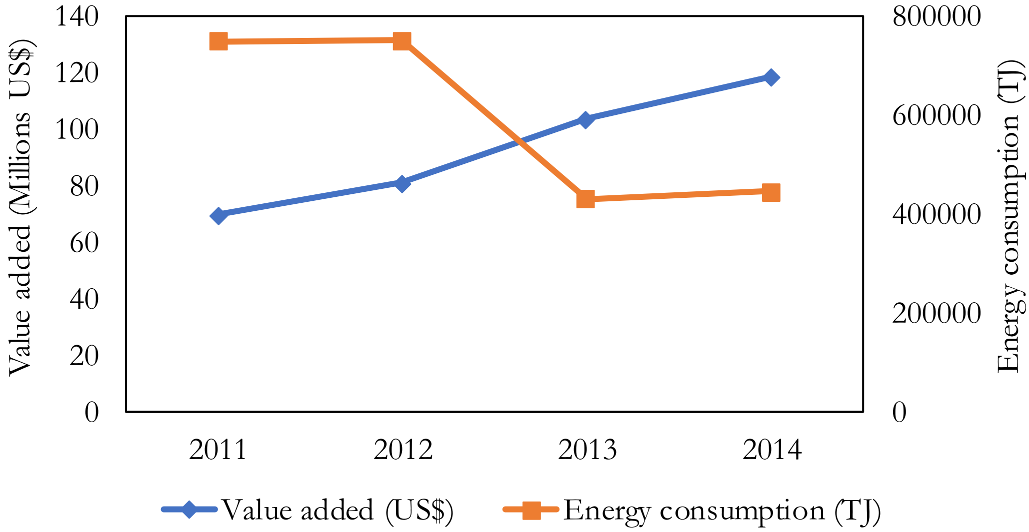
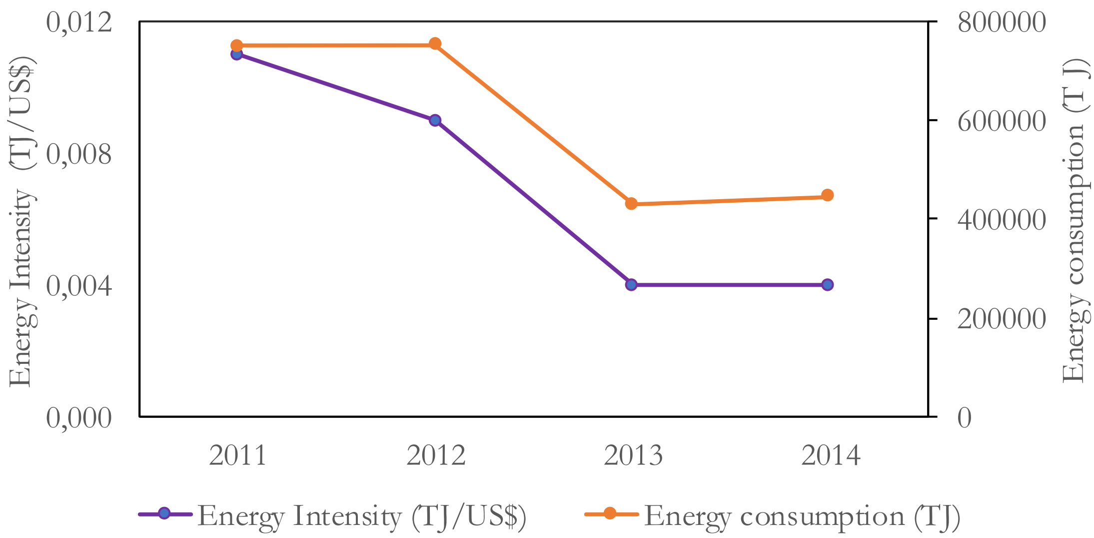


Figure 4.2

Energy consumption and energy intensity of the Indonesian manufacturing industry



4.2. Carbon dioxide emissions

From the energy consumption data of firms, we can generate CO_2 emissions produce by each firm. This calculation follows the sectoral approach (bottom-up) which using fuel use from firm data to derive carbon dioxide emissions. **Appendix 5** presents the details calculation of emissions per fuel types in manufacturing sectors. During period of study, 2011-2014, the highest carbon emission created from coal and diesel oil consumption. This indicates that industries still prefer to use coal as their main energy source. The lower prices of coals than other energy sources cause its higher demand. Moreover, Indonesia has coal reserves of around 38 billion tons and was predicted that the coal could provide the industry's demand until 60 to 65 years. The comparison between carbon emissions from government data and my own calculation of actual total CO_2 emissions in manufacturing sector from 2011 to 2014 are presented in **Table 4.3**.

Table 4.3

The comparison of CO_2 emissions between own calculation and government' data

Sources	2011	2012	2013	2014
CO_2 emissions (own calculation)	122,701	130,738	131,345	132,786
CO_2 emissions based on gov [a] data	139,708	132,984	82,715	87,032

Unit in Gg CO_2

[a] Ministry of Environment and Foresty (2019)

As can be seen in **Table 4.3** above, there are different results between my own calculation and government's emissions data, particularly for the period 2013 and 2014 which shows significant gap. There are several reasons behind this. Firstly, the government used energy demand consumption data at macro level to calculate CO_2 emissions, while in this study, I used data of energy usage of the plant based on survey to the firms. While using data based on survey, it is expected that we can calculate CO_2 emissions based on actual fuels consumption of the firm. However, the main reason of significant decrease of government's calculation from 2012 to 2013 is due to the changes of coal data collection method, not caused by mitigation actions. This information can be found in Ministry of Energy and Mineral Resource Report 2020 (Pusat Data dan Teknologi Informasi ESDM, 2020). Unfortunately, there is no further information about this data collection method, making it difficult to further investigation.

Figure 4.3 illustrates the total energy and emissions intensity of manufacturing firms. Similar to energy intensity, CO_2 emission intensity is estimated by dividing with the added value of the firm. The trend of energy intensity linear to the trend of CO_2 intensity during the period of study. When the energy intensity has declined over time, the CO_2 intensity has decreased as well. As already mentioned earlier, that the significant decline of energy intensity and CO_2 intensity in 2013 is due to the significant fall of coal consumption. However, it is important to acknowledge that the decline of coal consumption is because of the changes of data collection methods between 2012 and 2013. However, although the carbon emissions intensity has declined from 2011 to 2014, the amount of carbon emission has increased **(Figure 4.4)**. Thus, it is clear that the declining of emission intensity due to the rise of value added.

Figure 4.3
Energy intensity and emissions intensity of the Indonesian manufacturing industry

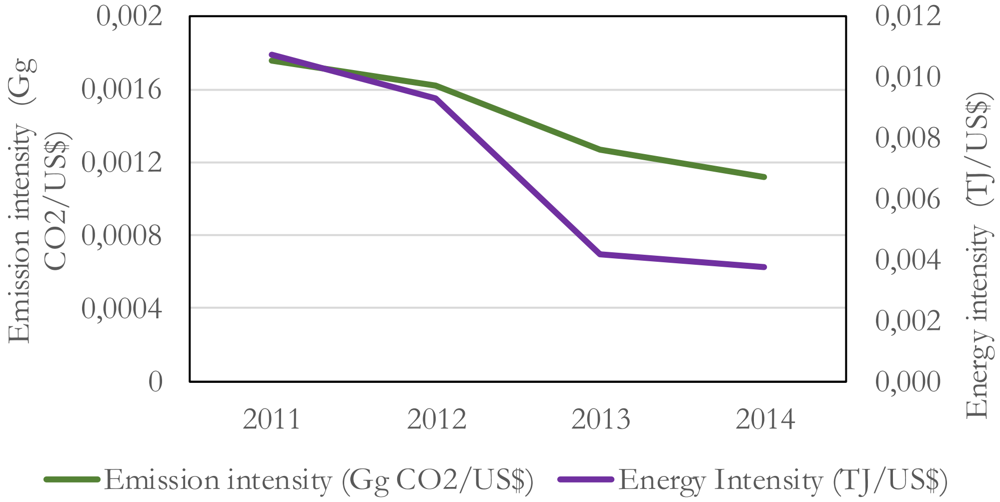
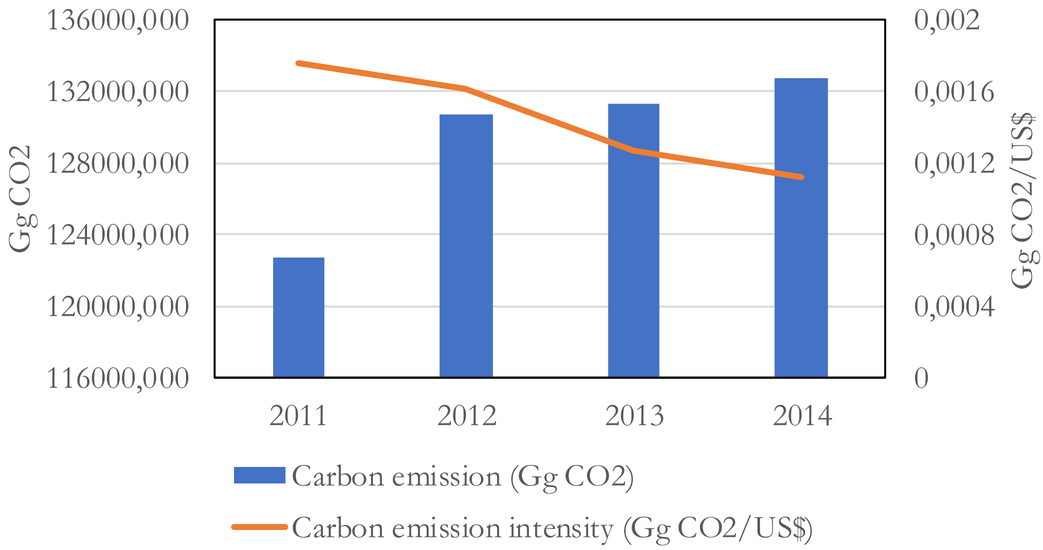


Figure 4.4
Carbon emissions and carbon emissions intensity of the Indonesian manufacturing industry



4.3. Determinants of carbon emission intensity

4.3.1. Ordinary least square regression

Table 4.4 reports the findings of OLS and interaction term regression in analysing the relationship between CO_2 intensity and several explanatory variables such as capital intensity, labor intensity, firm size, export intensity, maintenance intensity, ownership status. Column (1) shows OLS estimation where CO_2 intensity is the dependent variable. I add year dummy to control for time-specific fixed effects. In addition, Bu et al. (2019) argue that since firms normally develop year by year, then the serial autocorrelation issue might exist, making the model suffer from heterogeneity due to the huge variation across firms. Therefore, I also apply robust standard error for correlation across firm within the firm level. Since the equation use logarithms, the effect of independent variables on CO_2 intensity is expressed as an elasticity. This describes how CO_2 intensity vary in percentage terms in response to a one percentage point change in a certain explanatory variable. It can be seen that labor intensity, firm size, and export intensity have negative correlation with CO_2 intensity at 1% significance level. Other factors held constant, a 1% increase in labor intensity, CO_2 intensity decrease by 0.061%. It is also found that a decrease of 0.132% in CO_2 intensity is associated with a 1% rise in firm size. Similarly, other things equal, an increase of 1% in export intensity would follow by a decrease of 0.025% in CO_2 intensity. Conversely, a 1% rise in maintenance intensity, CO_2 intensity increase by 0.107%. Meanwhile other variables, capital intensity and ownership status, show insignificant results.

Although firm size, labor intensity, export intensity, and maintenance intensity have significant effects on CO_2 intensity, the effect of interaction between independent variables might different to the outcome. To examine this possibility, I set two interaction terms as in equation (6) with ownership status and export activity and equation (7) interaction of maintenance intensity and capital intensity as interaction variables. The reason of deciding this interaction variable is due to the insignificant variable of ownership in OLS and FE model. On the other hand, many literatures suggest that foreign firms are likely have low CO_2 intensity (Jiang et al., 2014; Eskeland and Harrison, 2003; Wang and Jin, 2002). Therefore, I try to interact ownership variable with export intensity variable since in the descriptive analysis, foreign firms are export intensive. Foreign firms are likely larger firm which can adopt cleaner technologies for their production. In addition, export intensive firms also cleaner since they need to meet the standard environmentally friendly products by importer country's regulation. Thus, the expectation effect of export activity of foreign firms would decrease CO_2 intensity. Columns (2)-(4) show the results of regression by adding ownership and export intensity as the interaction terms. Throughout the estimations, the estimated coefficients for the interaction terms appear significantly negative. These results suggest that foreign firms with export activity decrease the CO_2 intensity by 0.043%, 0.036% (after only controlling capital intensity), and 0.059% (by controlling firm size).

Furthermore, I also set another interaction term between maintenance intensity and capital intensity. This is because the sign of maintenance intensity is positively significant (baseline column), different with the expectation sign. Theoretically, firms that spend more money on maintenance tend to emit less carbon. However, since the sign of maintenance intensity on CO_2 intensity is positive, then it is suspected that firms with complex machines (this type of firm might tend to generate more emissions) need more money to maintain the equipment infrastructure. Therefore, I set the interaction term of maintenance intensity and capital intensity to investigate its different effect on the outcome. Capital intensive firms are likely to have higher maintenance intensity, thus if the reasoning of emission-intensive firms adopt complex machines generating high carbon emissions is true, then I expect for positive sign of the interaction term. On the baseline column, capital intensity is insignificant, while after adding the interaction term on columns (5)-(7), the capital intensity become positively significant. The interaction terms for all regression also found to have positive effect on CO_2 intensity. This can be interpreted that capital intensive firms spend more money on machinery maintenance are emit more emissions.

Table 4.4.

OLS regressions and interaction term

VARIABLES	Baseline (1)	Interaction term (2)	(3)	(4)	(5)	(6)	(7)
Capital intensity	-0.008	-0.008	0.016***		0.037***	0.034***	0.045***
	(0.006)	(0.006)	(0.006)		(0.012)	(0.012)	(0.012)
Labor intensity	-0.061***	-0.061***			-0.060***		0.018***
	(0.005)	(0.005)			(0.005)		(0.005)
Firm size	-0.132***	-0.133***		-0.105***	-0.132***	-0.119***	
	(0.005)	(0.005)		(0.005)	(0.005)	(0.005)	
Export intensity	-0.025***	-0.017***	-0.040***	-0.015**	-0.025***		
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)		
Maintenance intensity	0.107***	0.107***			0.120***	0.116***	0.107***
	(0.005)	(0.005)			(0.006)	(0.006)	(0.006)
Ownership	-0.049	0.028	-0.162***	0.102**	-0.052		-0.351***
	(0.039)	(0.052)	(0.051)	(0.052)	(0.039)		(0.036)
Ownership*exp intensity		-0.043**	-0.036**	-0.059***			
		(0.018)	(0.018)	(0.018)			
Maintenance*cap intensity					0.011***	0.012***	0.011***
					(0.003)	(0.003)	(0.003)
Constant	2.187***	2.191***	0.067***	1.569***	2.239***	2.176***	0.481***
	(0.073)	(0.073)	(0.007)	(0.070)	(0.074)	(0.072)	(0.026)
Year effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	95,189	95,189	95,189	95,189	95,189	95,189	95,189
R-squared	0.367	0.368	0.351	0.359	0.368	0.366	0.357
Adj. R^2	0.367	0.367	0.351	0.359	0.368	0.366	0.357
Prob>F	0	0	0	0	0	0	0

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.

4.3.2. Two-staged least square (2SLS) regression

In the basic equation (3), CO_2 intensity is dependent variable. The result shows that there is a negative relationship between CO_2 emission intensity and firm size. However, the results may suffer from endogeneity problems. To address this issue, I employ 2SLS regression with compensation as the instrumental variable. From **Table 4.5** column (1) presents the first stage regression results, revealing that compensation as the instrument variable has positive impact to firm size, which shows that the instrument is relevance in the first stage. In addition, first stage regression test suggests that the critical value of F-statistic for weak identification is higher than the critical Stock-Yogo value (see **Appendix 7.1**). It means that we reject the null hypothesis of instrument is weak.

Table 4.5.

Two-stage least square regression

Dependent variable	(1) First stage regression	(2) Second stage regression
	Firm size	CO_2 intensity
Compensation	0.099***	-
	(0.002)	
Capital intensity	-0.069***	-0.005
	(0.005)	(0.006)
Labor intensity	-0.547***	-0.033***
	(0.005)	(0.011)
Export intensity	0.161***	-0.034***
	(0.006)	(0.007)
Maintenance intensity	0.065***	0.103***
	(0.005)	(0.005)
Ownership	1.547***	-0.133***
	(0.034)	(0.050)
Firm size	-	-0.084***
		(0.018)
Constant	12.901***	1.555***
	(0.025)	(0.236)
Observations	95,189	95,189
R-squared	0.392	0.366
Adj. R^2	0.392	0.366
F-Statistic for weak identification	3606	-
Year effects	Yes	Yes

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The Hausman test was employed to test the existence of endogeneity **(Appendix 7.2)**. The result shows the significant statistics meaning that the variable is endogenous, justifying to use two-stage instrumental variable regressions. The Hausman test also presents that coefficient estimator of 2SLS is consistent. However, Cameron and Trivedi (2009) argue that IV estimator can be less efficient than OLS estimator. Column (2) presents second stage regression results, showing the impact of firm size on CO_2 intensity which negatively significant at level 1%. Comparing the result between OLS regression (**Table 4.4**. column 1) and 2SLS regression (**Table 4.5**. column 2), although firm size, labor intensity, export intensity, and maintenance intensity confirm the similar results regarding both sign and significancy, the impact of variable ownership on CO_2 intensity become negatively significant at level 1%. Controlling for potential endogeneity by implementing IV might explain the inconsistencies estimation.

4.3.3 Fixed effect (FE) and fixed effect instrumental variable (FE-IV)

Table 4.6 presents the results of regression FE (column 1) and FE-IV (column 2) which shows slightly different results. While all the sign of variables between both models are the same, the significancy of labor intensity yield different results. In the FE model, labor intensity has significant relationship with CO_2 intensity, while in the FE-IV estimation, the coefficient is insignificant. Furthermore, variable ownership in FE-IV become insignificant, while in 2SLS model, it is significant at 1%. After performing the Hausman test (**Appendix 8**), the result is insignificant which means that the FE and FE-IV estimates are not significantly different, thus FE model is preferable. This might be because the instrument variable is weak.

On column 1, capital intensity, labor intensity, firm size, and maintenance intensity are significant at level 1%. On the other hand, export intensity and firm ownership are insignificant. It is found that an increase of 1% in labor intensity, CO_2 intensity would decrease by 0.031%, other factors held constant. Labor intensity is significantly negative implying that labor intensive firms are emission efficient. This might be because labor intensive industry are typically non-complex industry which do not generate much pollution. Capital intensity also have negative implication to emission intensity meaning that firm with more capital are emitting less. A decrease of 0.074% of CO_2 intensity is associated with a 1% rise in capital intensity. It indicates that firms with bigger plant, high technology, and/or bigger property are cleaner than small capital industry.

Further, a 1% rise in firm size, CO_2 intensity decrease by 0.315%. This mean that bigger firms are more emission efficient or emitting less compared to small size firm. With the advantages of high profit, bigger firms can invest in cleaner technology and do research and development to improve their performance. Maintenance intensity, on the other hand, have positive effect to emissions intensity. A 1% rise in maintenance intensity, CO_2 intensity increase by 0.107%. It implies that firms with more expenses in maintenance, emit more emissions. However, the reason is not clear. Theoretically, firms that spend more money on machinery maintenance would emit less since the equipment are regularly being maintained. Perhaps, the large money spend on maintenance is a sign that emission-intensive firms adopt complex machines generating high carbon emissions. Meanwhile other variables, capital intensity and ownership status, show insignificant results.

Table 4.6

Fixed effects and fixed effect instrumental variable regression

VARIABLES	(1) FE	(2) FE-IV	(3) 2SLS
Capital intensity	-0.074***	-0.094**	-0.005
	(0.007)	(0.038)	(0.006)
Labor intensity	-0.031***	-0.048	-0.033***
	(0.006)	(0.032)	(0.011)
Firm size	-0.315***	-0.405**	-0.084***
	(0.010)	(0.168)	(0.018)
Export intensity	0.004	0.002	-0.034***
	(0.012)	(0.012)	(0.007)
Maintenance intensity	0.071***	0.061***	0.103***
	(0.007)	(0.020)	(0.005)
Ownership	-0.091	-0.081	-0.133***
	(0.082)	(0.084)	(0.050)
Constant	4.788***	6.028***	1.555***
	(0.139)	(2.298)	(0.236)
Observations	95,189	95,189	95,189
R-squared	0.573		0.366
Number of psid	28,115	28,115	
R-sq: within	0.573	0.572	
R-sq: between	0.151	0.135	
R-sq: overall	0.340	0.318	
Adj. R^2	0.573		0.366
Prob>F	0	0	
F	6338		
Corr	-0.119	-0.195	
sigma_u	1.449	1.508	
sigma_e	1.326	1.327	
Rho	0.544	0.563	
F-Statistic for weak identification			3606
Year effect	Yes	Yes	Yes

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

CHAPTER 5. CONCLUSION

Fossil fuels as an energy source is undeniably important for economic growth and human life. Aside from their importance providing energy, overconsumption of fossil fuels especially for combustion processes, will increase emissions level in the atmosphere. Although some mitigation action to address this issue has already determined, the demand of fossil is still high in some countries, including Indonesia. As manufacturing sector is the main consumer of fossil fuels, this paper tries to analyse the energy intensity of manufacturing sub-sectors in Indonesia and examine the determinants of CO_2 emission intensity at firm level. The unavailability of data plant emissions, requires author to calculate CO_2 emission from firms' fuels consumption based on IPCC Guidelines 2006.

This study found that the energy consumption in manufacturing sector based on fossil fuels has decreased from 749,842 TJ (2011) to 445,671 TJ (2014). Coal and diesel oil are the two dominant energy sources for industry which account for 89% of the total share of energy consumption. Food, beverages, and tobacco industry; fabricated metal and machinery; and non-metallic mineral industry are sub-sectors with the highest energy consumption along the period of study. However, among those three sub-sectors, only non-metallic mineral industry which shows high energy intensity. The lower energy intensity of food, beverages, and tobacco; and fabricated metal industry is due to the higher value added of the products, since energy intensity is defined as total energy consumption divided by value addition of the firm. During 2011-2014, the trend of the total energy consumption has decreased and the trend of total value addition of product has increased. This leads to the decreasing trend of energy intensity meaning that the firm using less energy to produce a product.

While the energy intensity has declined over time, the CO_2 intensity has decreased as well. However, the reduction of CO_2 intensity is not because the decreasing of the total carbon emission, instead it increases over time. Testing the hypothesis of the determinants of CO_2 intensity, this study employs OLS, 2SLS, FE, and FE-IV model. The results among all regressions slightly similar regarding significancy and sign. While the use of compensation as instrument variable might generate weak instrument, the ownership and export intensity variable show their significancy in 2SLS model. However, after inserting the instrument in FE-IV model, labor intensity, export intensity, and ownership become insignificant. Furthermore, using FE model, this study found that capital intensity, labor intensity, firm size, and maintenance intensity are significant at 1%. The big firm size is more emission efficient or emitting less compared to small size firm. Furthermore, capital and labor intensive firms are less-carbon intensive. These results might indicate that big firms may spend on clean technology and invest on high skilled labor to operate the technology, which will result on emission efficient. Conversely, maintenance intensity shows positive effect on emission intensity. While the reason might be unclear, it can be assumed that the maintenance expanses is spend on the complex machine which adopted by the emission-intensive firms.

Lastly, we hope that this study would provide some insight to Indonesian's policymakers in picturing the condition of energy and emissions of manufacturing sector. We would like to highlight that the policymakers should focus on industrial sub-sectors which contribute high energy and emissions intensity, especially non-metallic mineral industry. This is important since the amount carbon emission still has increased, even though its CO_2 intensity has declined. Moreover, the findings of determinants of CO_2 intensity might become a foundation on how policymakers formulate the regulations related firm's emissions.

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Appendices

Appendix 1.

Fuel consumption and energy consumption by fuel types

1.1 Fuel Consumption by fuel types

Unit= kg/liter

Fuel Type	Year				Total
	2011	2012	2013	2014	
Gasoline	750,272,237	606,682,382	573,252,932	1,007,752,407	2,937,959,958
Diesel	5,986,934,359	7,374,673,332	3,675,004,877	4,344,644,011	21,381,256,579
Kerosene	101,249,628	125,625,323	90,048,986	164,621,203	481,545,140
Coal	15,372,033,528	13,338,525,742	7,477,966,791	5,937,584,030	42,126,110,091
Coal briquettes	0	14,271,182	225,539,081	136,162,313	375,972,576
Gas	680,207,668	670,962,000	630,991,296	670,529,308	2,652,690,273
LPG	148,004,756	134,195,246	109,789,876	118,401,638	510,391,516
Lubricants	215,037,848	263,440,604	111,614,288	248,568,351	838,661,091
TOTAL	23,253,740,024	22,528,375,812	12,894,208,127	12,628,263,261	71,304,587,224

1.2. Energy Consumption by fuel types

Units= TJ

Fuel Types	NCV Converter (TJ/kg)	Year				Total
		2011 (TJ)	2012 (TJ)	2013(TJ)	2014 (TJ)	
Gasoline	0.0000443	33,273	26,876	25,395	44,643	130,152
Diesel	0.0000430	257,438	317,111	158,025	186,820	919,394
Kerosene	0.0000438	4,435	5,502	3,944	7,210	21,092
Coal	0.0000264	406,437	352,671	197,717	156,990	1,113,814
Coal briquette	0.0000207	0	295	4,669	2,819	7,783
Gas	0.0000480	32,650	32,206	30,288	32,185	127,329
LPG	0.0000473	7,001	6,347	5,193	5,600	24,142
Lubricants	0.0000402	8,645	10,590	4,487	9,992	33,714
TOTAL		749,842	751,599	429,718	445,671	2,377,419

Appendix 2.

Fuel consumption and energy consumption by sectors

2.1 Fuel Consumption by sectors

Unit= kg/liter

No	Sectors (2 digit ISIC)	Fuel Consumption				TOTAL
		2011	2012	2013	2014	
1	Food, beverages, and tobacco (10,11,12)	2,043,222,931	11,941,727,478	2,189,803,636	2,405,712,420	18,580,466,465
2	Textile, wearing apparel and leather (13,14,15)	1,963,454,027	1,451,184,279	1,290,717,797	1,599,994,194	6,305,350,297
3	Wood and wood products (16,31)	225,018,185	364,898,795	294,332,751	314,800,598	1,199,050,329
4	Paper and paper products (17,18)	1,060,099,121	2,083,608,731	1,040,487,719	1,075,925,229	5,260,120,800
5	Chemical, petroleum, coal, rubber, and plastic products (19,20,21,22)	2,656,298,577	2,139,168,863	2,617,043,748	2,164,085,027	9,576,596,215
6	Non-metalic mineral products (23)	2,939,965,786	2,054,789,353	4,301,207,197	2,966,398,804	12,262,361,140
7	Basic metal industries (24)	658,042,408	526,395,749	334,619,687	488,117,177	2.007,175,021
8	Fabcricated metal products, machinery, and equipment (25,26,27,28,29,30)	11,645,697,868	1,716,925,406	750,158,409	1,562,139,390	15,674,921,073
9	Other manufacturing industries (32,33)	61,941,121	249,677,158	75,837,183	51,090,422	438,545,884
	TOTAL	23,253,740,024	22,528,375,812	12,894,208,127	12,628,263,261	71,304,587,224

2.2 Energy Consumption by sectors

Units= TJ

No	Sectors (2 digit ISIC)	Energy Consumption (TJ)				Total
		2011	2012	2013	2014	
1	Food, beverages, and tobacco (10,11,12)	73,847	388,054	80,229	94,066	636,283
2	Textile, wearing apparel and leather (13,14,15)	60,158	44,877	39,551	48,422	193,007
3	Wood and wood products (16,31)	8,687	12,389	11,185	10,625	42,887
4	Paper and paper products (17,18)	30,751	57,560	31,148	34,048	153,508
5	Chemical, petroleum, coal, rubber, and plastic products (19,20,21,22)	84,633	82,984	99,160	83,446	350,224
6	Non-metalic mineral products (23)	81,468	61,298	119,277	86,708	348,751
7	Basic metal industries (24)	24,798	19,466	13,439	18,486	76,190
8	Fabricated metal products, machinery, and equipment (25,26,27,28,29,30)	382,739	74,097	32,441	68,249	557,526
9	Other manufacturing industries (32,33)	2,673	10,874	3,288	2,209	19,045
	TOTAL	749,842	751,599	429,718	446,260	2,377,419

Appendix 3.

Value added per sector

Kurs: 1 US$= Rp 14.250

No	Sectors	Value Added				Total
		2011	2012	2013	2014	
1	Food, beverages, and tobacco (10,11,12)	18,697,939	22,847,960	30,623,890	33,685,473	105,855,262
2	Textile, wearing apparel and leather (13,14,15)	7,164,535	8,271,141	11,450,179	12,083,407	38,969,262
3	Wood and wood products (16,31)	1,921,766	1,993,109	2,364,114	3,089,401	9,368,390
4	Paper and paper products (17,18)	4,806,918	4,388,339	4,815,341	4,968,069	18,978,667
5	Chemical, petroleum, coal, rubber, and plastic products (19,20,21,22)	14,238,581	14,126,625	20,152,506	25,688,643	74,206,354
6	Non-metallic mineral products (23)	2,596,203	3,187,725	3,320,521	5,536,515	14,640,963
7	Basic metal industries (24)	2,680,857	2,724,234	4,716,977	4,716,977	14,521,693
8	Fabricated metal products, machinery, and equipment (25,26,27,28,29,30)	16,998,827	22,596,575	25,427,918	27,474,133	92,497,453
9	Other manufacturing industries (32,33)	735,875	804,713	978,372	1,315,676	3,834,636
	TOTAL	69,841,501	80,940,421	103,532,466	118,558,294	372,872,681

Appendix 4.

Energy Intensity by sectors

		Energy Intensity (TJ/US$)			
No	**Sector**	**2011**	**2012**	**2013**	**2014**
1	Food, beverages, and tobacco	0.004	0.017	0.003	0.003
2	Textile, wearing apparel and leather	0.008	0.005	0.003	0.004
3	Wood and wood products	0.005	0.006	0.005	0.003
4	Paper and paper products	0.006	0.013	0.006	0.007
5	Chemical, petroleum, coal, rubber, and plastic products	0.006	0.006	0.005	0.003
6	Non-metallic mineral products	0.031	0.019	0.036	0.016
7	Basic metal industries	0.009	0.007	0.003	0.004
8	Fabricated metal products, machinery, and equipment	0.023	0.003	0.001	0.002
9	Other manufacturing industries	0.004	0.014	0.003	0.002

Appendix 5.

Actual CO_2 emissions per year by fuel combustion

5.1. Actual CO_2 emissions in 2011

Sector		Energy						
Category		Fuel combustion activities						
Period		2011						
Sheet		(CO_2 from energy sources - Sectoral Approach)						
	STEP 1	STEP 2		step 3		step 4		
	A	B(a)	C	D	E	F	G	
	Fuel Consumption	Conversion Factor	Apparent Consumption	Carbon Emission Factor	Total Carbon	Carbon oxidization factor	Actual CO_2 Emissions	
	Kg/liter	(TJ/kg)	(TJ)	(Kg C/TJ)	(Gg C)		(Gg CO_2)	
Fuel Types			**C=A*B**		**E=C*D/10^6**		**G=E*F*44/12**	
Gasoline	406,611,038	0.0000443	18,012.869	69300	1,248.291	1	4,577.070	
Diesel oil	3,414,128,845	0.0000430	146,807.540	74100	10,878.439	1	39,887.608	
Kerosene	54,027,702	0.0000438	2,366.413	71900	170.145	1	623.865	
Lubricants	120,164,827	0.0000402	4,830.626	73300	354.084	1	1,298.311	
LPG	83,234,812	0.0000473	3,937.006	63100	248.425	1	910.892	
Gas	358,287,832	0.0000480	17,197.816	56100	964.797	1	3,537.590	
Coal	7,648,459,520	0.0000264	202,225.270	96920	19,599.673	1	71,865.468	
Coal briquettes	0	0.0000207	0	97500	0	1	0	
Total	**12,084,914,576**		**395,378**		**33,464**		**122,701**	

5.2. Actual CO_2 emissions in 2012

Sector		Energy					
Category		Fuel combustion activities					
Period		2012					
Sheet		(CO_2 from energy sources - Sectoral Approach)					
	STEP 1	STEP 2		step 3		step 4	
	A	B(a)	C	D	E	F	G
	Fuel Consumption	Conversion Factor	Apparent Consumption	Carbon Emission Factor	Total Carbon	Carbon oxidization factor	Actual CO_2 Emissions
	Kg/liter	(TJ/kg)	(TJ)	(Kg C/TJ)	(Gg C)		(Gg CO_2)
Fuel Types			**C=A*B**		**E=C*D/10^6**		**G=E*F*44/12**
Gasoline	560,159,377	0.0000443	24,815.060	69300	1,719.683	1	6,305.506
Diesel oil	4,804,601,087	0.0000430	206,597.850	74100	15,308.900	1	56,132.635
Kerosene	80,599,914	0.0000438	3,530.276	71900	253.826	1	930.698
Lubricants	153,048,101	0.0000402	6,152.533	73300	450.980	1	1,653.595
LPG	64,370,736	0.0000473	3,044.735	63100	192.122	1	704.450
Gas	340,944,067	0.0000480	16,365.315	56100	918,094	1	3,366.345
Coal	6,549,481,727	0.0000264	173,168.3	96920	16,783,471	1	61,539.394
Coal briquettes	14,271,182	0.0000207	295.413	97500	28,802	1	105.610
Total	**12,567,476,191**		**433,969**		**35,656**		**130,738**

5.3. Actual CO_2 emissions in 2013

Sector		Energy					
Category		Fuel combustion activities					
Period		2013					
Sheet		(CO_2 from energy sources - Sectoral Approach)					
	STEP 1	STEP 2		step 3		step 4	
	A	B(a)	C	D	E	F	G
	Fuel Consumption	Conversion Factor	Apparent Consumption	Carbon Emission Factor	Total Carbon	Carbon oxidization factor	Actual CO_2 Emissions
	Kg/liter	(TJ/kg)	(TJ)	(Kg C/TJ)	(Gg C)		(Gg CO_2)
Fuel Types			**C=A*B**		**$E=C*D/10^6$**		**G=E*F*44/12**
Gasoline	573,252,932	0.0000443	25,395.105	69300	1,759.880	1	6,452.896
Diesel oil	3,675,004,877	0.0000430	158,025.210	74100	11,709.668	1	42,935.449
Kerosene	90,048,986	0.0000438	3,944.145	71900	283.584	1	1,039.808
Lubricants	111,614,288	0.0000402	4,486.894	73300	328.889	1	1,205.927
LPG	109,789,876	0.0000473	5,193.061	63100	327.682	1	1,201.501
Gas	666,067,052	0.0000480	31,971.218	56100	1,793.585	1	6,576.479
Coal	7,477,966,791	0.0000264	197,717.44	96920	19,162.774	1	70,263.506
Coal briquettes	225,539,081	0.0000207	4,668.659	97500	455.194	1	1,669.045
Total	**12,929,283,883**		**431,402**		**35,821**		**131,345**

5.4. Actual CO_2 emissions in 2014

Sector		Energy					
Category		Fuel combustion activities					
Category Code		2014					
Sheet		(CO_2 from energy sources - Sectoral Approach)					
	STEP 1	STEP 2		step 3		step 5	
	A	B(a)	C	D	E	F	G
	Fuel Consumption	Conversion Factor	Apparent Consumption	Carbon Emission Factor	Total Carbon	Carbon oxidization factor	Actual CO_2 Emissions
	Kg	(TJ/kg)	(TJ)	(Kg C/TJ)	(Gg C)		(Gg CO_2)
Fuel Types			**C=A*B**		**$E=C*D/10^6$**		**G=E*F*44/12**
Gasoline	997701344	0,0000443	44198,17	69300	3062,9331	1	11,230.754
Diesel oil	4344644011	0,0000430	186819,69	74100	13843,339	1	50,758.910
Kerosene	164621203	0,0000438	7210,4087	71900	518,42838	1	1,900.904
Lubricants	248568351	0,0000402	9992,4477	73300	732,44642	1	2,685.636
LPG	118401638	0,0000473	5600,3975	63100	353,38508	1	1,295.745
Gas	822050382	0,0000480	39458,418	56100	2213,6173	1	8,116.596
Coal	5937584030	0,0000264	156989,72	96920	15215,444	1	55,789.960
Coal briquettes	136162313	0,0000207	2818,5599	97500	274,80959	1	1,007.635
Total	**12,769,733,272**		**453,088**		**36,214**		**132,786**

Appendix 6.
FE and RE estimation and LM test and Hausman test

6.1 FE and RE estimation

Variables	(1) OLS	(2) Fixed Effect	(3) Random Effect
Capital intensity	-0.008	-0.074***	-0.023***
	(0.006)	(0.007)	(0.005)
Labor intensity	-0.061***	-0.031***	-0.039***
	(0.005)	(0.006)	(0.004)
Firm size	-0.132***	-0.315***	-0.164***
	(0.005)	(0.010)	(0.005)
Export intensity	-0.025***	0.004	-0.012**
	(0.006)	(0.012)	(0.006)
Maintenance intensity	0.107***	0.071***	0.101***
	(0.005)	(0.007)	(0.005)
ownership	-0.049	-0.091	0.013
	(0.039)	(0.082)	(0.037)
2012.year	-2.903***	-2.902***	-2.916***
	(0.014)	(0.015)	(0.014)
2013.year	-2.973***	-2.964***	-2.984***
	(0.014)	(0.016)	(0.014)
2014.year	-3.046***	-2.992***	-3.047***
	(0.014)	(0.016)	(0.014)
Constant	2.187***	4.788***	2.659***
	(0.073)	(0.139)	(0.067)
Observations	95,189	95,189	95,189
R-squared	0.367	0.573	-
Adj. R^2	0.367	0.573	-
Prob>F	0	0	0
Number of psid	-	28,115	28,115
R-sq: within	-	0.573	0.569
R-sq: between	-	0.151	0.183
R-sq: overall	-	0.340	0.366
F (9, 28114)	-	6338	-
Corr (u_i, Xb)	-	-0.119	-
Sigma_u	-	1.449	1.125
Sigma_e	-	1.326	1.326
Rho	-	0.544	0.419
Wald chi2	-		63893
Year dummy	Yes	Yes	Yes
Hausman test		0.000	
LM test			0.000

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

6.2 Lagrange Multiplier Test

```
. xttest0

Breusch and Pagan Lagrangian multiplier test for random effects

        lncarb_int[psid,t] = Xb + u[psid] + e[psid,t]

        Estimated results:
                                |       Var     sd = sqrt(Var)
                       ---------+-----------------------------
                       lncarb_~t |   5.074148       2.252587
                               e |   1.757943       1.325874
                               u |   1.266211        1.12526

        Test:   Var(u) = 0
                             chibar2(01) = 28703.21
                          Prob > chibar2 =   0.0000
```

6.3 Hausman Test

```
. qui xtreg lncarb_int lncap lnlabor lnfsize lnexport lnrepair ownership i.year, fe

. est store b_fe

. qui xtreg lncarb_int lncap lnlabor lnfsize lnexport lnrepair ownership i.year, re

. est store b_re

. hausman b_fe b_re, sigmamore

                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |      b_fe         b_re         Difference          S.E.
-------------+----------------------------------------------------------------
       lncap |   -.0742105    -.0232489       -.0509616         .003544
     lnlabor |   -.0313578    -.0389577        .0075999        .0020835
     lnfsize |    -.314843    -.1636286       -.1512144        .0060155
    lnexport |    .0038764    -.0123446        .0162211        .0076702
    lnrepair |     .071204     .1011906       -.0299866        .0031753
   ownership |   -.0911391     .0132151       -.1043542        .0493639
        year |
       2012  |   -2.902021    -2.916039        .0140174        .0031554
       2013  |   -2.964248    -2.983962        .0197133        .0036488
       2014  |   -2.992467    -3.047012        .0545449        .0043908
------------------------------------------------------------------------------
                           b = consistent under Ho and Ha; obtained from xtreg
            B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(9) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =      803.65
                Prob>chi2 =      0.0000

.
```

Appendix 7.

2SLS postestimation test

7.1. Weak identification test

```
Underidentification test (Kleibergen-Paap rk LM statistic):          2229.288
                                                  Chi-sq(1) P-val =    0.0000

Weak identification test (Cragg-Donald Wald F statistic):            8172.213
                         (Kleibergen-Paap rk Wald F statistic):      3605.871
Stock-Yogo weak ID test critical values: 10% maximal IV size            16.38
                                         15% maximal IV size             8.96
                                         20% maximal IV size             6.66
                                         25% maximal IV size             5.53
Source: Stock-Yogo (2005).  Reproduced by permission.
NB: Critical values are for Cragg-Donald F statistic and i.i.d. errors.

Hansen J statistic (overidentification test of all instruments):        0.000
                                                (equation exactly identified)

Instrumented:         lnfsize
Included instruments: lncap lnlabor lnexport lnrepair ownership 2012.year
                      2013.year 2014.year
Excluded instruments: lninsent
```

7.2. Endogeneity test (Hausman Test)

```
. estat firststage

  First-stage regression summary statistics
```

Variable	R-sq.	Adjusted R-sq.	Partial R-sq.	Robust F(1,28114)	Prob > F
lnfsize	0.3924	0.3924	0.0791	3605.87	0.0000

```
  (F statistic adjusted for 28115 clusters in psid)

. estat endog

  Tests of endogeneity
  Ho: variables are exogenous

  Robust regression F(1,28114)    =  7.48318  (p = 0.0062)
    (Adjusted for 28115 clusters in psid)
```

Appendix 8.

Hausman test FE and FE-IV model

```
. hausman ivfe fe

                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |      ivfe          fe         Difference          S.E.
-------------+----------------------------------------------------------------
     lnfsize |   -.4053813     -.314843       -.0905382        .1269216
       lncap |   -.0941609    -.0742105       -.0199504        .0279687
     lnlabor |   -.0483877    -.0313578       -.0170299        .0238744
    lnexport |    .0023147     .0038764       -.0015617        .0022333
    lnrepair |    .0605505      .071204       -.0106535        .0149364
   ownership |   -.0805033    -.0911391        .0106358         .015159
        year |
       2012  |   -2.871552    -2.902021        .0304693        .0427184
       2013  |   -2.925761    -2.964248        .0384873        .0539576
       2014  |   -2.937201    -2.992467        .0552662         .077478
------------------------------------------------------------------------------
                          b = consistent under Ho and Ha; obtained from xtivreg
           B = inconsistent under Ha, efficient under Ho; obtained from xtreg

    Test:  Ho:  difference in coefficients not systematic

                  chi2(9) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =        0.51
                Prob>chi2 =      1.0000
```