Decomposition of energy-related CO_2 emissions in the Indonesian manufacturing sector

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ABSTRACT

Energy consumption of the industrial sector accounts for 40% of total final energy consumption in Indonesia and consequently is a major source of the CO_2 emissions in the country. This paper identifies the different factors affecting the level of energy-related CO_2 emissions from the manufacturing sector in Indonesia between 1980-2000 using the complete decomposition approach. CO_2 emissions were decomposed into four components: coefficient of the CO_2 emissions, structural changes, economic activity, and energy intensity effects. The analysis also provides details on five energy intensive subsectors, i.e., textile, paper, chemical, basic metal and non-metal subsectors.

Economic growth has been the main contributor to the increase of CO_2 emissions, except between 1997-2000 which was the aftermath of the economic crisis of 1997. The structural effect was negative, reflecting the shift to a less energy intensive industrial structure over this period, which served to decrease CO_2 emissions. Although the coefficient effect was positive throughout the period of analysis, it showed a declining trend. Increases in CO_2 emissions, particularly after 1996, were largely driven by the energy intensity effect as a result of inefficiency in energy use.

At the subsectoral level, economic activities were the main component affecting the increase of CO_2 emissions for all periods of analysis in the textile, paper and chemical sub-sectors. However, all five energy intensive subsectors experienced a declining effect of economic activity after the 1997 economic crisis. The energy intensity effect due to some efficiency improvements in all subsectors led to reductions in CO_2 emissions. The emission coefficient effects were positive for all subsectors, except for chemicals. The non-metal subsector was the highest contributor in the emission coefficient effect, followed by the textile, basic metal and paper subsectors. This suggests that improvements in fuel switching and abatement technologies in the energy intensive manufacturing industries are necessary.

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1. INTRODUCTION

The main driver of the Indonesian economy is manufacturing industry sector that accounted for 25 percent of total GDP in 2000, which is the focus of this study. Prior to 1997, growth in GDP outpaced growth in energy consumption. This pattern changed after the 1997 economic crises, however, where the reverse occurred. Energy consumption of the industry sector accounts for 40% of the total final energy consumption in Indonesia and consequently is the major source of CO_2 emissions in the country. Recent rapid growth in energy demand has increased energy-related environmental problems. The situation has been further aggravated by the relatively low efficiency of energy use.

Probably, the most important factor contributing to the energy efficiency problem in Indonesia is the under-pricing of energy. The subsidy policy for electricity and petroleum products, such as diesel oil and kerosene mostly used in industry, has discouraged energy efficiency policies and programs. High levels of protection given to energy-intensive industries that are mostly state enterprises has also contributed to a lack of interests for energy efficiency initiatives in industry. With the current ongoing policy for reducing energy subsidies, however, energy efficiency issues have become more prominent.

Regardless of these constraints, there are several driving factors for imposing energy efficiency policies in Indonesia (APERC, 2003). First, increasing energy consumption due to population growth as well as the industrialization process. Second, declining domestic oil reserves, which between 1980-2002 have declined by 50%, from 9.5 thousand million barrels in 1980 to 5.0 thousand million barrels in 2002 (BP, 2004). Third, increasing public awareness and interests in environmental quality issues. Probably, the more attractive aspect from the government side for the imposition of energy efficiency policies is the potential to generate significant levels of revenue from the export of fossil fuels diverted from the domestic economy.

Although oil continues to lead the share of fuel mix in Indonesia’s final energy consumption, its growth rate after 1990 has been much slower than that of coal, electricity, and gas. Coal consumption increased significantly after the mid-1990s, a trend that has contributed to the increase in carbon dioxide emissions. As the main goal of Indonesian energy policy is generally associated with the reduction of energy use, especially the high-carbon emitting energy sources, it is important to investigate whether policy options for reducing energy consumption through the improvement of energy efficiency satisfy environmental criteria as well as the desired level of economic activity and the desired mix of fuel consumption. For this purpose, decomposing CO_2 emissions is necessary to distinguish the different components influencing the level of CO_2 emissions such that any particular energy and environmental policy options designed to reduce this level can be assessed.

While decomposition analysis has been widely used in energy research, few studies have been reported using Indonesian data. Priambodo and Kumar (2001) estimated energy-related carbon dioxide emissions in small and medium scale industries. Other studies have involved descriptive analysis and did not analyse the various factors influencing trends in energy use and emissions. This is concerned with the changes in energy-related carbon-dioxide emissions in manufacturing industries in Indonesia in the period 1980-2000. The decomposition was performed for nine manufacturing sub-sectors by giving in-depth analysis to the fuel mix used in industrial processes. Furthermore, the decomposition analysis focused on a number of specific energy intensive subsectors: textile, chemical, paper, non-metal and basic metal subsectors. Decomposition of CO_2 emissions is used to explain the variations of CO_2 emissions arising from economic activity, structural effect, coefficient effect of the CO2 emissions, and energy intensity effect.

In this study, two decomposition analyses on carbon emissions from energy consumption in manufacturing sector were carried out. First, detailed analysis on decomposition of the level of CO_2 emissions. Second, decomposition was performed on CO_2 emission intensity in order to observe the impacts of fuel mix options on CO_2 emission intensities of the manufacturing sector. These indicators are compared for each manufacturing energy intensive subsector to reveal the underlying factors that influences changes in the level of CO_2 emissions in the sector.

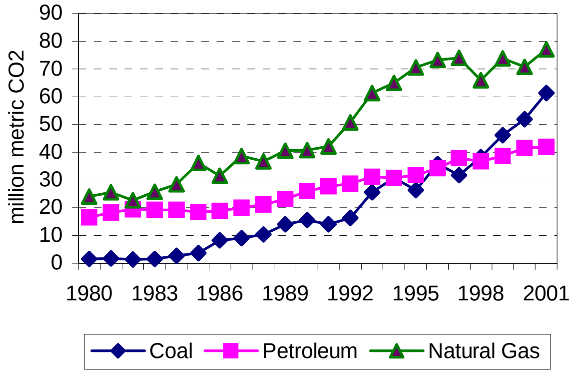
2. ENERGY CONSUMPTION AND CARBON EMISSIONS IN INDONESIA

Indonesia's per capita energy consumption was 0.69 toe/cap in 2000, which was relatively low in comparison to more industrialized countries (OECD) at 4.74 toe/cap, and only slightly higher than that of Vietnam (0.47 toe/cap) and the Philippines (0.56 toe/cap). Total final energy consumption of the country is dominated by oil that accounted for 68 percent in 2000, followed by gas (14 percent), electricity (10 percent), and coal (9 percent). Although oil continuously leads the share of fuel mix, its growth rate over the period from 1990 to 2000 was only 6 percent, much slower than that of coal (27 percent), and electricity

(11 percent), and slightly higher than that of gas (5 percent). Coal consumption increased from 21 percent between 1990-1997 to 40 percent between 1997-2000. The increasing trend towards coal consumption has contributed to the increase in carbon dioxide emissions (Figure 1).

Since the proportion of industrial energy use is relatively high compared with other economic sectors, it represents an important indicator of the structure of energy use of the country. The growth of oil consumption is decreasing through substitution by coal. (Figure 2). In 2000, total final energy consumption in industry was 23.08 Mtoe. Out of this total, 40 percent was oil, followed by gas 33 percent, coal 15 percent, and electricity 13 percent. There were crucial changes in gas and coal consumption trends over the decade between 1990-2000. Coal consumption more than doubled. Gas consumption grew at similar rate to oil consumption, and almost reach the level of oil consumption. Table 1 shows detailed structure and growth of final energy consumption in industry.

Fig 1. Trend of carbon emissions by fuel type in Indonesia



Source: EIA (2004)

Table 1. Structure and growth of final energy consumption in industrial sector

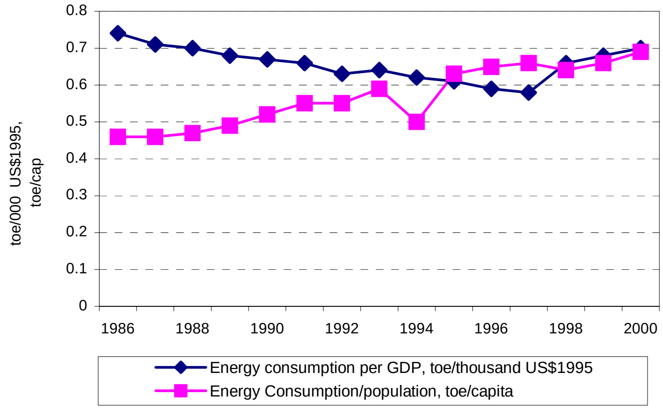
Type	In Mtoe			Consumption (% of total)			Growth in period of			
	1983	1990	2000	1983	1990	2000	83-90	90-97	97-00	90-00
Coal	0.14	1.13	3.46	1.6%	8.7%	15.0%	42.6%	17.8%	44.2%	25.7%
Oil	5.40	5.38	9.14	61.9%	41.5%	39.6%	0.3%	6.0%	4.8%	5.6%
Gas	2.88	5.25	7.55	33.0%	40.5%	32.7%	21.4%	3.7%	4.1%	3.9%
Electricity	0.30	1.22	2.93	3.4%	9.4%	12.7%	22.4%	11.9%	3.8%	9.5%
Total	8.72	12.98	23.08	100.0%	100.0%	100.0%	6.8%	5.6%	7.7%	6.2%

Source: IEA (2002)

Energy efficiency indicators

Energy consumption per unit of GDP, termed energy intensity, indicates the amount of energy consumed per unit of income generated by the country's economy which can be interpreted as an indicator of the changes in energy efficiency. Indonesia's energy intensity has steadily decreased over the period 1986-1998. However, after the economic turmoil of 1997, it rose from 0.66 to 0.70 toe/thousand US$95 (Figure 2). Energy intensity in industry is defined as the ratio of final energy consumption of the sectors being considered to the value added. There was little fluctuation in Indonesia's energy intensity in the industrial sector suggesting that there were no significant improvements in energy efficiency in this sector.

Figure 2. Energy efficiency indicators



Source: IEA (2002), own computation

One important factor that influenced the energy intensity is the structure of industry, which is the relative share of energy intensive and non-intensive industries. In 1971, the share of energy intensive industries in total manufacturing sector value added was 14.1 percent. This share had increased to 25.6 percent by 1990 and decreased slightly to 23.5 percent in 2000. The development of iron and steel industries during the late 1970s was responsible for the rise of energy intensive industries over this period (IEA, 1994).

Whether structural changes have played important roles in changes in energy intensity would be explained in the decomposition analysis in the following sections.

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Trend of carbon emissions

Relative to other Asian nations, the level of Indonesia's carbon emissions per dollar of GDP (carbon intensity) is moderately high (Table 2). This reflects Indonesia's almost complete dependence on fossil fuels (website EIA, 2004). Between 1981 and 2000, Indonesia's carbon intensity grew from 0.35 kg CO_2/US$95 PPP to 0.47 kg CO_2/ US$95 PPP.

In 2000, Indonesia's carbon intensity was higher than Singapore’s (0.46) and Thailand (0.40), but less than China's (0.62) and the OECD average (0.51).

Indonesia’s carbon emissions per capita were relatively low, although they grew significantly from 0.51 tonnes CO_2/cap in 1981 to 1.28 tonnes CO_2/cap in 2000. Carbon emissions per capita in 2000 were still significantly lower than Malaysia (4.56), Singapore (10.45), and Thailand (2.42) and OECD countries (11.09).

Table 2. Carbon dioxide emissions indicator

Country	CO_2 intensity, kg CO_2/US$95 PPP				CO_2 emissions/cap, tonnes CO_2/cap			
	1981	1990	2000	% chg 90-00	1981	1990	2000	% chg 90-00
Indonesia	0.35	0.35	0.47	34.3%	0.51	0.76	1.28	68.4%
Malaysia	0.43	0.49	0.56	14.3%	1.78	2.60	4.56	-24.5%
Philippines	0.14	0.16	0.24	50.0%	0.54	0.59	0.91	54.2%
Singapore	0.58	0.66	0.46	-30.3%	5.43	9.44	10.45	10.7%
Thailand	0.27	0.33	0.40	21.2%	0.67	1.40	2.42	72.9%
Vietnam	0.32	0.25	0.27	8.0%	0.26	0.27	0.52	92.6%
China	1.65	1.20	0.62	-48.3%	1.40	2.01	2.39	18.9%
USA	0.94	0.74	0.63	-14.9%	20.01	19.30	20.57	6.6%
Australia	0.82	0.78	0.70	-10.7%	13.94	15.20	17.19	13.1%
Japan	0.45	0.37	0.37	-1.6%	7.19	8.25	9.10	10.3%
OECD Avg.	0.72	0.58	0.51	-12.5%	10.70	10.55	11.09	5.1%

Source: IEA (2002)

3. The Data

The data used in this study are total fuel consumption of manufacturing industries in Indonesia. Data were collected by the Central Bureau of Statistics *(Biro Pusat Statistik, BPS Indonesia*) based on the annual survey of large and medium manufacturing industries from 1980 until 2000[2]. The manufacturing sector in this survey refers to non-oil and gas medium and large-scale manufacturing industries which follows the International Standard Industrial Classification (ISIC) Revision 2, ISIC 31 to 39.

This study considered end use energy consumption at the subsectoral and industrial levels, identified as fuel consumption of the surveyed industries. Therefore, the analysis refers to the final energy consumption of the manufacturing industries. The data consists of quantity and value of fuel and lubricant used during the survey year.

[2] This survey was carried out by *BPS Indonesia* to collect aggregate data on the number of establishments, capital status, the number of persons engaged, labor cost, electricity, energy, intermediate input, output value, value added, and value of transaction. Until 1997, the annual series of these surveys had been published in which the data classification followed the Indonesian Economic Activities Classification or Klasifikasi Lapangan Usaha Indonesia (KLUI) which referred to the International Standard Industrial Classification (ISIC) Revision 2. This classsification is divided into five hierarchical categories, i.e., sectors, sub-sectors, major groups, groups, and sub-groups. With this method, manufacturing sector is placed in Sector 3, and split into nine sub-sectors, from 31 until 39. Since 1998, the KLUI classification has been modified to follow the ISIC Revision 3, where the manufacturing industries are classified into 23 groups, from group 15 until 37. To ease data organisation, the ISIC Revision 2 was used in this research.

Figure 3 shows the trend of total energy consumption in the manufacturing sector by type of fuel. The use of natural gas and coal has increased sharply due to substitution for petroleum products in this sector since 1992. There were at least two prominent falls in energy consumption due to economic recession in this period. The first was in 1985 when total consumption declined by 14.7 percent from the previous year, and the second was in 1997 and 1998, with annual declines of 6.7 percent and 4.4 percent respectively from the previous years. This trend is important for selecting periods for the decomposition analysis.

Although the use of gas in this sector is significant, since the carbon emissions of gas are lower than that of coal and oil and also lower than indirect emissions of electricity, electricity and oil remained the largest contributors to CO_2 emissions during 1980-2000 (Figure 4).

Figure 3. Energy consumption in medium and large-scale manufacturing industries

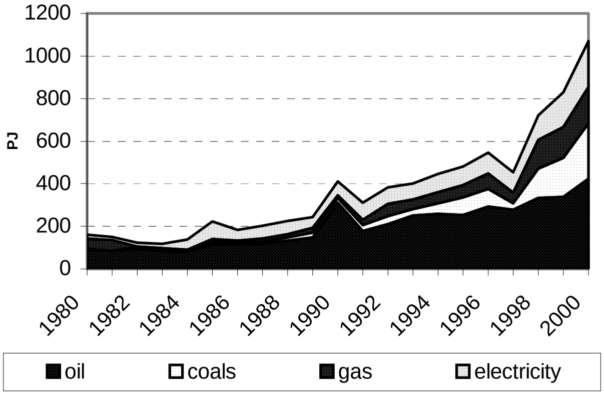


Fig 4. Trend of CO_2 emissions by type of fuel in medium and large-scale manufacturing sector

The average growth of energy consumption increased at a slower rate than value added growth prior to 1997, but it grew at a much higher rate from 1997 to 2000. This led to an increase in aggregate energy use per real manufacturing value added (aggregate energy intensity). Textile, paper, chemical, non-metal and basic metal subsectors accounted for the majority of energy use in the sector (energy intensive industries) but for only a relatively small proportion of the total value added. Figure 5 shows energy intensities and value added in the manufacturing sector in Indonesia in 2000.

The manufacturing sector has experienced structural changes over the period of study in response to the enactment of investment policies and regulations. A rapid industrialisation process took place mainly in basic metal, textiles, paper, and fabricated metal subsectors throughout the period of analysis. Manufacturing sectors grew quickly especially after implementation of the new government regulation No. 20 in 1994 which permitted 100%

foreign equity investment (see BKPM, 2004). Investments in paper, chemical and fabricated metal subsectors increased significantly. New investments in these subsectors dominated annual growth rates during the period of 1990-1997. However, after the economic crisis in mid-1997, the growth rate of all subsectors slowed down, particularly in the basic metal and non-metal subsectors (see Thee, 2001).

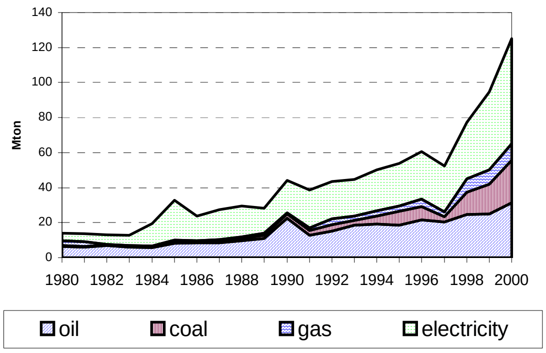
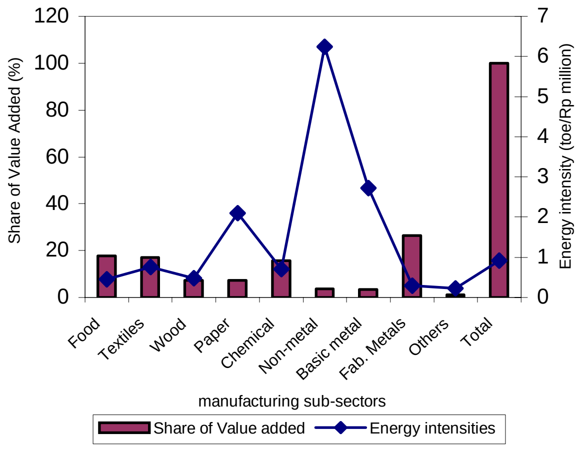


Figure 5. Subsectoral manufacturing energy intensities and value added in 2000.



Two important measures of industrialization in Indonesia are import substitution and export orientation that were initiated with the development of factories for manufacturing the previously imported products (Ishida, 1970). As a result, prior to 1985, economic policy was focused on developing import substitution industries (Table 3). During 1980-1985 the manufacturing sector grew, on average, by 17 percent per year. This policy led to a rapidly increasing growth in the basic metal subsector (106%). Wood, paper, and chemical subsectors grew moderately, around 24-27%, while food, textile, chemical and fabricated metal subsectors dominated the manufacturing sector throughout the period of analysis (1980-2000).

As government policy moved towards export-oriented and labour intensive industries after 1985, the growth rate of the total manufacturing sector declined to one-fifth of the previous growth rate. The growth rate of some energy-intensive industries such as basic metal and non-metal subsectors declined significantly suggesting a decrease in the share of energy-intensive manufacturing industries in period 1985-1990. Responds to this government policy, however, increased the growth rate of textiles and paper subsectors during 1985-1990, although then showed the declining trend after 1990.

Whether the fluctuations in value added and their impacts on energy consumption of manufacturing industries were influenced by the changes in the structure of industry or the improvements on energy efficiency in industry can be investigated using decomposition analysis.

Table 3. Value added in medium and large-scale manufacturing subsectors

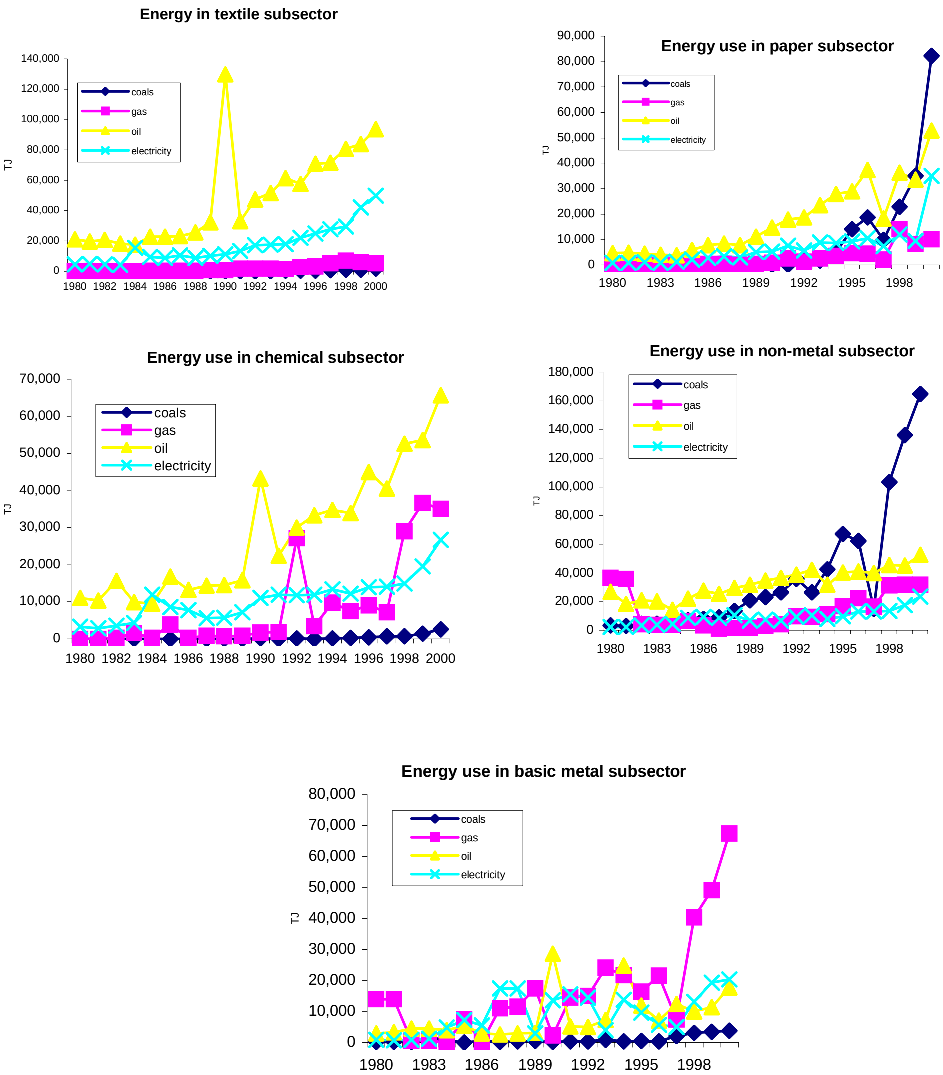
ISIC	Subsector	Annual output growth rate					Composition (percent of total VA)				
		80-85	85-90	90-97	97-00	80-00	80	85	90	97	2000
31	Food	10	19	8	-3	10	31	24	26	20	18
32	Textile	16	39	13	6	19	14	13	16	16	17
33	Wood	27	22	6	-4	14	8	10	12	8	7
34	Paper & pulp	25	28	16	12	20	3	3	5	6	7
35	Chemical	24	10	12	5	13	17	20	14	15	16
36	Non-metal	19	9	15	-6	12	6	6	4	5	4
37	Basic metal	106	25	11	-15	35	3	8	9	5	3
38	Fab. metals	15	14	21	11	16	18	16	14	24	26
39	Others	16	24	31	5	21	0	0	0	1	1
	Total	17	17	12	2	13	100	100	100	100	100

Fuel choice used in particular industries influenced the amount of energy used, and the emissions released, since conversion factors of energy to heat and to other form of end-uses varies by type of fuel. It is also influenced by any shift in the structure of manufacturing towards energy intensive or non-energy intensive industries. Variations in the share of output in an individual subsector also impact on the overall fuel mix in the sector.

The trend of emissions growth from the manufacturing sector varies as a result of changes in energy use and the options of fuel mix. Sub-sectors with a large proportion of highly CO_2 emitting fuel such as coal would release more carbon than sectors which are more dependent upon cleaner fuels, such as gas. Therefore, fuel choice would have a significant impact on the level of CO_2 emissions in the sectors. Results of decomposition would reveal the effect of variations in fuel mix on the level of carbon emissions in manufacturing subsectors and industries.

To evaluate the fuel mix in individual subsectors, it is important to understand the trend of each type of fuel used in any particular subsector within the period of analysis. Figure 6 displays the pattern of the fuel used in the energy-intensive industries: the textile, paper, non-metal and basic metal subsectors respectively.

Figure 6. Trends of fuel use in energy-intensive subsectors, 1980-2000



The use of oil was dominant in the textile and paper subsectors, and the consumption growth was relatively stable in non-metal subsector. Coal was the dominant fuel in the paper and non-metal sub-sector. In the paper subsector, coal started to be used in considerable quantities after 1994, and in the non-metal subsector after 1996. Use of coal was not significant in the other three sectors: textile chemical, and basic metal subsectors.

Gas was the dominant fuel in the chemical and basic metal subsectors, and gas consumption growth rose sharply in the paper and basic metal subsectors after the mid-1990s. The use of gas was not significant in the textile subsector. Significant quantities of electricity were used in the textile subsector and electricity exhibited an increasing trend in the paper subsector. Electricity consumption grew by a relatively small percentage in the non-metal subsector.

4. The Methodology

There are various decomposition methodologies widely used in energy related research, most of them being based on two approaches, the Laspeyres and Paasche indices and the Divisia index method. The divisia index method has been applied in many studies in decomposing energy consumption and energy intensity. They include Ang (1994); Ang and Lee (1994); Liu *et al* (1992). Study on energy related CO_2 emissions using the Divisia index method have been done, among them, by Torvanger (1991), Ang and Pandiyan (1997), Choi and Ang (2001). The obstacle in the use of the Divisia index method is the existence of a residual, which could possibly result in overestimation or under estimation of the result.

Ang and Lee (1994) compared five decomposition methods and concluded that adaptive weighting Divisia (AWD) was the most robust of the five methods. This method results in small residuals, however, there are problems in handling zero values.

Further development on decomposition methodology includes the complete decomposition model introduced by Sun (1998). The complete decomposition model is designed to improve the reliability and the accuracy of the decomposition model. With this approach, the residual values commonly arising in other decomposition methods, such as Divisia index method, can be removed by imposing the jointly created and equally distributed rule. This method has been increasingly used in analysing CO_2 emissions level and CO_2 emission intensity (Sun, 1999, 2000; Sun and Malaska, 1998; Luukkanen and Kaivo-oja, 2002; Paul and Bhattacharya, 2004; Kaivo-oja and Luukkanen, 2004). The complete decomposition method is used in this study to decompose the changes in the level of CO_2 emissions and CO_2 emissions intensity in the Indonesian manufacturing sector

Decomposition on CO_2 emissions

Following Sun (1999), CO_2 emissions (P) can be decomposed as the product of the CO2 emission coefficient (C), energy intensity (I), the share of value added in subsector i (S_i), and the total sum of economic activities in the sector (Q).

$$P = \sum_{i}^{n} \frac{P_{it}}{E_{it}} \frac{E_{it}}{Q_{it}} \frac{Q_{it}}{Q_t} Q_t = \sum_{i}^{n} C_{it} I_{it} S_{it} Q_t$$

where the subscript i denotes manufacturing sub-sector (i = 1,…,n); P_{it} the CO_2 emissions of the i-th subsector at time t; E_{it} the amount of delivered energy consumed by subsector i in manufacturing sector at time t; Q_{it} output or value added in subsector i at time t; Q_t the manufacturing output at time t;

Applying the complete decomposition approach, the change of CO_2 emissions in manufacturing sector in a given period is equal to the sum of effects of each factor: the coefficient effect of CO_2 emissions (C_{effect}), which is also called the pollution effect, the energy intensity effect (I_{effect}), the structural effect (S_{effect}) and the activity or production effect (Q_{effect}).

$$\Delta P = C_{effect} + I_{effect} + S_{effect} + Q_{effect}$$

The Q_{effect} is the main effect that creates CO_2 emissions and determines the trend based on the level in the base year.

Decrease of CO_2 emissions occurred if $C_{effect} + I_{effect} + S_{effect} < 0$, and an increase of CO_2 emissions occurred when $C_{effect} + I_{effect} + S_{effect} \geq 0$.

Decrease of CO_2 emissions = - ($C_{effect} + I_{effect} + S_{effect}$)

Emission coefficient effect is defined by the ratio of carbon dioxide emission and energy use. It evaluates fuel quality, fuel switching and the installation of abatement technologies. Intensity effect is defined by the ratio of energy consumption and total manufacturing output. The use of energy could be varied by several variables such as energy prices, energy efficiency initiatives, and technological choices (Paul and Bhattachrya, 2004). The energy intensity effect as a function of energy consumption would explain the energy efficiency status as well as changes in output share of each subsector. The changes in output share would represent the socio-economic behaviour of the manufacturing sector. The structural effect is defined as the ratio of the subsector's output to the total manufacturing output. This component explains the changes in the structure of manufacturing, i.e., the relative share of one particular sub-sector in the manufacturing sector. The activity or production effect is measured by total output in the manufacturing sector, which is also regarded as the theoretical CO_2 emissions caused by economic activities.

The formula used to calculate each effect is derived as a complete decomposition approach for a four-factor model as follows:

The coefficient effect of CO_2 emissions:

$$P_{effect} = \sum_i^n \Delta C_i I_{i,0} S_{i,0} Q_0 + \frac{1}{2}\sum_i^n (\Delta C_i)\{(\Delta I_i)S_{i,0}Q_0 + I_{i,0}(\Delta S_i)Q_0 + I_{i,0}S_{i,0}\Delta Q\}$$
$$+\frac{1}{3}\sum_i^n (\Delta C_i)\{(\Delta I_i)(\Delta S_i)Q_0 + I_{i,0}(\Delta S_i)\Delta Q + (\Delta I_i)S_{i,0}\Delta Q\} + \frac{1}{4}\sum_i^n (\Delta C_i)(\Delta I_i)(\Delta S_i)\Delta Q$$

The energy intensity effect:

$$I_{effect} = \sum_i^n C_{i,0}(\Delta I_i)S_{i,0}Q_0 + \frac{1}{2}\sum_i^n (\Delta I_i)\{(\Delta C_i)S_{i,0}Q_0 + C_{i,0}(\Delta S_i)Q_0 + C_{i,0}S_{i,0}\Delta Q\}$$
$$+\frac{1}{3}\sum_i^n (\Delta I_i)\{(\Delta C_i)(\Delta S_i)Q_0 + C_{i,0}(\Delta S_i)\Delta Q + (\Delta C_i)S_{i,0}\Delta Q\} + \frac{1}{4}\sum_i^n (\Delta C_i)(\Delta I_i)(\Delta S_i)\Delta Q$$

The structural effect:

$$S_{effect} = \sum_i^n C_{i,0}I_{i,0}(\Delta S_i)Q_0 + \frac{1}{2}\sum_i^n (\Delta S_i)\{(\Delta C_i)I_{i,0}Q_0 + C_{i,0}(\Delta I_i)Q_0 + C_{i,0}I_{i,0}\Delta Q\}$$
$$+\frac{1}{3}\sum_i^n (\Delta S_i)\{(\Delta C_i)(\Delta I_i)Q_0 + C_{i,0}(\Delta I_i)\Delta Q + (\Delta C_i)I_{i,0}\Delta Q\} + \frac{1}{4}\sum_i^n (\Delta C_i)(\Delta I_i)(\Delta S_i)\Delta Q$$

The production effect also termed as the theoretical CO_2 emissions caused by the economic activities:

$$Q_{effect} = \sum_i^n C_{i,0}I_{i,0}S_{i,0}\Delta Q_0 + \frac{1}{2}\sum_i^n (\Delta Q)\{(\Delta C_i)I_{i,0}S_{i,0} + C_{i,0}(\Delta I_i)S_{i,0} + C_{i,0}I_{i,0}\Delta S_i\}$$
$$+\frac{1}{3}\sum_i^n (\Delta Q)\{(\Delta C_i)(\Delta I_i)S_{i,0} + C_{i,0}(\Delta I_i)(\Delta S_i) + C_{i,0}(\Delta I_{i,0})(\Delta S_i)\} + \frac{1}{4}\sum_i^n (\Delta C_i)(\Delta I_i)(\Delta S_i)\Delta Q$$

Decomposition on CO_2 emission intensity

CO_2 emission intensity, *A*, is defined as the ratio between total carbon emitted by a specific subsector, *P*, and activity level or value added of that subsector, *Q*. In this study, CO_2 emission intensity *A* (*P/Q*) is decomposed into the product of the CO_2 emission coefficient of energy use (*C*), energy intensity (*I*), the share of value added in the specific sector (S_i) :

$$A = P/Q = \sum_i^n \frac{P_{it}}{E_{it}}\frac{E_{it}}{Q_{it}}\frac{Q_{it}}{Q_t} = \sum_i^n C_{it}I_{it}S_{it}$$

The description for this formula follow the notations detailed previously.

The change of CO_2 emission intensity in a given period is equal to the sum of the coefficient effect of CO_2 emissions (C_{effect}), which is also called pollution effect, the energy intensity effect (I_{effect}), and the structural effect (S_{effect}).

$$\Delta A = C_{effEct} + I_{effect} + S_{effect}$$

Similar with the CO_2 emission decomposition detailed previously, the formula used to calculate each effect in the CO_2 emission intensity is derived as a complete decomposition approach for a three-factor model.

Calculation of CO_2 emissions

Carbon dioxide (CO_2) emission are estimated by taking into account the carbon emission factors (TC/TJ), the fraction of oxidised carbon of the fuels (FCO) according to the method introduced by the IPCC (1995). Energy consumption data should be converted from its original unit to terajoules (TJ) unit using standard conversion factors.

The sectoral CO_2 emissions of the *j*-th fuel is obtained from the following relationship:

$$EC_j(t) = FC_j(t) \times CEF_j \times FCO_j \times M$$

where $EC_j(t)$ is the carbon dioxide emission of the *j*-th fuel at time *t*; $FC_j(t)$ the consumption of the *j*-th fuel at time t; CEF_j the carbon emission factor of the *j*-th fuel; FCO_j the fraction of carbon oxidised of the *j*-th fuel; and M the molecular weight ratio of carbon dioxide to carbon, 44/12.

Total emissions of CO_2 of the *i*-th subsector is

$$TC_i(t) = \sum_j EC_j$$

Total emissions of CO2 of the manufacturing is

$$C_t = \sum_i TC_i(t)$$

Table 4. Carbon emission factor and fraction of carbon oxidised

Fuel	Carbon emission factor (*CEF*) in *TC/TJ*	Fraction of carbon oxidised (*FCO*)
Motor gasoline	18.9	0.99
Fuel oil	20.2	0.99
Kerosene	19.6	0.99
Diesel oil	20.2	0.99
Other petroleum products	20.2	0.99
Coal	25.8	0.98
Soft coke	25.8	0.98
Natural gas	15.3	0.995
LPG	17.2	0.995

Source: IPPC (1995)

CO_2 emission of the electricity consumption

In estimating CO_2 emissions due to electricity consumption, also called indirect CO_2 emissions, data on particular fuel used for power generation are required. This estimation considers annual electricity consumption, CO_2 emissions factor due to electricity generation, and the transmission and distribution efficiency of electricity (Priambodo and Kumar, 2000). It is expressed in the following relationship:

$$EEC(t) = \frac{EC(t) \times CEF_e}{\eta_{TD}}$$

where $EEC(t)$ is CO_2 emission due to electricity consumption at time t; $EC(t)$ is electricity consumption at time t; CEF_e is carbon emission factor due to electricity generation (CO_2/MW_h) which is estimated as :

$$= \frac{\left(CEL_j(t) \times CEF_j \times FCO_j \times M\right)}{EL(t)}$$

where $CEL_j(t)$ is j-th fuel consumption for electricity generation at time t; $EL(t)$ is total electricity generated at time t.

Some assumptions are used in this analysis. For Indonesia, CO_2 emissions per unit of electricity generated, CEF_e, were assumed to be 0.79 ton of CO_2/MWh of electricity generated, which is in the range of 0.066-1.8 ton of CO_2/MWh as recommended in the research on energy use in Indonesia done by Kleeman, et.al (1994) as reported by Priambodo and Kumar (2000). Hence, the transmission and distribution efficiency η_{TD} of 0,79 was used to estimate the CO_2 emissions due to electricity generation.

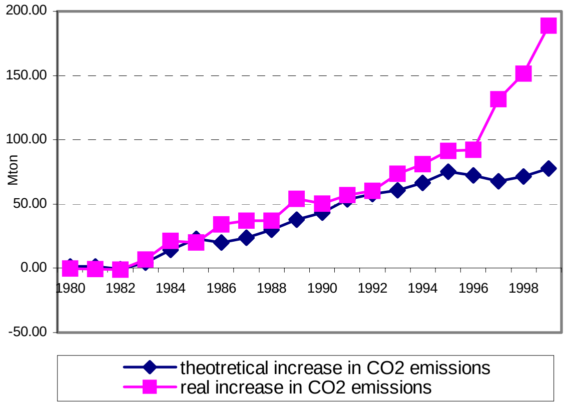
5. The Results

5.1. Decomposition of CO_2 emissions

The result of the decomposition shows that all four components of effects contributed to increase the changes in CO_2 emissions, dominated by economic activity and structural changes in the manufacturing sector. An increase of CO_2 emissions occurred in 12 out of 20 years of the observation. Figure 7 illustrated the pattern of changes in CO_2 emissions. It shows that real increases in CO_2 emissions, (ΔP), were greater than the theoretical emissions caused by economic activities in most observation years, suggesting fuel switching and abatement technologies were necessary. Theoretical CO_2 emissions or the change of CO_2 emissions due to economic activities over the period 1980-2000 was 77.5 Mt, while real CO_2 emissions, ΔP, increased by 188 Mt.

Table 5 shows in more detail how each effect contributed to changes in CO_2 emissions, as also illustrated in Figure 8. The coefficient effect of CO_2 emissions was mostly positive over the entire period, suggesting the need for fuel switching and environment related policies. The increasing trend of coal consumption was probably responsible for the increase in the pollution effect. Which subsector would specifically need the fuel switching and environmental related treatment is explained at subsectoral level analysis in the following sub-section.

Figure 7. The increase of CO_2 emissions in manufacturing sector, 1980-2000



Overall, the energy intensity effect contributed to the increase in CO_2 emissions, although it showed a declining trend in several years of observation. This reflected the fact that energy efficiency improvements and changes in fuel mix option are necessary, as there has been an increasing use of coal and a large proportion of oil consumption in the final fuel mix in several subsectors. The heavy industrialisation during 1980-1985 would also have increased energy intensity in the sector.

The declining trend of energy intensity in some years was not necessarily the result of energy efficiency improvement, since changes in the structure of industry could also reduce the energy intensity effect. After the 1997 economic crisis, output of energy intensive subsectors dropped significantly, and this unexpected change increased energy intensity. Reductions in the subsidy on energy prices starting in 1998 has not yet shown significant influence on reducing energy intensity effect.

Figure 8. Decomposition of changes in CO_2 emissions in manufacturing sector

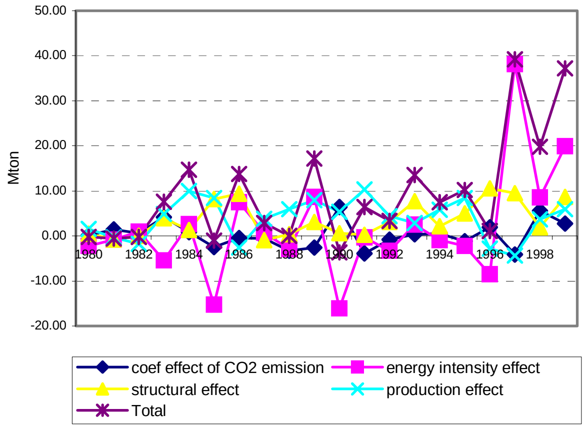


Table 5. Decomposition of changes in CO_2 emissions in manufacturing sector (Mt)

Period	Coef. effect of CO_2 emission	Intensity effect	Structural effect	Prod. effect (theoretical emission)	Total (ΔP)	Decrease of CO_2 emission
1980	0.10	-2.22	0.43	1.51	-0.18	1.69
1981	1.42	-0.87	-0.82	-0.28	-0.55	0.27
1982	0.55	1.02	0.00	-1.76	-0.18	-1.57
1983	4.14	-5.48	3.98	4.91	7.55	-2.64
1984	0.80	2.57	1.29	10.02	14.68	-4.66
1985	-2.43	-15.23	8.22	8.39	-1.05	9.43
1986	-0.47	7.49	9.34	-2.62	13.73	-16.36
1987	-0.63	0.71	-0.96	3.80	2.91	0.89
1988	-3.35	-2.95	0.42	5.92	0.04	5.88
1989	-2.63	8.69	3.12	7.99	17.18	-9.19
1990	6.40	-16.05	0.60	5.38	-3.68	9.06
1991	-3.85	-0.30	0.25	10.28	6.38	3.90
1992	-0.79	-3.31	3.11	4.35	3.37	0.98
1993	0.39	2.48	7.71	2.89	13.47	-10.58
1994	0.55	-0.99	2.12	5.81	7.49	-1.68
1995	-1.14	-2.18	5.05	8.46	10.19	-1.73
1996	1.91	-8.55	10.51	-2.83	1.04	-3.87
1997	-4.09	38.17	9.45	-4.32	39.20	-43.53
1998	5.61	8.60	1.90	3.68	19.78	-16.11
1999	2.68	19.90	8.72	5.96	37.25	-31.30
Total	5.19	31.49	74.44	77.51	188.62	-111.11

In the periodwise analysis shown in Table 6, it also indicates that economic growth was the main contributor to the increase in CO_2 emissions, except during period of 1997-2000. The economic crisis in 1997 reduced the value added which then led to a decline in CO_2 emissions. The declining structural effect after the crisis helped to explain this trend (Figure 9).

The structural effect was negative during 1980-1990 and through the whole period 1980-2000. This reflected a shift to less energy intensive in industrial structure that occurred in those periods, especially after 1985, which then contributed to the decrease in CO_2 emissions.

Although the coefficient effect of emission showed a decreasing rate averaging at 17 percent throughout the period of analysis. The average change in CO_2 emissions (ΔP) during 1997-2000 reached 80.5 Mton which was much higher than in the previous period of analysis. This sharp increase was driven by a large increase in energy intensity effect (91 percent of the total effect) during that period. Either inefficiency in energy use or the change in the fuel mix option could be the underlying factors for these changes.

Table 6. Contribution of each effect of changes in CO_2 emissions (Mton)

Effects	1980-1990	%	1990-1997	%	1997-2000	%	1980-2000	%
Coef. effect of CO_2 emission	5.2	30	4.0	24	2.4	3	15.7	17
Intensity effect	-18.6	-108	-33.3	-200	73.4	91	-15.7	-17
Structural effect	-9.1	-53	7.5	45	2.1	3	-25.3	-27
Production effect	39.7	230	38.4	231	2.6	3	117.6	127
Total (ΔP)	17.2	100	16.6	100	80.5	100	92.4	100
Decrease of CO_2 emissions	22.4	130	21.8	131	-77.9	-97	25.2	27

Figure 9. Decomposition of changes in CO_2 emissions in the selected periods (Mton)

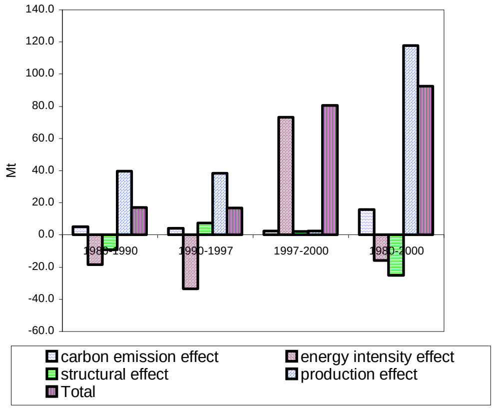


Figure 10 depicted the effect of changes on CO_2 emissions of the energy intensive subsectors during the selected periods. Economic growth was the main component affecting the increase of CO_2 emissions in all periods of analysis except in the period 1997-2000, where the economic crisis led the production effect decreased CO2 emissions.

Contribution of structural changes in the manufacturing sector to the change in CO2 emissions after the economic crisis in 1997 was not too significant.

Decrease in energy intensity effect in all energy sub-sectors in period of 1990-1997 led to reduction in CO_2 emissions. This was due to some efficiency improvement as well as a shift in the structure of industries.

The coefficient effect of CO_2 emissions or the pollution effect was positive for all energy intensive subsectors over the entire period 1980-2000, except in the chemical subsector. The non-metal subsector contributed to the highest level of the pollution effect, followed by textile, basic metal and paper.

Textile subsector

In the textile sub-sector, the coefficient effect of CO2 emissions was positive in all period of analysis except for 1980-1990 suggesting that fuel substitution and abatement technologies for reducing emissions were necessary. The level of the pollution coefficient effect was highest over the period 1990-1997, and decreased significantly thereafter. The energy intensity effect was the driving component in reducing CO_2 emissions over the period 1990-1997.

Paper subsector

In the paper sub-sector, the intensity effect was the highest contributor to the increase in CO_2 emissions during 1997-2000 suggesting the need for energy efficiency improvements in this subsector. It was also as a result of a sharp increase in the use of coal within that period, which led to a positive pollution effect. The positive pollution effect suggested the need for fuel switching in this subsector.

Chemical subsector

The declining share of output of the chemical subsector resulted in a negative structural effect in chemical sub-sector, which became the driving component in reducing CO_2 emissions during 1980-1990. The emission coefficient effect was negative over the period 1980-1990 and between 1997 and 2000 due to fuel switching and abatement technologies implemented in this sub-sector. This sector used less coal, and there has been an increasing trend on the gas consumption.

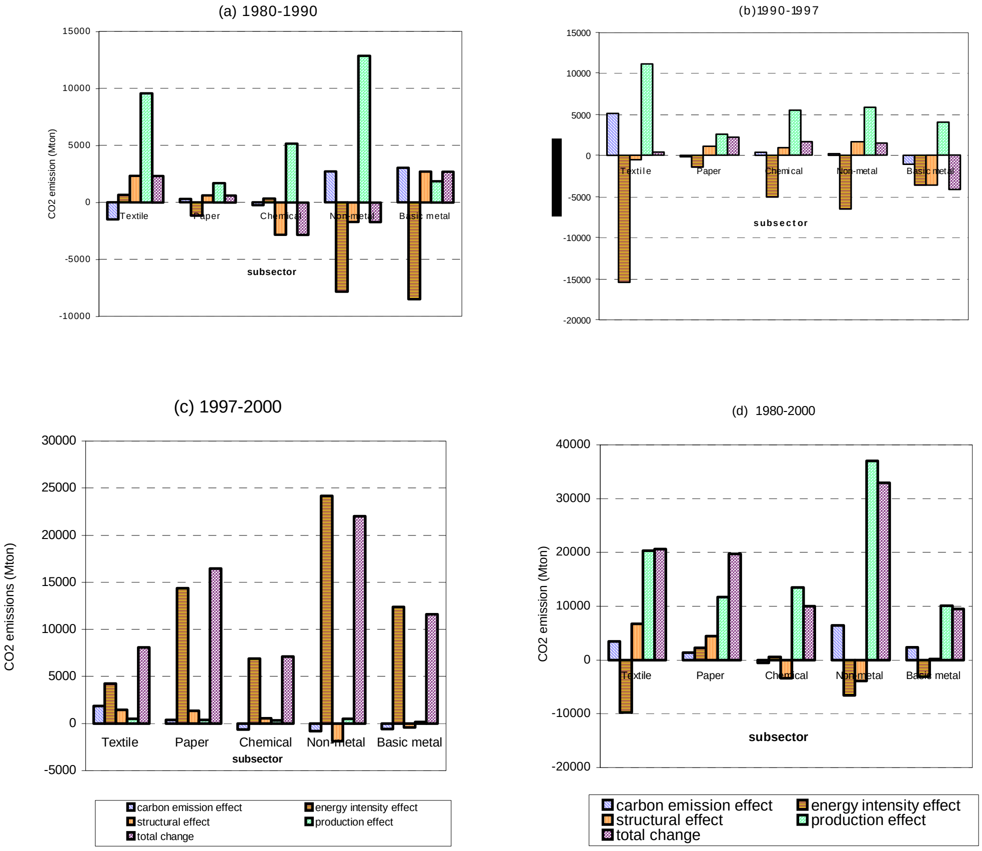
Non-metal subsector

The intensity effect was also the highest contributor to increase the changes in CO_2 emissions in the non-metal sub-sector as it was in the paper subsector over the period 1997-2000. The non-metal and the paper subsector have similar characteristic in terms of fuel use, where coals and oil were dominated. However, the intensity effect over the entire time period of analysis, 1980-2000, was negative. A negative pollution effect in the same period reflected the abatement efforts that were implemented in this subsector.

Basic metal subsector

With the exception of the period 1997-2000, the intensity effect was negative in the basic metal subsector due to efficiency improvements in the iron and steel industry. The negative pollution effect between 1990-1997 and 1997-2000 was due to *fuel substitution* introduced in this subsector. The use of gas was dominated, while coal was not used significantly in the basic-metal subsector.

Figure 10. Decomposition of changes in CO_2 emissions in manufacturing energy intensive subsectors over selected periods (Mton)



5.2.Decomposition of CO_2 emission intensity

With the decomposition of CO_2 emission intensity, the analysis can be focused on structural changes, energy efficiency and the emission coefficient effect since the production effect is eliminated in the analysis.

The main contribution for the increase in CO_2 emission intensity within the main period 1980-2000 was from the increase in emission coefficient effect and structural effect due to a shift to more energy intensive industries.

Decomposition of CO_2 emission intensity shows that energy efficiency improvement was necessary as energy intensity effect sharply increased and shared around 94 percent of the total changes immediately after the economic crisis in 1997 (Table 7). The economic crisis in 1997 led to an increase in the total changes of CO_2 emission intensity. Reducing subsidy on energy prices has not yet shown significant impact in reducing CO2 emission intensity.

Table 7. Contribution of the effects of changes in CO_2 emission intensity

Effects	1980-1990	%	1990-1997	%	1997-2000	%	1980-2000	%
Coef. effect of CO_2 emission	0.73	-128	0.21	-54	0.09	3	1.08	79
Intensity effect	-2.19	384	-1.64	421	2.66	94	-0.99	-73
Structural effect	0.89	-156	1.04	-267	0.07	2	1.27	93
Total changes, ΔA	-0.57	100	-0.39	100	2.82	100	1.36	100

Figure 11. Decomposition of changes in CO2 emission intensity over selected periods

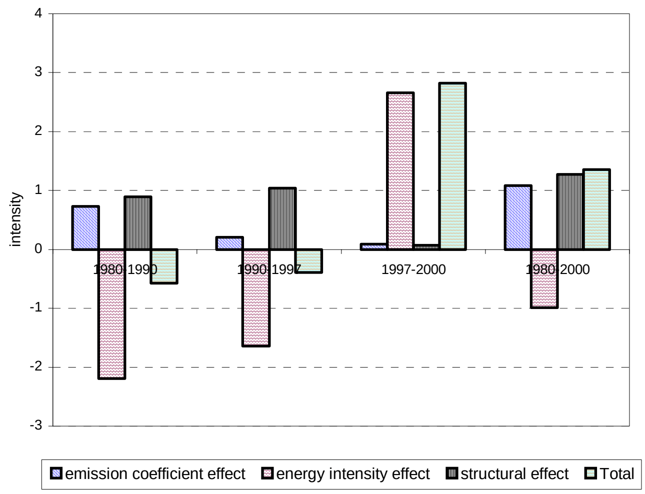
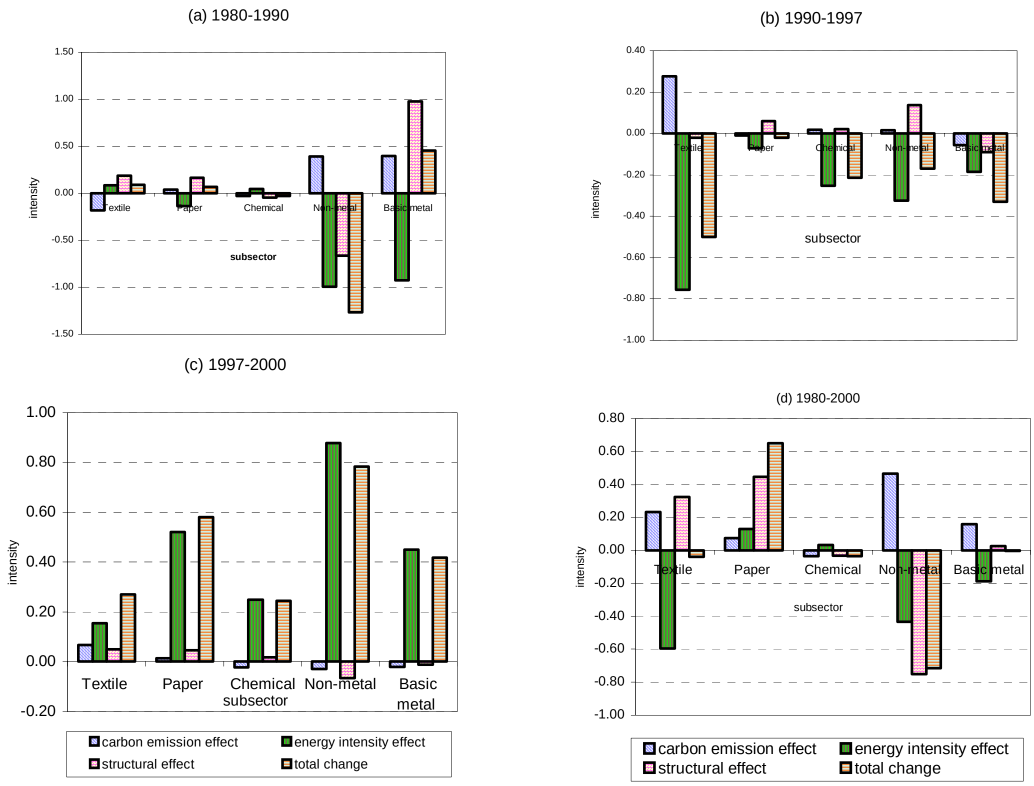


Figure 12 demonstrates decomposition on CO_2 emission intensity in the energy intensive subsectors. Except in chemical subsector, all subsectors showed positive emission coefficient effect throughout period of analysis, suggesting the need for fuel switching and abatement technologies, as it is also recommended in the previous analysis.

The total change of CO_2 emission intensity for 1997-2000 was positive in all subsectors, demonstrating the impacts of the economic crisis on the production activity of these subsectors. Energy efficiency improvement occurred in all energy intensive subsectors over the period of 1990-1997. The sharp increase in the use of oil resulted in the positive emission coefficient effect in the textile subsector after 1990. In chemical subsector, pollution effect was negative over the period of 1980-1990 and 1997-2000 due to fuel structure of this subsector. Fuel switching to the use of gas resulted in the reduction of emission coefficient effect in basic metal subsector.

Fig 12. Decomposition of changes in CO_2 emission intensity in manufacturing energy intensive subsectors over selected periods.



6. CONCLUSION

1. Decomposition analysis on the level of CO_2 emissions shows that economic growth was the main contributor to the increase the changes on the CO_2 emissions.
2. The emission coefficient effect was mostly positive between 1980-1990 and over the entire period of analysis, as also suggested in the decomposition of CO_2 emission intensity. This led to increase the level of CO_2 emissions, which indicate the potential for fuel switching and abatement technologies in the manufacturing sector.
3. The total change of CO_2 emission intensity over the period of 1997-2000 was positive in all subsectors, demonstrating the impacts of the economic crisis on the production activity of these subsectors. Reduction in the subsidy on energy prices starting in 1998 that should be expected to reduce energy intensity effect has not yet shown significant influence.

4. Decrease in energy intensity effect in all energy intensive sub-sectors in period of 1990-1997 led to reduction in CO_2 emissions. This was due to some efficiency improvement as well as a shift in the structure of industries, especially in the textile and basic metal subsector.
5. The declining share of output that resulted in negative structural effect was the driving factor in reducing the CO_2 emissions in chemical subsector.
6. A decrease in CO_2 emission coefficient effect depends on the fuel mix option used in a particular subsector and technology currently employed in the industrial processes. Therefore, the increasing trend of the coal consumption, especially in the paper and non-metal subsectors after mid-1990 was likely responsible for the increase of the CO2 emission coefficient effect in these subsectors. In the same period, the intensity effect was also the highest contributor to total changes in CO_2 emissions in both subsectors.
7. In basic metal and chemical subsector the decomposition indicated that the fuel substitution to less-emitted fuel has reduced the emission coefficient effect which led to decrease in the level of CO_2 emission and CO_2 emission intensity.

Further analysis is required to investigate which industries of a particular manufacturing subsector that contributed to the changes in CO_2 emissions and CO_2 emissions intensity. Decomposition at the industrial level (ISIC at three-digit level) is necessary to identify changes in the structure of industry and in the fuel mix option of the industries within a particular subsector. The estimation of the effect of changes in the decomposition is more accurate at a higher level of disaggregation. Policy scenarios regarding energy efficiency and technological improvements, fuel structure, as well as penetration of other type of fuels to the decomposition model would also be useful.

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