# Structural Analysis of Socio-Technical Impacts on Energy Use and Related Greenhouse Gas Emissions in Korea Based on Energy Input-Output Tables

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# ABSTRACT

Korea ranks in the top 10 countries for its Greenhouse Gas (GHG) emissions from energy use. What is more important is that the increased rate of Korean GHG emissions has reached the highest in the world since 1990, when global GHG emission mitigation efforts began. More than 80% of the GHG emissions in Korea are produced by the energy sector. Thus, among Korea's policies for global climate change, that for the energy sector is very important. Although Korea does not have binding GHG emission targets under the Kyoto Protocol, it nevertheless declared a voluntary mitigation target in November 2009. However, for countries such as Korea in the non-Annex I group under the Kyoto Protocol, it is more important to have the capability to analyze the emission characteristics in each industrial sector than to engage in declarations pertaining to reductions in total emissions, because this will lead to a better position to prevent loss of economic competitiveness in the post-Kyoto Protocol era. In this respect, this study is beneficial to those countries that are developing the analysis capability.

This study adopted a hybrid input-output (IO) analysis approach in order to quantitatively examine the relationship between economic activity, energy usage, and GHG emissions, along with a model using data from 1985 to 2005 in Korea. Although the IO analysis has inherent limitations and potential for misuse, it has an important function in comprehensive economic studies. The IO analysis provides a useful framework for tracing energy use and other activities such as environmental pollution that are associated with inter-industry activities. For the purpose of the analysis, the original IO analysis table composed of monetary unit is extended into a hybrid IO table that contains both monetary and physical units. Moreover, in this study, an index decomposition analysis (IDA) is applied to analyze the changes in GHG emissions according to time series energy use.

The analysis model has hybrid unit energy IO (E-IO) tables with 90×90 sectors including eight energy sectors, based on the 403 categories of IO tables announced by the Bank of Korea. The sectors were classified into energy, energy intensive, and energy less-intensive groups. Then, the factor decomposition of $CO_2$ emissions change was performed using the IDA method. The established E-IO model analyzed the characteristics of each energy source used in each sector of the Korean economy, as well as the emissions characteristics of three GHGs ($CO_2$, $CH_4$, and $N_2O$). The compatibility of the estimated emissions was verified in a follow-up comparison with the estimated emissions stated in the national communication report prepared for the United Nations Framework Convention on Climate Change (UNFCCC). Furthermore, using the IDA method, the changes in the GHG emissions were categorized into three effects: the energy consumption effect ($\mathrm{D_{tot}}$), social factor effect ($\mathrm{D_{soc}}$), and technology change effect ($\mathrm{D_{tech}}$).

During the E-IO model development process, the requirements of the energy conservation condition and Hawkins-Simon condition were verified as necessary conditions. Additionally, arbitrariness of the IDA results depending on the units (monetary or physical) was avoided because a location where unit problems could occur was not present in the proposed IDA. Even though the concept behind this study is widespread and is composed of the well-organized form by Miller and Blair (1985, 2009), this study bears significance for its real scale E-IO analysis focusing on Korea’s economic sector, energy use, and realistic assessment of GHG emissions.

Structural analyses for each year have elucidated the structure of energy use and GHG emissions in each industrial sector in Korea. Sectors 27 (chemical fibers) and 35 (primary iron and steel products) were characterized with relatively low levels of both energy use and GHG emission intensity; however, in these sectors, the induced effect of energy intensity and GHG emission intensity was higher than the direct effect. In the energy group, sectors 9 (hydropower generation)

and 11 (atomic power generation) were inferior to the other sectors in terms of embodied energy intensity, but were superior in terms of GHG emission intensity. Furthermore, sector 12 (town gas) was inferior in terms of GHG emission intensity despite being characterized with a high embodied energy intensity.

The time series analysis of the E-IO tables from 1985 to 2005 demonstrated that the non-energy sectors exhibited a gradual improvement during this period. However, the energy group underwent numerous improvements, but its GHG emission intensity increased during the same period. This suggests that the GHG emissions that were contributed by the energy sectors significantly increased Korea's GHG emissions.

In the IDA, an increase in $\mathrm{D_{tot}}$ was the largest effect in the increase of the GHG emissions, whereas $\mathrm{D_{tech}}$ had a growing negative effect during 1995 and 2000. However, as time passed, the magnitudes of the three decomposition effects became smaller. This demonstrates that the changes in the GHG emissions relevant to energy use in the intermediate sectors of Korea have gradually stabilized; moreover, it has been demonstrated that this phenomenon was more prominent in the energy sectors. In addition, the relative importance of $\mathrm{D_{tot}}$ exhibiting a considerable impact from 1985 to 1995 tended to decrease gradually, whereas the relative levels of importance of $\mathrm{D_{soc}}$ and $\mathrm{D_{tech}}$ increased during 2000 and 2005.

In addition, the acceptability was verified based on the validity of the analysis results from the whole procedure of energy input-output analysis and decomposition analysis of two sectors: organic basic chemical products and cement and concrete products. Empirical tests were performed using changes in energy consumption, production, process improvements, and new facilities. Although the results exhibited unstable fluctuations in the Divisia index decomposition analysis, it was verified that the entire procedure could provide a useful decision-making basis in understanding each industry's energy consumption and GHG emissions.

This study provides useful information for energy use and GHG emissions by enlarging the current understanding of interactions among energy, emissions, and economic structure. This can assist Korean policy makers and other developing countries through the publication of the IO table, in order for these groups to prepare for GHG reductions.

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# Chapter 1. Introduction

## 1.1. Background and necessity of the study

### 1.1.1. Korean energy and environment situation

Even though the Asian financial crisis of 1997-1998 hit Korea particularly hard, Korea's primary energy consumption more than doubled during the past 15 years, from 93.2 million tons of oil equivalent (M-TOE) in 1990 to 228.6 M-TOE in 2005. This amounts to a 6.2% average annual growth rate (AAGR) in energy consumption, which is comparable to 5.6% AAGR in gross domestic product (GDP) during the same period. With regard to the fuel source, the consumption of high carbon containing coal and oil decreased from 26.2% and 53.8%, respectively, in 1990 to 24.0% and 44.4%, respectively, in 2005 of the total primary energy consumption. In contrast, low carbon containing natural gas and renewable energies, except hydropower, increased from 3.2% and 0.9%, respectively, in 1990 to 13.3% and 1.7%, respectively, in 2005.

Korea's rapid industrialization process over the decade from 1990 to 2000 resulted in an increase in energy consumption in the industrial sector by more than 250% from 36.2 M-TOE in 1990 to 94.2 M-TOE in 2005. Although the increasing number of automobiles has dramatically increased the national energy consumption in the transportation sector, the energy consumption in the industrial sector still outranks the other sectors of national energy consumption. In 2005, the industrial sector accounts for 55.2% of Korea's final energy consumption, followed by the residential and commercial (21.6%), transportation (20.8%), and other (2.4%) sectors.

With regard to the energy type in the final energy consumption, petroleum products constituted the largest share for each user group. Coal was the second most prevalent energy source, although its use remained relatively static between 1985 and 2005 because the consumption of more environmentally friendly town gas and low carbon electricity increased, as shown in Tables 1.1 and 1.2.

According to the energy statistics published by Korea Energy Economics Institute (KEEI) [1], Korea’s greenhouse gas (GHG) emissions increased gradually from 247.8 million tons of carbon dioxide (Mt $CO_2$) in 1990 to 498.9 Mt $CO_2$ in 2005, in the energy sector. Furthermore, its share in total emission also increased from 81.1% in 1990 to 83.6% in 2005. Korea’s GHG emissions, including final demand, amounted to an AAGR of 5.1% in the energy sector from 1990 to 2005. During this period, the GHG emissions from the energy transformation industries and transport industries increased by 10.6% and 5.8% per annum, respectively. However, the rate of GHG emissions fell for the energy industries (3.1%), manufacturing and construction industries (0.4%), and transport industries (1.2%) from 2000 until 2005 compared with the consumption over the entire period (Figure 1.1).

**Table 1.1 Trend of total primary energy consumption in Korea (kTOE)**

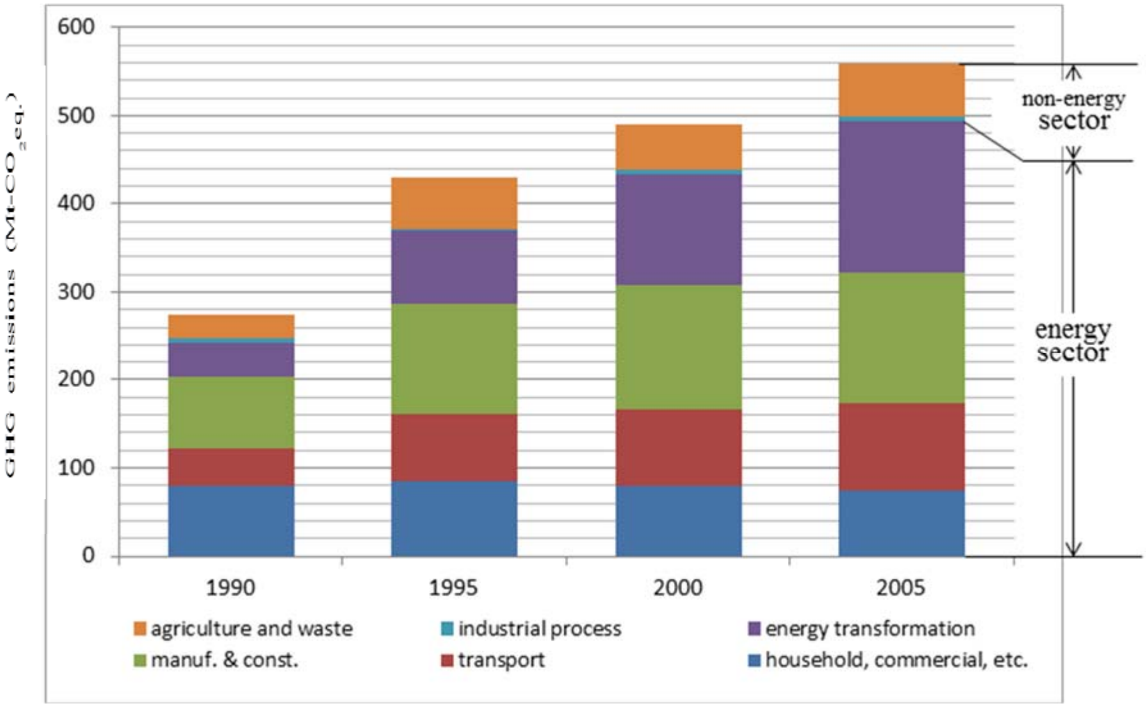
| Energy source | 1985 | 1990 | 1995 | 2000 | 2005 |
|---|---|---|---|---|---|
| Crude petroleum | 27,142 | 50,175 | 93,955 | 100,279 | 101,526 |
| Coal | 22,022 | 24,385 | 28,091 | 42,911 | 54,788 |
| Atomic power generation | 4,186 | 13,222 | 16,757 | 27,241 | 36,695 |
| Water power generation | 915 | 1,590 | 1,369 | 1,402 | 1,297 |
| LNG | - | 3,023 | 9,213 | 18,924 | 30,355 |
| Woods and other | 2,031 | 797 | 1,051 | 2,130 | 3,961 |
| Total | 56,296 | 93,192 | 150,436 | 192,887 | 228,622 |

Source: KEEI, Yearbook of Energy Statistics

**Table 1.2 Trend of total final energy consumption in Korea (kTOE)**

| Sector | Energy source | 1985 | 1990 | 1995 | 2000 | 2005 |
|---|---|---|---|---|---|---|
| Industry | Petroleum products | 10,697 | 20,014 | 36,810 | 48,193 | 50,905 |
| | Coal | 6,490 | 10,806 | 16,244 | 19,129 | 21,238 |
| | Electricity | 2,812 | 5,095 | 8,293 | 11,374 | 14,346 |
| | Town gas | 15 | 235 | 863 | 3,308 | 4,655 |
| | Others | - | - | 736 | 1,908 | 3,222 |
| | Total | 20,014 | 36,150 | 62,946 | 83,912 | 94,366 |
| Residential & Commercial | Petroleum products | 3,525 | 8,876 | 17,632 | 13,492 | 9,437 |
| | Coal | 11,399 | 9,027 | 1,514 | 718 | 1,074 |
| | Electricity | 1,155 | 2,421 | 4,801 | 7,891 | 12,233 |
| | Town gas | 69 | 777 | 4,607 | 9,024 | 12,503 |
| | Others | 2,031 | 872 | 897 | 1,245 | 1,614 |
| | Total | 18,179 | 21,973 | 29,451 | 32,370 | 36,861 |
| Transportation | Petroleum products | 6,645 | 14,086 | 27,010 | 30,770 | 34,983 |
| | Coal | - | - | - | - | - |
| | Electricity | 62 | 87 | 138 | 175 | 224 |
| | Town gas | - | - | - | - | 339 |
| | Others | - | - | - | - | - |
| | Total | 6,707 | 14,173 | 27,148 | 30,945 | 35,546 |
| Public & Others | Petroleum products | 1,712 | 2,276 | 1,424 | 1,140 | 1,393 |
| | Coal | 50 | 21 | - | - | - |
| | Electricity | 333 | 514 | 808 | 1,160 | 1,785 |
| | Town gas | - | - | 125 | 229 | 313 |
| | Others | - | 1 | 59 | 96 | 577 |
| | Total | 2,095 | 2,812 | 2,416 | 2,625 | 4,068 |

Source: KEEI, Yearbook of Energy Statistics




Remarks: GHG emission data in 1985 is not available for Korea.
Source: Korea Energy Economics Institute

**Figure 1.1 GHG emissions in Korea (Mt $CO_2$-eq.).**

### 1.1.2. Necessity of the study

According to World Resources Institute (WRI)[2], not surprisingly, Korea ranks 26th in per capita GHG emissions, 12th in total GHG emissions, and first in the world for the GHG emission increase rate during the period from 1990 to 2002 (Table 1.3). Korea's highest increase rate of per capita $CO_2$ emission was higher than that of Indonesia (97%), Iran (93%), and Saudi Arabia (91%). Furthermore, in terms of the increase rate of non-$CO_2$ GHG emissions over the same period, Korea ranked second with a 49% increase rate. As of 2000, only Saudi Arabia, which is the largest petroleum exporting country, emitted more non-$CO_2$ GHGs than Korea.

**Table 1.3 Energy and environment status of Korea in the world (as of 2003)**

| | Standings in the World |
|---|---|
| Energy | • $10^{th}$ in energy consumption<br>• $7^{th}$ in oil consumption<br>• $4^{th}$ in oil import<br>• $2^{nd}$ in coal and LNG import |
| Environment (Climate change) | • $26^{th}$ in capita GHG emission<br>• $12^{th}$ in total GHG emission<br>• $1^{st}$ in per capita GHG emission increase rate (1990-2002)<br>• $2^{nd}$ in non-$CO_2$GHGs emission increase rate (1990-2000) |

According to the IEA [3, 4], the Korean $CO_2$ emissions from energy consumption have decreased to 448.9 Mt $CO_2$ in 2005 from 462.1 Mt $CO_2$ in 2004. However, Korea still ranks in the top 10 countries for its GHG emissions from energy use. What is more important is that the increased rate of Korean GHG emissions has reached the highest in the world since 1990, when global GHG mitigation efforts commenced. During that time, especially from 1990 until 2004, Korean emissions of GHGs increased from 226 Mt $CO_2$ to 462.1 Mt $CO_2$. The increase rate was 104%, which is significantly higher than the average increase rate worldwide (54%) and that of the OECD countries (17%). Korean GHG emission per capita is the highest amongst the OECD countries.

During the same period, the Korean economy developed significantly with an annual growth rate of 7-8%, and its GDP has grown 2.8 times. When comparing Korea's GHG emission levels with other countries, it must be understood that the Korean rate is out of the average range. Among the OECD countries, the Czech Republic, Germany, Hungry, Poland, and the United Kingdom have succeeded in lowering their GHG emission levels; Denmark, Iceland, Luxemburg, and Sweden have maintained their GHG emission levels. Therefore, Korea must develop its own energy policy with consideration of its economy, as well as with an understanding of its energy and GHG emissions.

As previously discussed, more than 80% of the GHG emissions in Korea have stemmed from the energy sector since 1990 when Korea began reporting its GHG emission statistics. Thus, among Korea's policies for global climate change and its effects, those for the energy sector are critical. The AAGR of the GHG emissions caused through energy consumption has decreased to 3.3% for the period from 2000 to 2005 from that of 5.1% for the 1990 to 2005 period. This demonstrates that the Korean GHG emission situation has begun to improve.

Although the AAGR of GHGs has decreased, the total amount of GHG emissions in Korea has increased. The energy-related GHG emissions are classified as follows: socio-economic factors, energy intensity, and fuel mix (Kaya identity, WRI [2]).

$$CO_2 = Population \times \frac{GDP}{Populatiom} \times \frac{Energy}{GDP} \times \frac{CO_2}{Energy} \tag{1.1}$$

In Eq. (1.1), the first factor, i.e. population, is not a meaningful factor for the decrease of GHGs that result from energy consumption because Korea's population growth is almost the lowest in the world. The next factor, i.e. GDP, is a positive factor for economic development and is a significant demo-economic index. The remaining two factors, i.e. the energy intensity factor and the GHG emission factor, are two important targets that can allow Korea to decrease its GHG emission level. Between these two factors, the third factor, i.e. the energy intensity factor, can be regulated either by shifting to less energy-intensive industries or by promoting more effective energy conservation. Finally, the last factor can be controlled using an appropriate energy mix, e.g. substituting coal and petroleum with low carbon emitting energies such as liquid natural gas (LNG) and renewable energy. However, these types of policy measures in the energy sector require significant social expenditure. Therefore, for cost efficient policy-making, it is necessary to understand the interactions between the economic activities, energy use, and GHG emissions.

The statistics from the IEA [3] regarding the energy consumption of OECD countries demonstrates that Korean energy intensity until the 1980s was well maintained. However, since 1990, it has deteriorated to become three times worse than that of Japan, which has the strongest performance in the OECD countries in 2005 (Table 1.4). However, Korea's GRG emission intensity has been slightly below the OECD country average since 1990 (Table 1.5).

**Table 1.4 Energy intensity of OECD countries (M-TOE/B-2000 US$)**

| | France | Germany | Italy | Japan | Korea | UK | USA | OECD Average |
|---|---|---|---|---|---|---|---|---|
| 1975 | 0.227 | 0.302 | 0.196 | 0.135 | 0.267 | 0.247 | 0.385 | 0.291 |
| 1980 | 0.223 | 0.291 | 0.177 | 0.123 | 0.322 | 0.226 | 0.351 | 0.274 |
| 1985 | 0.219 | 0.272 | 0.161 | 0.111 | 0.287 | 0.206 | 0.294 | 0.244 |
| 1990 | 0.205 | 0.228 | 0.156 | 0.107 | 0.315 | 0.179 | 0.271 | 0.224 |
| 1995 | 0.205 | 0.196 | 0.159 | 0.112 | 0.336 | 0.173 | 0.258 | 0.218 |
| 2000 | 0.190 | 0.178 | 0.156 | 0.111 | 0.348 | 0.151 | 0.230 | 0.201 |
| 2005 | 0.187 | 0.173 | 0.16 | 0.105 | 0.316 | 0.133 | 0.208 | 0.190 |

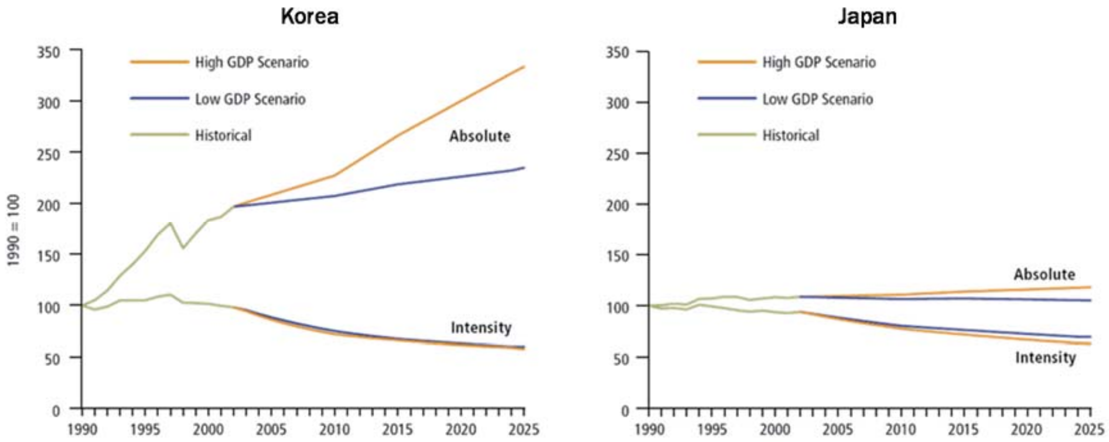
Source: OECD/IEA, Key world energy statistics, 2006.

**Table 1.5 $CO_2$ emission intensity in OECD countries (t $CO_2$/TJ)**

| | France | Germany | Italy | Japan | Korea | UK | USA | OECD Average |
|---|---|---|---|---|---|---|---|---|
| 1975 | 62.3 | 74.3 | 65.4 | 67.0 | 75.0 | 69.4 | 63.0 | 64.7 |
| 1980 | 57.5 | 70.6 | 65.7 | 61.1 | 72.1 | 68.7 | 61.7 | 62.9 |
| 1985 | 42.2 | 67.8 | 64.2 | 57.8 | 68.4 | 64.8 | 61.2 | 60.5 |
| 1990 | 37.6 | 64.6 | 64.8 | 57.9 | 58.8 | 63.7 | 60.7 | 58.9 |
| 1995 | 35.7 | 61.6 | 61.4 | 55.2 | 59.2 | 57.1 | 59.4 | 57.2 |
| 2000 | 35.7 | 58.6 | 59.3 | 54.5 | 54.2 | 56.1 | 59.9 | 56.9 |
| 2005 | 34.3 | 57.2 | 59.4 | 56.0 | 53.2 | 57.2 | 59.4 | 56.4 |

Source: OECD/IEA, Key world energy statistics, 2006.

WRI [2] presented a meaningful graph (Figure 1.2) implying that the GHG emission intensities in 2025 will be less than those in 2002 in both Korea, which is a rapidly developing country, and Japan, which has a mature economy, regardless of the two economic growth scenarios. The amount of GHG emissions expected from Japan in 2025 is almost the same as that produced in 1990 despite the presumed economic growth. However, Korea is expected to increase its GHG emissions by over 250%. This presumption implies that matured countries, such as Japan, are able to establish efficient energy-environment policies based on solid understandings of the mechanisms of economic activities, energy use, and GHG emissions. However, less mature countries, such as Korea, cannot yet reach this point without a steep increase in their GHG emissions. If the global regime on climate change is enforced in Korea, then concrete understandings of the interactions among these factors must be prepared.




Source: Kevin, A.B., Baumert, H., and Jonathan, P., Navigating the numbers: Greenhouse gas data and international climate policy, World Resources Institute (WRI), 2005.

**Figure 1.2 Projection comparison of absolute emission and emission intensity of $CO_2$ between Korea and Japan.**

Without appropriate understandings and knowledge regarding the interactions between the economy, energy, and environment, any energy policy designed to manage climate change may have less efficient implementation. The various policy actions that have been undertaken to date have been insufficient to substantially reduce the GHG emissions in Korea's energy use. In order to prevent an international paradigm in the post-Kyoto era, Korea must begin specific actions. Currently, Korea plans to eliminate the policies that were based on common practice as well as social distortions and search for effective and efficient policies.

In general, energy policies are formed based on three levels of statistics. The first level is the national level aggregation data such as national GDP and GHG emissions. The second level is partially grouped data such as primary, secondary, and tertiary industries. The third level is the individual industry data, which is as detailed as possible and includes the fishery processing, steel manufacturing industry, education industry, and so on.

Energy is commonly cited as a production factor instead of labor. Thus, reducing energy consumption causes the national GDP to decline. Therefore, the national energy policy should be constructed in order that is has a smaller influence on the GDP while simultaneously achieving the policy goals. It is known that a combination of the third statistics and IO analysis is a useful tool for economic analysis and it will be a powerful method of building national policy.

As a first step in establishing an efficient policy in energy conservation and mitigation of GHG emissions, it is important to understand the interrelations between the economic activities, energy use, and GHG emissions. Then, a fundamental model describing the national energy and GHG emission situation should be prepared with harmonization of the census and estimation. The energy input-output (E-IO) analysis will have an important function in the estimations that will be used in constructing the energy and climate change policies, because the input-output model is a well-known quantitative economic technique that represents the interdependencies between different sectors of a national economy or different regional economies.

## 1.2 Literature review

There are numerous cases around the world that use an energy and/or environmental analysis with an IO approach. Table 1.6 presents some examples, which are described in more detail here. Energy analyses and environment analyses have been performed simultaneously for various countries: Gay and Proops [5] performed important research on the energy analysis and the environmental analysis for $CO_2$ emissions that result from the economic activities of thirty-eight sectors using England's IO table from 1984. Lenzen [6] reported on the intensities of primary energy and GHGs ($CO_2$, $CH_4$, $N_2O$, $CF_4$, and $C_2F_6$) in terms of MJ/$ and kg $CO_2$ equivalent/$, respectively, using Australia's IO table from 1992/93. Cruz [7] used Portugal's IO table to analyze the interactions between energy, environment, and economy.

Japan has also conducted studies using energy and environment analyses using IO tables. The following three reports are the prominent researches that introduced the key cases. The first was written by Keio University's Keio Economic Observatory [8]; the second was written by the Center for Global Environmental Research (CGER) in the National Institute for Environmental Studies (NIES) [9]; and the third case was prepared by the Socio-economic Research Center in the Central Research Institute of Electric Power Industry (CRIEPI) [10]. Based on these reports, Kim [11], Nansai [12], and Hondo [13] issued their academic papers.

**Table 1.6 Energy and environment studies using IO analyses**

| Units in IO table / Time span | Single unit | Hybrid units |
|---|---|---|
| One year | Gay and Proops (1993), Lenzen (1998), Park (1999), Cruz (2002), Kim (2006), Hondo (2002), Nansai (2003), Kim (2004) | Choi and Lee (2004) Chung, Tohno, and Shim (2009) |
| Time series | Tsukamoto (2008), Wiedmann (2010) | Kim (1998) Chung and Tohno (2009) |

Park [14] and Kim [15] estimated the amount of $CO_2$ emissions caused by final energy consumption. Kim [16] composed E-IO tables for coal, petroleum, gas, and electric power using IO tables from 1985, 1990, and 1995. Using these tables, Kim analyzed the amount of energy input and the amount of $CO_2$ emissions from 18 non-energy sectors. Choi and Lee [17] analyzed the energy consumption of 28 non-energy sectors that used five primary energy sources and 11 final energy sources in order to determine the amount of $CO_2$ emission accumulated in Korea's export goods. In order to achieve this, a combined IO table of $CO_2$ emissions was composed. Chung, Tohno and Shim [18] constructed a 96×96 hybrid E-IO table using energy units for each energy sector using the Korean IO table from 2000. This study was extended further back to 1985 by Chung and Tohno [19]. While Tsukamoto [20] and Wiedmann [21] studied time series with single unit IO tables to assess the $CO_2$ emission from three types of power plant through LCA and to distinguish GHG emissions embodied in UK trade, respectively.

For time series IO data, decomposition analyses have been widely used to identify the influencing factors in terms of energy and $CO_2$ emissions. Structural decomposition analyses (SDA) and index decomposition analysis (IDA) are typically used as preferred methods of decomposition analysis. In IDA, the arithmetic mean Divisia index (AMDI) and the log mean Divisia index (LMDI) methods are appropriate to use for the weight function. However, Ang [22] noted that the AMDI methods have two shortcomings: first, they fail the factor-reversal test; second, they fail when the data set contains zero values, e.g. when an energy source begins or ceases to be used in a sector during the study period. The LMDI can be shown to converge when the zero values in the data set are replaced by small positive numbers, but the AMDI does not have this convergence property. Thus, the LMDI method is the preferred IDA method from both theoretical and practical viewpoints. The results given through the multiplicative decomposition and additive decomposition are related by a simple formula and are interchangeable.

The most common application areas for LMDI analyses are energy demand and supply analyses, as well as analyses of energy-related GHG emissions. Most recent studies have concentrated on the decomposition of national $CO_2$ emissions and emission intensities of the industrial and power sectors (Table 1.7). A more detailed review is presented in Chapter 5.

Besides numerous examples of decomposition studies with aggregated coefficients for national $CO_2$ emissions (or emission intensities), Lin et al. [23] of Taiwan and Sands and Schumacher [24] of Germany are notable examples that have used input-output tables. Rhee and Chung [25] confined their input-output analysis to Korean and Japanese $CO_2$ emissions and attempted to analyze the interrelationship of $CO_2$ emissions via international trade. The sources of change in GHG emissions were categorized into three major composite factors: fuel efficiency, production techniques, and final demand. For this decomposition analysis, they also used the mean rate-of-change index (MRCI) rather than the mean Divisia index (MDI). Chung, Tohno and Choi [26] decomposed the changes that affect GHG emissions into three factors (the energy consumption effect, the social effect, and the technological effect) using the Sato-Vartia index for the three periods of 1985-1995, 1995-2000, and 2000-2005 in Korea.

**Table 1.7 Recent weighted decomposition cases of input-output coefficients**

| Researcher | Publication year | Country/ Region | Calculation | Time span | Application |
|---|---|---|---|---|---|
| Lin et al. | 2006 | Taiwan | Additive LMDI | 1991-2001 | $CO_2$ emissions |
| Rhee and Chung | 2005 | Korea and Japan | MRCI | 1990-1995 | $CO_2$ emissions |
| Sands and Schumacher | 2009 | Germany | Additive LMDI | 1995-2006 | GHG emissions |
| Chung, Tohno, and Choi | 2011 | Korea | Multiplicative LMDI | 1985-2005 | Energy intensity and GHG emissions |

## 1.3. Statement of purpose

The overall objective of this study is to establish a model that determines the relationship between economic activity, energy use, and GHG emission in Korea. Estimates are presented for energy use over time and changes in GHG emission patterns, followed by an analysis of the influencing factors. Furthermore, the socio-technical impacts on industry are also analyzed. This study will provide an intellectual framework for future studies in predicting changes in energy use and GHG emissions according to economic activity.

For this purpose, the E-IO approach was adopted because it can offer insights to the relationships between the economy, energy, and GHG. The E-IO tables in this study were constructed using the hybrid approach. The first objective of this study is to examine the convertibility of monetary IO and physical IO, and to develop hybrid units in E-IO tables for the reference year. This process is described as follows. An E-IO table was derived from an inter-industry transaction table from 2000. Based on this hybrid IO table, the interactions between the economic sector, energy sources, and GHG emissions were analyzed. Note that the IO table used in this study was issued by the Bank of Korea (BOK) in 2003. When this study commenced, the 2005 inter-industry survey table had not been released. This table serves as the foundation for the analysis of the GHG emissions according to the industry.

The second objective is to measure the changes in GHG emissions according to industry over time. In accordance with the aforementioned process, E-IO tables were created for the years from 1985 to 2005. In order to consider the changes in industry classification standards and the value of money over time, identical conditions were applied with conversions from the current values, which vary over time, into time-independent constant units. During this stage of research, the inter-industry transaction table of 2005 was announced.

Furthermore, the energy and climate change policies affect many aspects and alter the structure of economies. Therefore, this requires a comprehensive approach when examining the policies. The index decomposition analysis (IDA) provides a tool for the approach that uses IO tables. In order to identify the influencing effects, an IDA was performed for the GHG emissions derived from the time series E-IO tables.

The third objective is to verify the usefulness of the proposed model by conducting empirical analyses of the social and technical effects for two significant industries using the IDA.

## 1.4. Study structure

This study is organized as follows (Figure 1.3). Chapter 2 reviews the typical analytical processes of both the conventional input-output approach and the input-output approach with hybrid units. The convertibility of the two approaches is demonstrated using an energy model that includes a monetary unit and a physical unit (calorific value) for the input-output table. Chapter 3 constructs a 96×96 hybrid energy input-output (E-IO) table using energy unit for each energy sector from the Korean IO table for 2000 developed by the BOK in 2003. This process is represented by the yellow boxes in Figure 1.3. Using this E-IO table, the energy and

GHG emission intensities (both direct and embodied) that are caused by energy use are estimated for each sector. Using the verification and validation tests in Chapters 2 and 3, four sequential 96×96 hybrid unit E-IO tables for 1985, 1990, 1995, and 2000 are generated in Chapter 4. Chapter 5 analyzes the changes in the GHG emissions in Korea from 1985 to 2005 as represented by the loop of red boxes in Figure 1.3. Based on the E-IO results, the changes are decomposed into three factors, i.e. the energy consumption effect, the social effect, and the technological effect, using the Sato-Vartia index for the three periods of 1985-1995, 1995-2000, and 2000-2005 as indicated by the process of green boxes in Figure 1.3. Chapter 6 presents an empirical study of the structural analysis of social and technical effects for two sectors. Chapter 7 concludes the paper by providing policy implications for the transition to a low carbon economy in Korea.

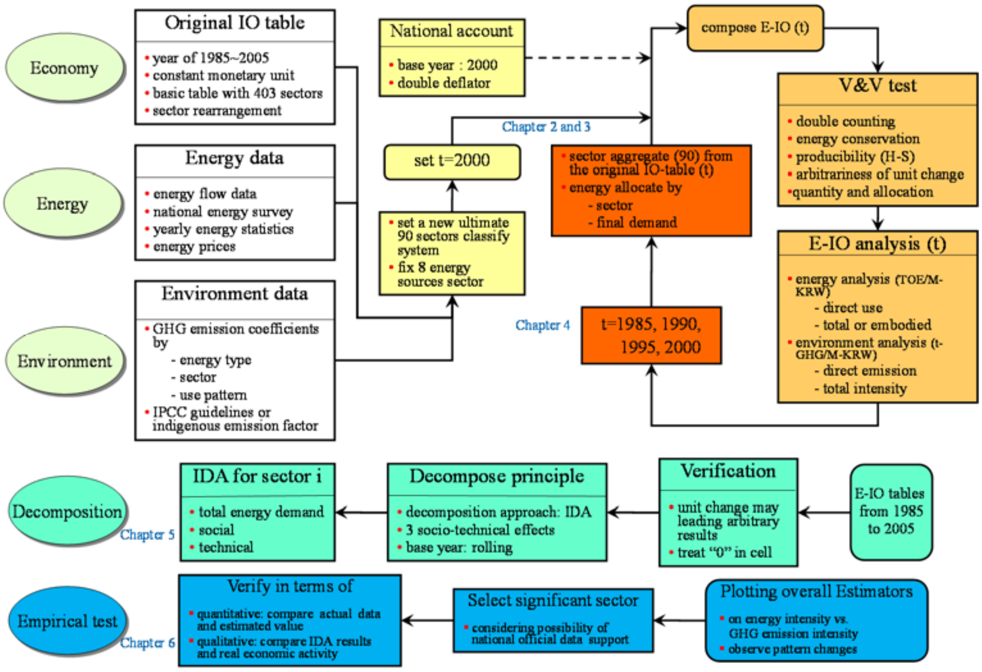



**Figure 1.3 Simplified procedure of E-IO analysis and IDA.**

## 1.5. Study originality

Hybrid unit IO analyses provide useful frameworks for tracing energy consumption and other related characteristics such as GHG emissions or flows of physical materials associated with inter-industry activities. National policies on energy and the environment frequently require databases that use physical units rather than monetary units. Thus, the E-IO approach is much more suitable for analyzing the energy and GHG emissions compared with conventional input-output models because it can manage data that is measured in physical units, such as specifying the technical coefficients in tons of oil equivalent (TOE) as inputs, required per monetary worth of an industry's output, and per TOE output in energy industry. The E-IO table, as well as the conventional IO table, is beneficial for evaluating energy consumption because it is well suited to consider recursive impacts; but it can be applied straightforwardly to an assessment in physical form. The conventional IO analysis suffers from a shortcoming of calculation in monetary form.

This study adopts the hybrid IO approach for the analysis of energy use from 1985 to 2005 in Korea. The IDA is used to analyze the changes in GHG emissions according to time series energy use. This study provides useful information for energy and climate change policies in Korea through the elucidation of the quantitative relationship between the economic activity, energy use, and GHG emissions. This study can be easily applied not only to the Korean policy-making group, but also to other developing countries in order to prepare a new global paradigm on energy and the environment if the relevant IO tables and statistics are available.

The concept behind this study is already known through the work of Bullard and Herendeen [27] and Miller and Blair [28]. Although it is based on the existing methodology, this study is significant for its overwhelming trial in the composition of reliable real scale hybrid unit E-IO tables from 1985 to 2005 and in its attempt to analyze the entire horizon of E-IO tables. The originality of this study is explained in detail as follows.

- In Korea, the BOK manages the economic data while KEEI manages the energy and GHG emission data. These two institutions use different periods and different methods to classify the economic sectors in publishing census data. Therefore, previous studies that have used both BOK and KEEI data have only focused on a few classified sectors. Because this study estimates the hybrid unit E-IO tables from 1985 to 2005 using the BOK data only, the composition of higher resolution tables was possible with the ability to publish additional E-IO tables.

  - First, in building the serial hybrid unit E-IO tables, this study produces hybrid unit E-IO tables with real prices (in KRW at year 2000 prices), which include the energy data, for all research years from 1985 to 2005. It is not easy to convert the normal price data into real price data for non-consecutive input-output tables, and the BOK does not provide real price tables for all research years. Further complicating this task, the total energy demand in the input-output table does not match the total primary energy or final energy consumption in the energy balance table provided by KEEI [1] because the accounting rules of these two data sources differ. In order to connect the input-output table and the energy balance table, this research identifies the total demand and total supply for each energy source in the energy balance, which aligns with the accounting concept of the input-output table. This process ensures usefulness of the hybrid unit E-IO table.
  - Second, in addition to the typical sector category, this research suggests sector grouping according to their characteristics in the energy input structure. This work identifies and presents three groups in the hybrid unit E-IO tables. Information regarding the energy-intensive group can benefit energy policies to improve their effectiveness. This sector grouping has never been attempted previously; thus, it provides further originality to this research. The sector characteristics in the energy input structure are assessed using the distance function of energy intensity, which simultaneously considers the individual sector's final energy input per total input and final energy input per total energy input in terms of monetary units. This data building process is original and has been not been used in the existing literature.

- This study performed the entire process of E-IO analysis based on the hybrid unit E-IO tables from 1985 to 2005. Empirical analyses that demonstrate the usefulness of the E-IO analysis are also included with the routine analyses in this process.
- For the characteristics of the GHG emissions according to sector, not only the intensity of $CO_2$, but also those of $CH_4$ and $N_2O$, which are also known as direct impact compounds, are analyzed. This research analyzes the GHG emissions from the E-IO tables that offer equally spaced time series data for GHG emissions for all periods. This analysis has originality in producing detailed GHG emission data that are matched with the E-IO table format and that consider the differences in GHG emissions characteristics for each sector and energy.
- Typical decomposition analyses do not analyze more than pair-wise comparisons of GHG emissions for two consecutive periods, but this research adopts a rolling base year method and compares multiple time series data. This research enables the determination of inclining or declining trends of dominant effects. The interpretation of the trend is undertaken through the selection of specified sectors and empirical analyses are conducted in order to demonstrate the social and technological impacts on GHG emissions.

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# Chapter 2. Convertibility of Monetary and Physical Input-Output Analysis and an Application to Energy Sources

Convertibility of Monetary and Physical Input-output Analysis- an Application to Energy Sources -, *Korean J. of LCA*, 2008;9(1): pp47-55

In the midst of the increasing importance of the LCA concept, an input-output approach is emerging as a useful methodology to assure the robustness of a solution. An input-output analysis is based on an input-output table using monetary units. Nowadays, the importance of a material flow analysis is increasing. Thus, attempts to construct an input-output table with hybrid units reflecting the physical units have been made. In this study, typical analytical processes of both the conventional input-output approach and the input-output approach with hybrid units are compared. The convertibility of these approaches is demonstrated using an energy model, including a monetary unit and an energy unit, for an input-output approach. Additionally, the linkage effects of various energy sources are analyzed using an E-IO table.

## 2.1 Energy analysis: IO analysis studies

The IO table demonstrates exchanges of goods and services between industrial sectors in matrix form; Wassily Leontief won the Nobel Prize in 1973 for developing this model. This table is mostly presented using monetary units and has been applied broadly to energy analyses beyond economic analyses because of its high usability with a system of linear equations.

There have been many studies internationally on an energy analysis based on a conventional IO analysis. The following are representative examples. Studies of Wright [1] and Bullard and Herendeen [2], which used US IO tables to determine the primary energy requirements of all sectors, have been regarded as the first ones. Peet et al. [3] performed an energy analysis of direct and indirect household energy consumption in New Zealand from 1974 to 1980. Park and Heo [4] used a process analysis for energy intensive products, and applied an IO analysis to other energy consumption products by referring to Lenzen [5].

Contrary to the above analysis, the following studies relied on the hybrid unit IO model. Miller and Blair [6] wrote a well-organized textbook on E-IO analysis. Pachauri and Spreng [7] determined the indirect energy requirement of India's households according to private final consumption expenditures based on India's IO tables of 1983/84, 1989/90, and 1993/94 (Table 2.1).

**Table 2.1 IO analysis studies applied to energy issues**

| Conventional IO | Hybrid IO |
|---|---|
| Wright(1974)<br>Bullard and Herendeen(1975)<br>Peet et al.(1985)<br>Park and Heo(2007) | Miller and Blair(1985)<br>Pachauri and Spreng(2002) |

## 2.2 Typical analysis process

### 2.2.1 Process of conventional IO analysis

An IO table is classified by intermediate demand sectors with the value added derived from goods or services purchased from related sectors and final demand sectors, such as household or government sectors. For instance, the thermal power generation sector provides electricity as its output to almost every industrial sector by receiving input from energy sectors such as coal or fuel oil, and non-energy sectors such as machinery & equipment or plastic products.

Therefore, the original model can be defined with the total sum of an intermediate demand and the final demand, as shown in Eq. (2.1):

$$x_i \equiv \sum_j z_{ij} + y_i \tag{2.1}$$

where $x_i$ is the total production of sector $i$, $z_{i,j}$ is the number of transactions in sector $j$ after producing sector $i$, and $y_i$ is the final demand of sector $i$.

When an input ratio such as Eq. (2.2) is introduced into this definition, an efficient modeling equation can be expressed.

$$a_{ij} = z_{ij}/x_j, \ for\ all\ i \tag{2.2}$$

where $a_{ij}$ is the ratio of input, $i$ to $j$, to the total output of sector $j$.

Here, $a_{ij}$ is a linear relation coefficient that reflects the technological requirements of production by sector $j$ for the inputs from sector $i$; $a_{ij}$ is known as a 'technological coefficient' or 'input coefficient'. For example, if sector $i$ is ‘fuel oil', and sector $j$ is 'thermal & self-power generation’, then $a_{ij}$ is the (average) quantity of fuel oil needed to produce one unit of thermal & self-power generation. Or if we express our relationships in terms of economic value rather than physical quantity, it means the monetary value of the fuel oil consumed to produce one unit of monetary worth of an average thermal & self-power generation.

When Eq. (2.2) is introduced into Eq. (2.1), Eq. (2.1) can be redefined as follows:

$$x_i \equiv \sum_j a_{ij} x_j + y_i \qquad (2.3)$$

The IO approaches seen above were devised by Wasilly Leontief in 1930. This was later explained using the compact notation of linear algebra. To demonstrate economic activities of groups that are desegregated by $n$ sectors, the following matrix must be defined: let **X** be a vector $n\times1$ of goods required for the total output of the economy, **Y** be a vector $n\times1$ of goods required to satisfy the final demand, and **A** be a matrix $n\times n$ of the input coefficients for the economy. Eq. (2.3) can then be expressed as the following linear equation:

$$\mathbf{X}=\mathbf{AX}+\mathbf{Y} \qquad (2.4)$$

Here, **AX** expresses an intermediate demand of economic activity, and **Y** denotes the final demand. If Eq. (2.4) is solved for matrix **X**, it becomes

$$\mathbf{X}=(\mathbf{I}-\mathbf{A})^{-1}\mathbf{Y} \qquad (2.5)$$

where $(\mathbf{I}-\mathbf{A})^{-1}$ is known as a 'Leontief inverse matrix' or simply an ‘inverse matrix'.

The inverse matrix includes all the direct and indirect requirements for production in the economy that are necessary to satisfy a certain vector of the final demand commodities. Here, Eq. (2.5) can be expanded as an infinite geometric series:

$$(\mathbf{I}-\mathbf{A})^{-1} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \dots \qquad (2.6)$$

This series is convergent if **A** satisfies the same conditions stated in chapter 3.2.4. A substitution of Eq. (2.6) into Eq. (2.5) gives

$$\mathbf{X}=\mathbf{Y} + \mathbf{AY} + \mathbf{A}^2\mathbf{Y} + \mathbf{A}^3\mathbf{Y} + \dots \qquad (2.7)$$

We can decompose the total demand for $n$ goods produced in the economy as follows:

1) **Y** is required for the final demand (i.e., by consumers).

2) **AY** is needed to produce goods **Y**. This is the 'first-round indirect effect'.

3) $\mathbf{A}^2\mathbf{Y}$ is needed to produce goods **AY**. This is the 'second-round indirect effect'.

4) $\mathbf{A}^3\mathbf{Y}$ is needed to produce goods $\mathbf{A}^2\mathbf{Y}$. This is the 'third-round indirect effect'.

In the energy and environment analysis, the energy and environment emission intensity (J/$, kg-$CO_2$/$, etc.) must be multiplied on the right side of Eq. (2.5). Clearly, the process traces inputs or outputs back to the primary resources; the first term of energy inputs or environmental loads are the direct energy requirement or load, respectively; and the subsequent infinite terms of energy inputs or environmental loads are the indirect energy requirement or emission, respectively. The total energy requirement or environmental load can be divided into direct and indirect terms. The total energy requirement is called the embodied energy.

### 2.2.2 Process of E-IO analysis

An E-IO analysis is often concerned with the energy measured in physical units, for example, TOE or some other convenient energy units and non-energy flows in money.

The basic process of the E-IO method was introduced in detail by Miller & Blair (1985) and applied to energy systems by Kim (1998), Pachauri and Spreng (2002), and Choi and Lee (2004).

As may be expected, one way to obtain transaction amounts in physical units is to first compute the total monetary requirement by a conventional IO analysis, and convert these values into TOE by means of prices relating money outputs to energy outputs.

This study explains briefly the basic concept of analyzing the linkage effects for each energy source. To calculate the energy and environmental inventories caused by economic activities using E-IO mixed with heterogeneous units, additional definition of the matrices and vectors are needed as follows:

**Z*** is an $n\times n$ matrix, which is a new transaction matrix, because $k$ energy sectors in a conventional IO table are changed row-wise from the monetary price to the energy unit. Thus, this matrix has the original inter-sector transaction matrix **Z** in the non-energy sectors, and the energy rows are replaced by the corresponding rows in energy flow matrix **E**.

**X*** and **Y*** are $n\times 1$ vectors, which designate the total output and final demand, respectively. These two vectors are also mixed with monetary and energy units according to the sectors.

**F*** is an $n\times 1$ vector and is an artificial vector to isolate the energy rows in a matrix manipulation. The definitions of these quantities are as follows:

$$Z_i^* = \begin{cases} E_k, \text{for energy rows} \\ Z_j, \text{for non} - \text{energy rows} \end{cases} \tag{2.8}$$

$$X_i^* = \begin{cases} F_k, \text{for energy rows} \\ X_j, \text{for non} - \text{energy rows} \end{cases} \tag{2.9}$$

$$Y_i^* = \begin{cases} e_k, \text{for energy rows} \\ y_j, \text{for non} - \text{energy rows} \end{cases} \tag{2.10}$$

$$F_i^* = \begin{cases} F_k, \text{for energy rows} \\ 0, \text{for non} - \text{energy rows} \end{cases} \tag{2.11}$$

**E** is a $k\times n$ matrix and designates the energy flows. $\mathbf{E}_y$ and **F** are $k\times 1$ vectors of physical units designating the energy consumed by the final demand and total energy consumption in the economy, respectively. Hence, the total amount of energy consumed (and produced) by the economy means the addition of energy (of each type depicted by the rows of $\mathbf{E}_i$ and $\mathbf{E}_y$) consumed by intermediate sectors and that consumed by the final demand. This can be shown as follows:

$$\boldsymbol{E_i} + \boldsymbol{E_y} = \boldsymbol{F} \tag{2.12}$$

When this definition is used, the corresponding matrices, $\mathbf{A}^* = \mathbf{Z}^*(\widehat{\mathbf{X}^*})^{-1}$ and $\mathbf{(I\text{-}A^*)^{-1}}$, can be calculated easily. The hat (^) denotes the diagonal matrix of the vector.

However, these matrices have different characteristics from the traditional Leontief model. For example, the input coefficient matrix $\mathbf{A^*}$ indicates the direct requirement and inverse coefficient matrix $\mathbf{(I\text{-}A^*)^{-1}}$, meaning the total requirements have different elements because these are mixed matrices of heterogeneous units.

$$Z^* = \begin{bmatrix} toe & toe \\ \$ & \$ \end{bmatrix};\ Y^* = \begin{bmatrix} toe \\ \$ \end{bmatrix};\ X^* = \begin{bmatrix} toe \\ \$ \end{bmatrix};\ F^* = \begin{bmatrix} toe \\ \$ \end{bmatrix}$$

When calculating an input coefficient matrix, it is composed of four elements of heterogeneous characteristics, as shown in Eq. (2.13).

$$A^* = Z^*\,(\widehat{X^*})^{-1} = \begin{bmatrix} {}^{toe}/_{toe} & {}^{toe}/_{\$} \\ {}^{\$}/_{toe} & {}^{\$}/_{\$} \end{bmatrix} \tag{2.13}$$

The $\mathbf{(I\text{-}A^*)^{-1}}$ matrix has the same characteristic as $\mathbf{A^*}$shown in Eq. (2.13).

## 2.3 Inductive evidence to convertibility in E-IO

A conventional IO table of a single unit based on money and a hybrid E-IO table combined with various kinds of units produce the same analytical results. Yet, an input coefficients matrix is manipulated based on the price information according to the sectors. This can be easily shown through the following example.

To illustrate that the two different tables lead to the same results, two transaction matrices are assumed: a homogeneous unit conventional IO table and a hybrid E-IO table composed of two kinds of units (Table 2.2).

Sectors e-1 and e-2 denote the energy sector, and those of m-3 and m-4 designate the non-energy industry sector. In the elements of the transaction matrix, $m_{i,j}$ is a value expressed as a monetary unit, and $e_{i,j}$ is a value expressed as an energy unit (e.g., joules, calories, TOE, etc.). In addition, $mx_i$ is in a monetary unit and $ex_i$ is a value expressed as an energy unit in the total output column. The energy input coefficient is a value that divides $m_{i,j}$ expressed as a monetary unit by energy price $p_i$, under the assumption that $p_i$ is constant irrespective of sector $j$.

**Table 2.2 Structure of two kinds of transaction matrix**

| I | e-1 | e-2 | m-3 | m-4 | $\sum_i x_{i,j}$ |
|---|---|---|---|---|---|
| e-1 | $m_{1,1}$ | $m_{1,2}$ | $m_{1,3}$ | $m_{1,4}$ | $mx_1$ |
| e-2 | $m_{2,1}$ | $m_{2,2}$ | $m_{2,3}$ | $m_{2,4}$ | $mx_2$ |
| m-3 | $m_{3,1}$ | $m_{3,2}$ | $m_{3,3}$ | $m_{3,4}$ | $mx_3$ |
| m-4 | $m_{4,1}$ | $m_{4,2}$ | $m_{4,3}$ | $m_{4,4}$ | $mx_4$ |

| II | e-1 | e-2 | m-3 | m-4 | $\sum_i x_{i,j}$ |
|---|---|---|---|---|---|
| e-1 | $e_{1,1}$ | $e_{1,2}$ | $e_{1,3}$ | $e_{1,4}$ | $ex_1$ |
| e-2 | $e_{2,1}$ | $e_{2,2}$ | $e_{2,3}$ | $e_{2,4}$ | $ex_2$ |
| m-3 | $m_{3,1}$ | $m_{3,2}$ | $m_{3,3}$ | $m_{3,4}$ | $mx_3$ |
| m-4 | $m_{4,1}$ | $m_{4,2}$ | $m_{4,3}$ | $m_{4,4}$ | $mx_4$ |

Herein, the input coefficient matrix on the right side of Table 2.2 has different unit values divided by four elements, as shown in Eq. (2.13). Their expressions are as follows:

1) for a sector from energy to energy representing $\frac{toe}{toe}$,

$$a'_{i,j} = \frac{e_{i,j}}{ex_j} = \frac{\left(m_{i,j}/p_i\right)}{\left(mx_j/p_j\right)} = \frac{m_{i,j}}{mx_j}\frac{p_j}{p_i} = a_{i,j}\frac{p_j}{p_i} \quad (2.14)$$

2) for a sector from energy to non-energy representing $\frac{toe}{\$}$,

$$a'_{i,j} = \frac{e_{i,j}}{mx_j} = \frac{\left(m_{i,j}/p_i\right)}{mx_j} = \frac{m_{i,j}}{mx_j}\frac{1}{p_i} = a_{i,j}\frac{1}{p_i} \quad (2.15)$$

3) for a sector from non-energy to energy representing $\frac{\$}{toe}$,

$$a'_{i,j} = \frac{m_{i,j}}{ex_j} = \frac{m_{i,j}}{\left(mx_j/p_j\right)} = \frac{m_{i,j}}{mx_j}p_j = a_{i,j}p_j \quad (2.16)$$

4) for a sector from non-energy to non-energy representing $\frac{\$}{\$}$,

$$a'_{i,j} = \frac{m_{i,j}}{mx_j} = a_{i,j} \quad (2.17)$$

As shown above, through the price vector of each energy source, the conventional input coefficients matrix can be simply converted into the coefficients of the E-IO model. Obviously, the results can be presumed to be in diversified form owing to the different dimensions in both matrices. The concept of Eqs. (2.14) – (2.17) will be applied to a combined unit model of two or more units. Therefore, the values for the energy sectors can be used as inherent physical units to prepare an initial IO table to perform the energy analysis using an IO analysis.

To estimate the co-relationships among each energy source, this study used an IO table with heterogeneous units: which are the physical units of TOE for energy sectors and money transaction units for non-energy sectors.

## 2.4 Application of linkage effect analysis of energy sources

### 2.4.1 Composition of an input coefficient matrix in the energy sector

Regarding the energy flow in the energy sector, for primary energy such as coal, crude petroleum, and natural gas, the energy input is little, while the energy output becomes a large amount (that is, $a_{ii}$ has small values). On the contrary, non-primary energy such as naphtha, gasoline, fuel oil, and thermal & self-power generation has plenty of energy input (that is, $a_{ij}$ has large values). Atomic power generation has an especially huge amount of energy output but a small amount of energy input. Table 2.3 shows the extraction of $a_{ij}$ of 14 energy sectors in the Korean E-IO table from 2000 described in chapter 3.

**Table 2.3 Input coefficients matrix of an energy sector ($a_{ij}$)**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.2E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.6E+00 | 0.0E+00 | 0.0E+00 | 3.1E-01 | 0.0E+00 |
| 2 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 6.1E-01 | 8.7E-01 | 7.6E-01 | 1.5E-01 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |
| 3 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.5E+00 | 0.0E+00 | 0.0E+00 |
| 4 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 2.0E-03 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 1.0E-03 | 0.0E+00 | 1.9E-01 | 0.0E+00 | 3.9E-05 | 0.0E+00 | 0.0E+00 |
| 5 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 2.4E-05 | 3.5E-03 | 1.3E-04 | 5.8E-05 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |
| 6 | 1.5E-05 | 0.0E+00 | 0.0E+00 | 3.6E-04 | 1.4E-04 | 1.5E-02 | 6.7E-04 | 7.0E-04 | 9.2E-04 | 8.1E-04 | 6.0E-04 | 3.1E-04 | 1.4E-04 | 0.0E+00 |
| 7 | 2.1E-04 | 0.0E+00 | 0.0E+00 | 2.9E-03 | 4.0E-03 | 3.5E-02 | 2.0E-02 | 2.0E-02 | 1.0E-02 | 4.4E-01 | 5.3E-03 | 2.8E-02 | 2.6E-01 | 0.0E+00 |
| 8 | 2.8E-05 | 0.0E+00 | 0.0E+00 | 4.6E-03 | 4.0E-04 | 1.5E-03 | 1.2E-03 | 1.2E-01 | 2.1E-03 | 1.6E-03 | 8.9E-04 | 8.6E-04 | 7.3E-04 | 0.0E+00 |
| 9 | 1.0E-05 | 0.0E+00 | 0.0E+00 | 1.4E-05 | 1.7E-05 | 4.1E-05 | 5.6E-05 | 1.9E-05 | 4.6E-03 | 2.8E-05 | 3.2E-04 | 1.0E-04 | 1.4E-04 | 0.0E+00 |
| 10 | 2.4E-04 | 0.0E+00 | 0.0E+00 | 4.0E-04 | 5.3E-04 | 2.9E-03 | 2.1E-03 | 8.0E-04 | 2.4E-03 | 4.9E-02 | 9.9E-03 | 2.6E-03 | 3.2E-02 | 0.0E+00 |
| 11 | 1.9E-04 | 0.0E+00 | 0.0E+00 | 2.5E-04 | 3.0E-04 | 8.9E-04 | 1.1E-03 | 4.2E-04 | 3.9E-03 | 4.8E-03 | 1.3E-02 | 1.9E-03 | 2.9E-03 | 0.0E+00 |
| 12 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 7.3E-06 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 4.9E-07 | 0.0E+00 | 2.0E-01 | 0.0E+00 | 2.0E-03 | 4.1E-02 | 0.0E+00 |
| 13 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 3.0E-07 | 3.9E-04 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 2.6E-01 | 0.0E+00 |
| 14 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 | 0.0E+00 |

Remarks: Energy sources are numbered as follows: 1-Coal, 2-Crude petroleum, 3-Natural gas, 4-Coal products, 5-Naptha, 6-Gasoline, 7-Fuel oil, 8-Miscellaneous petroleum refinery products, 9-Water power generation, 10-Thermal &self-power generation, 11-Atomic power generation, 12-Town gas, 13-Heat, and 14-Woods.

Figures larger than 1, such as $a_{1,4}$ and $a_{1,10}$, occurred in the carry-over of energy between years**.**

### 2.4.2 Estimation of linkage effect

#### 2.4.2.1 Linkage effects

The linkage effects have two viewpoints: one is the backward linkage (*BL*) effect or power of dispersion, which illustrates the degree of purchasing intermediate goods from other industries, and the other is the forward linkage (*FL*) effect or sensitivity of dispersion, which shows the degree of providing intermediate goods to other industries.

In a conventional IO analysis, the linkage multiplier is used to measure the aforementioned effects. The linkage multiplier for each energy source is calculated using the elements of Leontief's inverse matrix, as shown in Eqs. (2.18) and (2.19). Eqs. (2.18) and (2.19) denote the row-wise averages of $b_{ij}$ and column-wise $b_{ij}$ with respect to the average of the total technological coefficients matrix, respectively.

Let **B** be an inverse matrix, $\mathbf{(I\text{-}A^{*})^{-1}}$, whose element is $b_{ij}$, then

$$FL\ coefficient = \frac{\frac{1}{n}\sum_i b_{ij}}{\frac{1}{n^2}\sum_{ij} b_{ij}} \tag{2.18}$$

$$BL\ coefficient = \frac{\frac{1}{n}\sum_j b_{ij}}{\frac{1}{n^2}\sum_{ij} b_{ij}} \tag{2.19}$$

The two kinds of linkage analysis are useful to evaluate the level of intermediate demand or input of an energy source.

#### 2.4.2.2 Estimation results

Figure 2.1 shows the results plotted from the analysis of the forward and backward linkage effects for each energy source calculated from Table 2.3. An analysis of the coefficients of the forward and backward linkages allows the most important sectors in the economy to be identified. The forward linkage effect means the downstream effect (i.e., the effect caused by the sale). The backward linkage effect is a coefficient that evaluates the effect evoked upstream (i.e., the effect from the purchase).

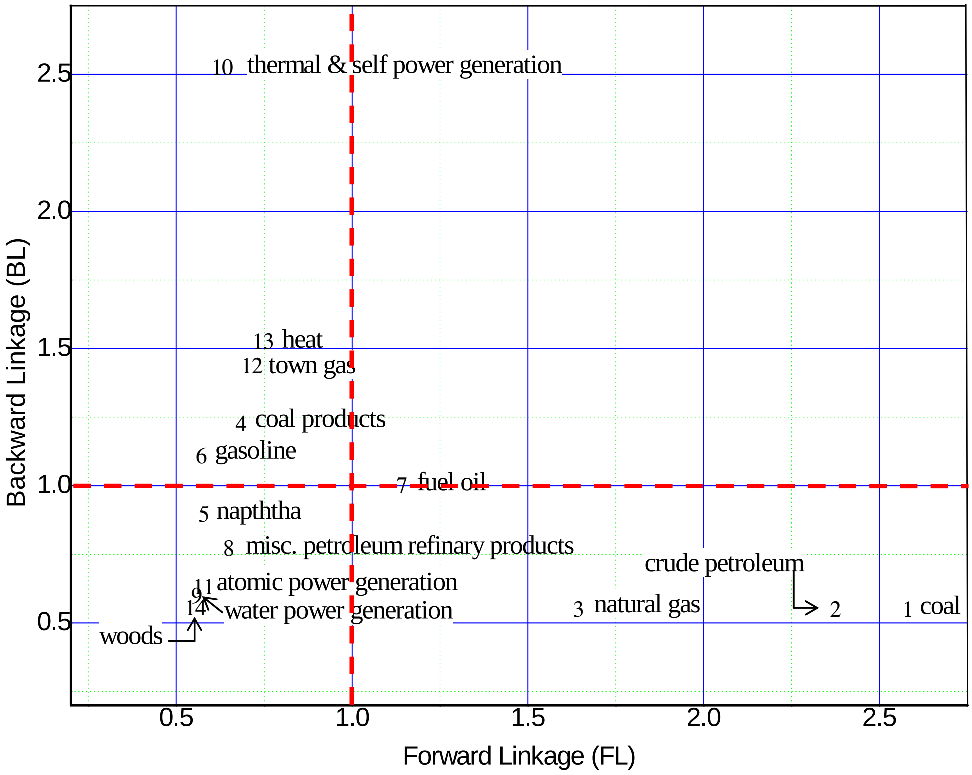


**Figure 2.1 Estimation of linkage effect coefficient.**

In Figure 2.1, it can be observed that the linkage coefficients are plotted as "1," which is the average of 2 coefficients depending on the energy source. The primary energy in sectors #-1, 2, and 3 shows that the forward linkage coefficient is large and the backward linkage coefficient is small. On the contrary, sectors #-4, 6, 10, 12, and 13 belong in the region of small forward linkage coefficient but large backward linkage coefficient. Both coefficients are smaller in sectors #-5, 8, 9, 11, and 14; whereas both of the coefficients are relatively large in only one sector, #-7.

According to Eqs. (2.18) and (2.19), the forward linkage effect is arranged in the following order:

| | | | |
|---|---|---|---|
| 1. | sector-1 (Coal, 2.581) | 8. | sector-8 (Misc. petroleum refinery products, 0.648) |
| 2. | sector-2 (Crude petroleum, 2.375) | 9. | sector-10 (Thermal & self-power generation, 0.630) |
| 3. | sector-3 (Natural gas, 1.644) | 10. | sector-5 (Naphtha, 0.578) |
| 4. | sector-7 (Fuel oil, 1.141) | 11. | sector-11 (Atomic power generation, 0.577) |
| 5. | sector-13 (Heat, 0.747) | 12. | sector-6 (Gasoline, 0.570) |
| 6. | sector-12 (Town gas, 0.715) | 13. | sector-9 (Water power generation, 0.557) |
| 7. | sector-4 (Coal products, 0.683) | 14. | sector-14 (Woods, 0.554) |

The backward linkage effect is in the following order:

| | | | |
|---|---|---|---|
| 1. | sector-10 (Thermal &self-power generation,2.531) | 8. | sector-8 (Misc. petroleum refinery products, 0.778) |
| 2. | sector-13 (Heat, 1.532) | 9. | sector-11 (Atomic power generation, 0.637) |
| 3. | sector-12 (Town gas, 1.443) | 10. | sector-9 (Water power generation, 0.603) |
| 4. | sector-4 (Coal products, 1.231) | 11. | sector-14 (Woods, 0.560) |
| 5. | sector-6 (Gasoline, 1.114) | 12. | sector-1 (Coal, 0.555) |
| 6. | sector-7 (Fuel oil, 1.008) | 13. | sector-2 (Crude petroleum, 0.554) |
| 7. | sector-5 (Naphtha, 0.901) | 14. | sector-3 (Natural gas, 0.554) |

That is, the larger forward linkage effect of an energy sector implies that an expansion of its output is more essential to other energy sectors than an equal expansion in other energy's output in terms of supporting productive activity. Similarly, a larger backward linkage effect of an energy sector means that an expansion of its output is more beneficial to other energy sectors than an equal expansion of another energy output in terms of causing other productive activities.

The results from the two effects can be summarized. Energy sources from sectors 1, 3 and 7 in primary energy have larger forward linkage coefficients, as shown in Figure 2.1. This means that the primary energy is provided to other intermediate sectors and has a larger effect on other industries. On the contrary, smaller forward linkage coefficients are shown in most final energies, which are used by the end user, except sector 7. Obviously, the backward linkage coefficients appear lower if the primary energies are directly extracted from nature (e.g., sectors #-1-3), or if there is no intermediate input from the other energy sources, as sectors #-9, 11 and 14 show, then the value is lower along the Y-axis.

## 2.5 Conclusion

In this study, typical processes for both a conventional IO approach and an E-IO approach having hybrid units were compared. The convertibility of these approaches was demonstrated using an energy model including the monetary unit and energy unit for an IO approach. In addition, the linkage effects of 14 assorted energy sectors were analyzed using the E-IO table.

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# Chapter 3. An Analysis of Sectoral Energy and GHG Emission Intensity in Korea: An Energy IO Approach

An estimation of energy and GHG emission intensity caused by energy consumption in Korea: An energy IO approach, *Applied Energy*, 2009;86: pp1902-1914

In this chapter, a 96×96 hybrid energy input–output (E-IO) table is constructed by using energy units for each energy sector from the 2000 Korean IO table developed by the BOK in 2003. By using this E-IO table, the amount of energy intensities and GHG emission intensities, caused by energy use, are estimated for each sector.

## 3.1 Introduction

Korea must prepare to the era of post-Kyoto Protocol paradigm. According to the OECD/International Energy Agency (IEA) [1], the $CO_2$ emissions in Korea caused by energy consumption has reduced from 462.10 million ton of $CO_2$ (Mt-$CO_2$) in 2004 to 448.91 Mt-$CO_2$ in 2005. However, Korea is still ranked 10th in the world for its greenhouse gas (GHG) emissions caused by energy use. Therefore, it is necessary to reduce GHG emissions from the energy sector in Korea.

There is an urgent need for the development of a quantitative model that can reliably establish a relationship between economic activity and energy consumption/environmental load. A reliable econometric model should be developed for various applications. Such a model can be used for reorganization of the industrial structure or energy conservation and for policymaking. The results obtained with such a model can assist in the understanding of the structure of national energy use and the dynamics of GHG emissions. In addition, such a model will help to reduce unnecessary trial-and-error implementations of energy and environmental policies by analyzing the effect of a mandatory reduction in GHG emission on the country's economy.

The global environmental impact of climate change, which is the result of an entire life cycle of a technology, is regarded as a more urgent international issue than the local or regional environment impact of climate change; the impact is evaluated in the technology use stage. Therefore, the proposed model should be able to evaluate the environmental loads of products and services associated with economic sectors including direct and indirect energy use.

In the analysis of energy and GHG emissions, applicable methodologies need to satisfy a prerequisite. The requisite is a clear and comprehensive understanding of factors of internal interactions that influence economy, energy, and GHG emissions. In seeking an effective model, the methodologies can be classified into so called bottom-up, top-down, and hybrid models in terms of approaching paths.

Bottom-up analysis provides retails for individual process or enterprise but lack of comprehensiveness; top-down approaches can apply both to represent whole economy or society and to reflect its sub-sector. Bottom-up models need disaggregated data and aggregate to the lack of comprehensiveness, while top-down models start with aggregated information and disaggregate as far as they can. Systems can be represented based on technology and cost data and description of physical flows in bottom-up approach. On the other hand, the systems can be described based on macro input-output (IO) or econometric analysis and production functions, e.g., linear, fixed proportional, Cobb-Douglas, etc., to determine technology substitution possibilities in top-down approach.

Although different approaches have their own advantages and shortcomings, well-constructed models have been introduced and demonstrated their usefulness. In bottom-up approach, MARKAL(MARKet ALlocation)[2] and MESSAGE(Model for Energy Supply Strategy Alternatives and their General Environmental Impact)[3] are examples and HERMES(Harmonized European Research for Macrosectoral and Energy Systems)[4], MIDAS(MIxed DAta-frequency Sampling)[5], and computable general equilibrium(CGE)[6] applications, such as GREEN(GeneRal Equilibrium ENvironment)[7] and Jorgenson-Wilcoxen models[8], are noticeable in top-down. While ETA-MACRO[9], MESSAGE-MACRO[10], MARKAL-MACRO[11], and HERMES-MIDAS[12] are prominent in mixed or hybrid model.

In this study, the top-down approach (IO analysis) is applied to quantify the relations of economy, energy, and GHG emissions in detail and to get comprehensive messages for energy and environment in Korea

It is recognized that the IO analysis has unavoidable limitations. The latent limitations of the IO table used in this analysis are as follows.

- price distortion at the process of unit conversion,
- aggregation error in composing a sector, and
- missing necessary product or service in the candidate sector.

Despite the limitations in the conventional IO approach, an IO analysis with the E-IO table can be successfully used in energy and environmental analysis to produce reliable results.

This is because in an E-IO table,

- the types of energy source and the tariff structure are simple;
- each energy source has a large volume in both trading and GHG emission amount;
- the dynamics of GHG emission is simple; and
- all economic sectors consume energy use.

Hybrid IO analyses were performed by the following researchers.

- Miller and Blair [25] authored a well-organized textbook on E-IO analysis.
- Kim [26] constructed an E-IO table for coal, petroleum, gas, and electric power by using IO tables pertaining to the years 1985, 1990, and 1995 and studied the relationship between the energy input and $CO_2$ emissions from 18 non-energy sectors.
- Choi and Lee [27] analyzed the energy consumption of 28 non-energy sectors that used 5 primary energy sources and 11 final energy sources. Through this analysis, they constructed a hybrid IO table of $CO_2$ emission and determined the amount of $CO_2$ emitted by Korea's goods export sector.

When an energy and environmental analysis performed by using a hybrid IO table produces a transactions table, the monetary values pertaining to the energy sectors are substituted with physical units. Thus, hybrid IO analysis helps to eliminate the effect of price distortion on the results and makes the analysis of the implications of the results easy.

One of the objectives of this study is to determine the intensities of energy use and GHG emissions associated with energy use and to identify the behavior of the intensities in Korea through a hybrid E-IO table with higher sectoral resolution. By using an IO table developed by the BOK [28], we created a hybrid E-IO table that consisted of 14 energy sectors and 82 non-energy sectors of the Korean economy. The E-IO analysis performed in this study is different from those performed in previous studies conducted in Korea; in our study, 96 sectors were considered and the number of GHG species was expanded to include $CO_2$, $GH_4$, and $N_2O$ in order to provide a more reliable policy recommendation. The results of our study will enable energy policy planners to understand the co-relationship between national economic activity, energy use, and GHG emissions on sectoral basis.

## 3.2 Construction of the E-IO table

### 3.2.1 Composition of the E-IO table

An E-IO table is constructed by using the IO table of 2000 developed by the BOK in 2003 [28]. In the E-IO table, energy sectors are expressed in terms of physical units, i.e., tons of oil equivalent (TOE); on the other hand, non-energy sectors are expressed in terms of monetary units, i.e., Korean Won (KRW), as in the case of a conventional IO table. Hence, each column of the table contains values with different units, i.e., TOE for energy sectors and KRW for non-energy sectors, while each row contains values with the same units. Therefore, for energy sectors, each row represents the structure of energy transactions between sectors, and the sum of the values in a row equals the total output of the energy sector corresponding to that row. On the other hand, for non-energy sectors, each row represents the transactions structure of the total output of the sector corresponding to that row, as shown in Figure 3.1.

<table>
<tr><th colspan="2" rowspan="2">To<br>From</th><th rowspan="2">Energy group</th><th colspan="2">Non-energy group</th><th rowspan="2">Final use group</th><th rowspan="2">Total output</th></tr>
<tr><th>Energy intensive group</th><th>Less energy intensive group</th></tr>
<tr><td colspan="2">Energy group</td><td>$E_k$</td><td colspan="2">$E_k$</td><td>$e_k$</td><td>$F_k$</td></tr>
<tr><td rowspan="2">Non-energy group</td><td>Energy intensive group</td><td rowspan="2">$Z_j$</td><td colspan="2" rowspan="2">$Z_j$</td><td rowspan="2">$Y_j$</td><td rowspan="2">$X_j$</td></tr>
<tr><td>Less energy intensive group</td></tr>
<tr><td colspan="2" rowspan="2">Total input</td><td></td><td colspan="2">Total input for energy sector (TOE)</td><td></td><td></td></tr>
<tr><td></td><td colspan="2">Total input for non-energy sector (KRW)</td><td></td><td></td></tr>
</table>

**Figure 3.1 Basic structure of an E-IO table.**

### 3.2.2 Sector rearrangement

The 404 industrial sectors considered in the IO table developed by the BOK [28] are consolidated into 96 sectors. These sectors are subdivided into three groups. The first group, the energy group, comprises 14 energy sources, and the other sectors belong to the non-energy group, which is further divided into two subgroups (energy intensive and less energy intensive), as shown in Table 3.1. Detailed information on the sector aggregation was added to the appendix 1.

**Table 3.1 Summary of the rearranged sectors**

| Group | | Code & sector name | | |
|---|---|---|---|---|
| Energy group | | 1-Coal | 2-Crude petroleum | 3-Natural gas |
| | | 4-Coal products | 5-Naphtha | 6-Gasoline |
| | | 7-Fuel oil | 8-Misc. Petroleum refinery products | 9-Hydropower generation |
| | | 10-Thermal-, self-power generation | 11-Atomic-power generation | 12-Town gas |
| | | 13-Heat | 14-Wood | |
| Non- energy group | Energy intensive group | 15-Crops-p | 16-Fishery products | 17-Metallic minerals |
| | | 18-Nonmetallic minerals | 19-Sugar, starches | 20-Fiber yarn |
| | | 21-Fiber fabrics-p | 22-Wood, wooden products-p | 23-Pulp, paper-p |
| | | 24-Organic basic chemical products | 25-Inorganic basic chemical products | 26-Synthetic resins, synthetic rubber-p |
| | | 27-Chemical fibers | 28-Fertilizers, agricultural chemicals-p | 29-Other chemical products |
| | | 30-Glass products | 31-Pottery, clay products | 32-Cement, concrete products |
| | | 33-Other nonmetallic mineral products | 34-Pig iron, crude steel | 35-Primary iron, steel products |
| | | 36-Nonferrous metal ingots, primary nonferrous metal products-p | 37-Fabricated metal products-p | 38-Machinery, equipment of general purpose-p |
| | | 39-Wholesale, retail trade | 40- Restaurants, drinking establishments, hotels, other lodging places | 41-Transportation, warehousing-p |
| | | 42-Public administration, defense | 43-Gas, water supply | 44-Medical, health services, social security-p |
| | | 45-Other services-p | | |
| | Less energy intensive group | 46-Crops-p | 47-Livestock breeding | 48-Forestry products |
| | | 49-Meat, dairy products | 50-Processed seafood products | 51-Polished grains, flour, milled cereals |
| | | 52-Bakery, confectionery products, noodles | 53-Seasonings, fats, oils | 54-Canned or cured fruits, vegetables, misc. food preparations |
| | | 55-Beverages | 56-Prepared livestock feeds | 57-Tobacco products |
| | | 58-Fiber yarn-p | 59-Apparel, accessories | 60-Other fabricated textile products |
| | | 61-Leather, fur products | 62-Wood, wooden products-p | 63-Pulp, paper-p |
| | | 64-Printing, publishing, reproduction of recorded media | 65-Synthetic resins, synthetic rubber-p | 66-Fertilizers, agricultural chemicals-p, |
| | | 67-Drugs, cosmetics, soap | 68-Plastic products | 69-Rubber products |
| | | 70-Nonferrous metal ingots, primary nonferrous metal products-p | 71-Fabricated metal products-p | 72-Machinery, equipment of general purpose-p |
| | | 73-Machinery, specialized equipment | 74-Electronic machinery, equipment, supplies | 75-Electronic components, accessories |
| | | 76-Radio, television, communications equipment | 77-Computers, office equipment | 78-Household electrical appliances |
| | | 79-Precision instruments | 80-Motor vehicles | 81-Ship building, repairing |
| | | 82-Other transportation equipment | 83-Furniture | 84-Other manufacturing products |
| | | 85-Building construction, repair | 86-Civil engineering | 87-Transportation, warehousing-p |
| | | 88-Communications, broadcasting | 89-Finance, insurance | 90-Real estate agencies, rental services |
| | | 91-Business services | 92-Educational, research services | 93-Medical, health services, social security |
| | | 94-Culture, recreational services | 95-Other services, | 96-Nonclassifiable activities |

Remarks: The name of a sector followed by the suffix "-p" refers to a sector that has been partially extracted from one large sector in the BOK IO table

### 3.2.3 Treatment of energy data

In general, the hybrid IO approach is accurate because it uses the national average price of energy source [28] when the variation in the price of the energy source is small across sectors. However, when the variation in the price of energy source across sectors is high, the accuracy decreases. Each energy source follows the law of one price except electric power, which varies from consumer group in Korea [29].

In this study, sectors with similar energy consumption patterns were grouped together in order to compensate for this weakness in the analysis. In order to examine the validity of our estimated energy consumption data (E-IO case), we compared it with the primary energy consumption data obtained from the national energy census performed by KEEI [29].

**Table 3.2 Comparison of primary energy consumption (kTOE)**

| Energy source | E-IO | KEEI | E-IO/KEEI (%) |
|---|---|---|---|
| Coal | 43,896 | 42,911 | 102 |
| Crude petroleum | 121,901 | 100,279 | 122 |
| Natural gas | 19,811 | 18,924 | 105 |
| Hydropower | 487 | 1,402 | 35 |
| Thermal & self-power | 14,473 | 32,349 | 45 |
| Atomic power | 9,378 | 27,241 | 34 |

Table 3.2 shows that the values obtained from E-IO analysis and those introduced at KEEI are not always similar. The main reasons for these differences in values are as follows.

First, the methods used to obtain these values differ fundamentally in terms of accounts aggregation. The KEEI energy balance data were eliminated data on energy transformation, international bunkers, and stock change. Of which international bunkers include whole foreign flag overseas vessels and aircrafts refueled at Korea. For example, as can be seen in Table 3.2, the total supply (demand) of crude petroleum calculated using the E-IO table is 121,901 kTOE ($10^3$ TOE), which is 22% greater than the primary energy consumption reported by KEEI. This discrepancy can be attributed to the following additional accounts that are considered in the "E-IO case" but excluded by the KEEI.

- electric generation, district heating, and gas manufacturing: 6,684 kTOE
- international bunkers: 7,163 kTOE
- statistic difference: 2,308 kTOE
- imports difference between BOK and energy balance sheet: 3,229 kTOE

When these accounts were not considered in the E-IO analysis, the total primary energy consumption of crude petroleum decreased from 121,901 kTOE to 102,517 kTOE, which is comparable to the value obtained by KEEI.

Secondly, the values pertaining to thermal & self-power, hydropower and atomic power generation differ considerably between these two methods. In the study conducted by KEEI, the primary energy consumption was calculated by considering the thermal efficiency, unlike in the case of our E-IO analysis. The differences in the values listed in Table 3.2 for thermal &

self-power, hydropower and atomic power generation (45%, 35% and 34%, respectively) are close to the differences in the thermal efficiencies at those energy transformations. In fact, the efficiency of the thermal & self-power plant in 2000 was 39.45%. Thermal efficiency was not considered in our analysis because there is no direct GHG emission from hydropower and atomic power generations. It has already been considered in the calculation of primary energy.

### 3.2.4 The producibility condition

In the Leontief inverse matrix of the E-IO table used in this study, the total outputs must satisfy the condition of non-negativity in terms of economic producibility. This condition can be checked with satisfaction of the Hawkins and Simon (H–S) [30] condition.

Miller and Blair [25] introduced the H–S conditions in a Leontief model to obtain a nonnegative solution, such that a non-negative output is the result of a given nonnegative final demand. This condition was verified in our E-IO table by performing the following steps.

- The following conditions must be satisfied for the (**I**-**A**) coefficients matrix to satisfy the H–S conditions (here, **I** is an identity matrix and **A** is an input coefficient matrix). First, all the diagonal elements in the matrix must be positive, and all the non-diagonal elements must be non-positive. The E-IO table constructed in this study satisfies both conditions.
- Secondly, the determinants of all leading principle sub-matrices (minors) in the coefficients matrix (**I**-**A**) of each year were positive; This implies that all the (**I**-**A**) matrices calculated in this study satisfy the H–S condition.

Therefore, the Leontief inverse matrix was assumed to satisfy the H–S conditions.

### 3.2.5 Prevention of double count error

In order to perform an E-IO analysis, it is important to understand the concept of energy flow accurately. There are three representative types of energy use in economic sectors. They involve different energy consumption processes and result in different GHG emissions, as shown in Figure 3.2.

Type 1 is the simplest case of energy use in the final demand sector, which comprises a private sector (*Pv*) as well as a government one (*Gv*) in the IO table constructed by BOK (2003). In type 1, the sector acquires the required amount of energy from the energy source (*e*) and emits GHGs directly after consuming this energy.

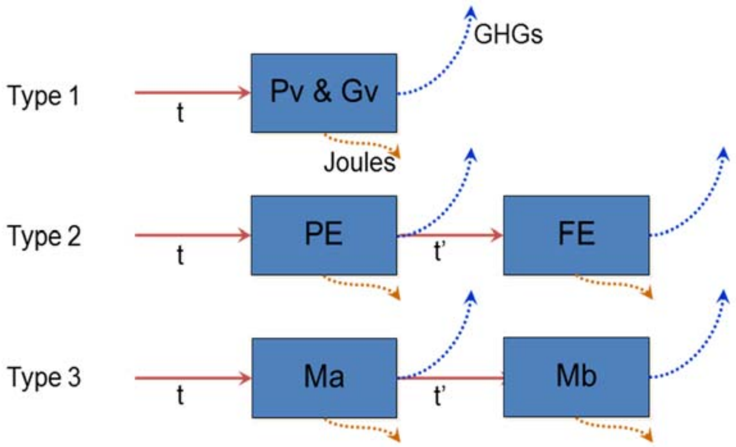


**Figure 3.2 Three types of energy use and GHG emission in economic sectors.**

Type 2 pertains to the energy group. Fourteen energy sources were consolidated from mixed sectors such as the following: (1) coal, which can provide primary energy (*PE*) to be used directly by the end users; (2) crude petroleum, which can be converted into a secondary energy (*SE*) source like naphtha and gasoline; and (3) power generation, in which *PE* or *SE* from other sources is used as fuel to generate final energy (*FE*) in the form of electricity. At this stage, we need to ascertain whether the total input energy (*t*) is used to acquire the energy or as raw material (*t'*) for the next step. This will prevent an energy source from being considered twice when calculating energy and GHG emissions intensities.

Lastly, type 3 represents the input energy use in non-energy sectors. The input energy sources in non-energy manufacturing sectors (*Ma*) are mainly used for combustion; however, in some cases, they are used for downstream manufacture (*Mb*) such as in the case of petrochemical products or pavement materials. This study considers the input ratios of asphalt and naphtha in the civil engineering and petrochemical sectors, respectively. The input percentages of coal, naphtha, and miscellaneous petroleum refinery products to raw materials were 2.5%, 75%, and 76%, respectively.

## 3.3 E-IO analysis

An estimation of energy consumption and intensity of GHG emission associated with energy use by using the E-IO table produced the results that were dissimilar to those obtained by using the conventional IO table. The E-IO analysis is generally carried out in three steps, as shown in Figure 3.3. The monetary transaction data and price data (represented dotted circles) for each energy source were obtained from Korea's conventional IO tables. After simple calculations with some data at the first box, an E-IO table containing values with two different types of units, so called hybrid-units type E-IO table, is constructed. In this study, the hybrid-units type E-IO table which was developed by Shim [31] was used to estimate the energy intensities and GHG emission intensities for three types of element for 96 economic sectors in Korea. Then, the E-IO analysis is performed to explain the co-relationship among an economic activity, energy use, and GHG emissions.

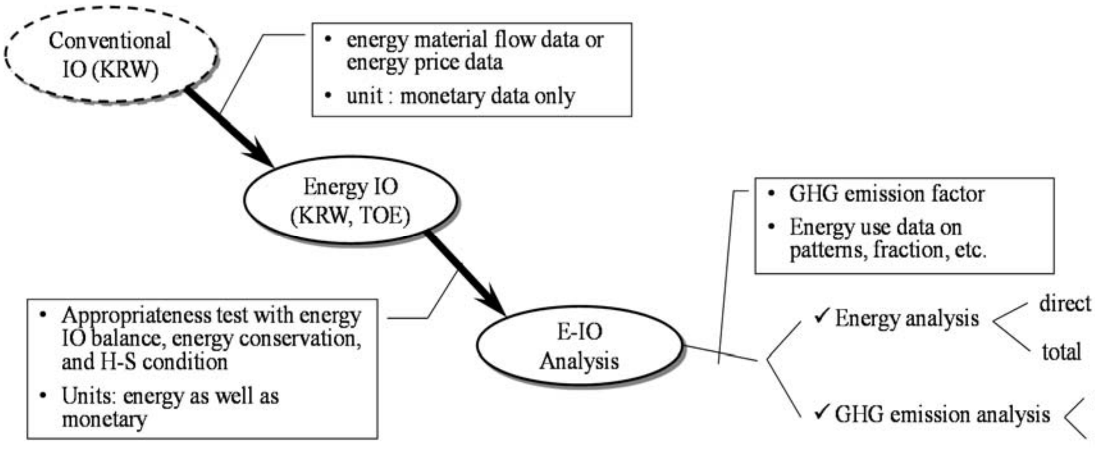


**Figure 3.3 General procedure of E-IO analysis.**

### 3.3.1 Procedure for estimating energy intensity

In an E-IO table, energy flow is expressed in physical units such as TOE or other convenient energy units, while non-energy flows are expressed in monetary units.

In order to obtain all the values in the table in physical units, the total monetary requirement is computed by using a conventional IO table and then to convert these values to TOE using unit prices of energy outputs. The basic procedure of performing an E-IO analysis was introduced by Miller and Blair [25]

In order to estimate the energy and environment inventories associated with economic activities by using the E-IO table in monetary and physical units, the following additional definitions of matrices and vectors are needed as described in chapter 2.

**Z*** is the new transactions matrix of dimensions $n \times n$ obtained by changing $k$ energy sectors in a conventional IO table from monetary units to energy units row-wise. Thus, this matrix is comprised of the original inter-sector transactions matrix **Z** in the non-energy sectors and an energy flow matrix **E** in the energy sectors. $n$ is the number of sectors ($n$ = 96 and $k$ = 14 in this study).

**X*** and **Y*** are $n \times 1$ vectors that represent the total output and the final demand, respectively. These two vectors contain elements with both monetary and energy units. Hence **X** and **Y** mean total output and final demand for non-energy rows respectively. **e** shows final energy demand in energy rows.

**F*** is an artificial $n \times 1$ vector that is used to isolate energy rows during matrix manipulation. **F*** consists of zero vector for non-energy rows and **F** representing total energy consumption for energy rows.

These matrices are defined as follows

$$Z_i^* = \begin{cases} E_k, \text{for energy rows} \\ Z_j, \text{for non} - \text{energy rows} \end{cases} \quad (3.1)$$

$$X_i^* = \begin{cases} F_k, \text{for energy rows} \\ X_j, \text{for non} - \text{energy rows} \end{cases} \quad (3.2)$$

$$Y_i^* = \begin{cases} e_k, \text{for energy rows} \\ y_j, \text{for non} - \text{energy rows} \end{cases} \quad (3.3)$$

$$F_i^* = \begin{cases} F_k, \text{for energy rows} \\ 0, \text{for non} - \text{energy rows} \end{cases} \quad (3.4)$$

**E** is a $k \times n$ matrix that represents energy flows. $\mathbf{E_y}$ and **T** are $k \times 1$ vectors expressed in terms of physical units, and they designate the energy consumed by a final demand and the total energy consumption in the economy, respectively. Hence, the total amount of energy consumed (and produced) by the economy is the sum of the energy (of each type represented by the rows in **E**) consumed by intermediate sectors and that consumed by the final demand. This can be expressed as follows:

$$\mathbf{E} + \mathbf{E}_y = \mathbf{T} \quad (3.5)$$

When this definition is used, the corresponding matrices $\mathbf{A}^* = \mathbf{Z}^*(\widehat{\mathbf{X}^*})^{-1}$ and $(\mathbf{I}\text{-}\mathbf{A}^*)^{-1}$ can be calculated easily. Hat (^) over a capital letter indicates that the elements composing the vector have been converted to a diagonal of a corresponding matrix. However, these matrices have characteristics different from those of the traditional Leontief matrices. For example, the input coefficient matrix $\mathbf{A}^*$, which represents direct requirements, and the inverse coefficient matrix $(\mathbf{I}\text{-}\mathbf{A}^*)^{-1}$, which represents total requirements, have different elements because they are combined with a matrix having hybrid units.

$$Z^* = \begin{bmatrix} TOE & TOE \\ KRW & KRW \end{bmatrix}; \quad X^* = \begin{bmatrix} TOE \\ KRW \end{bmatrix}; \quad Y^* = \begin{bmatrix} TOE \\ KRW \end{bmatrix}; \quad F^* = \begin{bmatrix} TOE \\ 0 \end{bmatrix}$$

An input coefficient matrix is composed of four elements with heterogeneous characteristics, as shown in Eq. (3.6).

$$\mathrm{A}^* = \mathrm{Z}^* \, (\widehat{\mathrm{X}^*})^{-1} = \begin{bmatrix} {}^{toe}/_{toe} & {}^{toe}/_{\$} \\ {}^{\$}/_{toe} & {}^{\$}/_{\$} \end{bmatrix} \quad (3.6)$$

$(\mathbf{I}\text{-}\mathbf{A}^*)^{-1}$ has the same characteristics as $\mathbf{A}^*$ shown in Eq. (3.6). Both matrices are of dimensions $n \times n$.

By using the $\mathbf{A^*}$ and $\mathbf{(I-A^*)^{-1}}$ matrices, the direct energy coefficients ($\mathbf{EI_\delta}$) and total or embodied energy coefficients ($\mathbf{EI_\alpha}$) can be calculated by the following equations.

$$\mathbf{EI}_\delta = \hat{\mathbf{F}}^*(\hat{\mathbf{X}}^*)^{-1}\mathbf{A}^* \tag{3.7}$$

$$\mathbf{EI}_\alpha = \hat{\mathbf{F}}^*(\hat{\mathbf{X}}^*)^{-1}(\mathbf{I}-\mathbf{A}^*)^{-1} \tag{3.8}$$

By using Eqs. (3.7) and (3.8), the rows pertaining to 14 energy sectors are isolated from the $\mathbf{A^*}$ and $\mathbf{(I-A^*)^{-1}}$ matrices shown in Eq. (3.6). The reasons for isolating these rows are as follows: 1) the results of the analysis can be explained systematically; and 2) the difference in the nature of the results obtained for the 14 energy sectors and that of the results obtained for the 2 groups comprising non-energy sectors. This implies that the denominators in the case of the energy sectors and the non-energy sectors are in energy units (TOE) and monetary units (KRW), respectively.

In the case of the energy group, the values are expressed in terms of TOE/TOE, which is the energy ratio of the 14 energy sources that are components of this group. However, in the case of the non-energy group, the values are expressed in terms of TOE/KRW, which is the energy intensity, i.e., energy use per unit production. Hereafter, each sector will be represented by its sector number for the sake of convenience.

### 3.3.2 Estimation of the GHG emissions

In this study, we confine our focus to $CO_2$, $CH_4$, and $N_2O$ emissions only, mainly because they are listed in the Intergovernmental Panel on Climate Change (IPCC) (revised in 1996) [32] as having a direct causative role in global warming. For the assessment of the amount of GHG emissions caused by energy consumption alone, the emission factors recommended in the IPCC Guidelines [32] were used. However, these factors were partly modified in order to reflect the conditions in Korea. Two modifications were performed according to the recommendations of the IPCC. Firstly, the fraction of carbon stored and fraction of carbon oxidized in the case of each fuel was ascertained in order to study the differences in the consumption pattern of the 14 energy sources. Secondly, since the energy sources were classified into 14 sectors, the emission factors were modified by a weighted average of included energy sources. The modified $CO_2$ emission coefficients for each fuel type are shown in Table 3.3. The emission coefficients of $CH_4$ and $N_2O$ pertaining to each type of fuel recommended in the IPCC guidelines were not modified. The GWPs (Global Warming Potentials) of $CH_4$ and $N_2O$ emissions were set at 21 and 310, respectively, for calculation of the $CO_2$ equivalent ($CO_2$-eq.) emissions.

In 2007, the IPCC [33] issued an updated guideline report on emission coefficients in "IPCC 2006 Guidelines for National Greenhouse Gas Inventories," which was not formally adopted for formulating national policies. OECD/IEA [34] still uses the IPCC Guidelines [32], which were not adopted in Korea. Nevertheless, the guidelines provide consistent information on past GHG emission statistics in Korea. On the basis of these backgrounds, we will use the emission coefficients prescribed by the IPCC Guidelines [32].

**Table 3.3 Modified GHG emission factors for each energy source (t-$CO_2$-eq./TOE)**

| Energy source | Emission factor | Included fuels |
|---|---|---|
| Coal | 3.732 | |
| Crude petroleum | 3.009 | |
| Natural gas | 2.298 | |
| Coal products | 4.077 | BKB and patent fuel, coke, coal briquette, etc. |
| Naphtha | 0.752 | |
| Gasoline | 2.842 | Jet oil A-1, P-4 |
| Fuel oil | 2.790 | Kerosene, diesel, bunker A~C, and LPG |
| Misc. petroleum refinery products | 0.773 | Asphalt, lubricant, paraffin wax, etc. |
| Hydropower generation | 0 | |
| Thermal and self-power generation | 0 | |
| Atomic power generation | 0 | |
| Town gas | 2.334 | Naphtha, propane, LNG |
| Heat | 0 | LNG, LSWR, bunker C, and waste burning |
| Wood | 1.178 | |

Remarks: Unlike the common sense of a thermal and self-power generation with zero emission factor, this study is based on the consumer use phase in calculation.

The direct emission intensity of GHG ($\mathbf{GI_\delta}$) and the total intensity ($\mathbf{GI_\alpha}$) of the intermediate transaction sectors by energy use are calculated using Eqs. (3.9) and (3.10), respectively. The dimension of the above matrices is $k \times n$.

$$\mathbf{GI}_\delta = \hat{\mathbf{F}}(\hat{\mathbf{X}}^*)^{-1}\mathbf{MA}^* \tag{3.9}$$

$$\mathbf{GI}_\alpha = \hat{\mathbf{F}}(\hat{\mathbf{X}}^*)^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A}^*)^{-1} \tag{3.10}$$

where $\mathbf{M}$ is a symmetric matrix with dimensions $n \times n$, and it designates the emission factors of specific GHGs (e.g., $CO_2$, $CH_4$, $N_2O$) by type of energy resource ($k$ = 1,2, … ,14 in Table 3.3). The unit is measured from the amount of GHG emission per production price.

We also calculated the direct GHG emissions intensity of the final demand sector, which includes a private sector and a government sector.

## 3.4 Results: Creation of inventory database

### 3.4.1 Energy intensity analysis

#### 3.4.1.1 Energy intensity by industrial sector

Two energy intensities were estimated: the direct energy intensity calculated by using the input or technical coefficients matrix and the embodied energy intensity calculated from the

Leontief inverse coefficients matrix. The indirect energy intensity for each sector can be acquired by subtracting the direct energy intensity from the total energy intensity.

The average values of the direct and total energy intensities were found to be 0.132 and 0.640 (TOE/M-KRW), respectively. In terms of direct energy use, sectors with high energy intensities in the energy group, the energy intensive group and the less energy intensive groups were sectors 10 (thermal and self-power generation; 2.440 TOE/M-KRW), 24 (organic basic chemical products; 1.137 TOE/M-KRW), and 69 (rubber products; 0.092 TOE/M-KRW), respectively. The sectors with high embodied energy intensities in the energy group, the energy intensive group and the less energy intensive groups were sectors 10 (4.571 TOE/M-KRW), 24 (2.607 TOE/M-KRW), and 65 (synthetic resins and synthetic rubber; 1.559 TOE/M-KRW), respectively. In both cases, the sectors with the highest direct energy intensity were almost the same, as can be seen in Table 3.4.

**Table 3.4 The top three sectors in direct and total energy intensities in each group (TOE/M-KRW)**

| | | Direct energy use | | Total energy use | |
|---|---|---|---|---|---|
| | | Sector | Value | Sector | Value |
| Energy group | | 10-Thermal and self-power generation | 2.440 | 10-Thermal and self-power generation | 4.571 |
| | | 12-Town gas | 1.560 | 13-Heat | 2.767 |
| | | 4-Coal products | 1.203 | 4-Coal products | 2.223 |
| Non-energy group | Energy intensive group | 24-Organic basic chemical products | 1.137 | 24-Organic basic chemical products | 2.607 |
| | | 34-Pig iron and crude steel | 0.651 | 34-Pig iron and crude steel | 2.481 |
| | | 33-Other nonmetallic mineral products | 0.649 | 27-Chemical fibers | 1.759 |
| | Less energy intensive group | 69-Rubber products | 0.092 | 65-Synthetic resins and synthetic rubber-p | 1.559 |
| | | 68-Plastic products | 0.072 | 66-Fertilizers and agricultural chemicals-p | 1.217 |
| | | 53-Seasonings,fats and oils | 0.066 | 68-Plastic products | 0.848 |

Except primary energy sources, sectors 10 (thermal and self-power generation), 33 (other nonmetallic mineral products) and 87 (transportation, warehousing-p) were characterized by the largest ratios of direct to total energy intensity in each group, 53.4%, 51.9% and 35.1%, respectively, as shown in Figure 3.4. This ratio close to 100% means that direct intensity accounted for almost all of the total intensity because of small indirect intensity. In other words, latent impacts of a unit change in final demand can be observed from the direct changes in the sector easily. In contrast, the ratio close to 0% means that contribution of indirect energy intensity is quite significant.

The effect of the increase in direct consumption is extremely smaller than that of the increase in total energy consumption in sectors 35 (primary iron and steel product) and 77 (computer and office equipment), which had very small consumption ratios of 6.3% and 2.8%, respectively. The consumption ratios of sectors 2 (crude petroleum), 3 (natural gas), and 14 (wood) in the energy group were 0% because the raw materials in these sectors were imported completely from overseas.

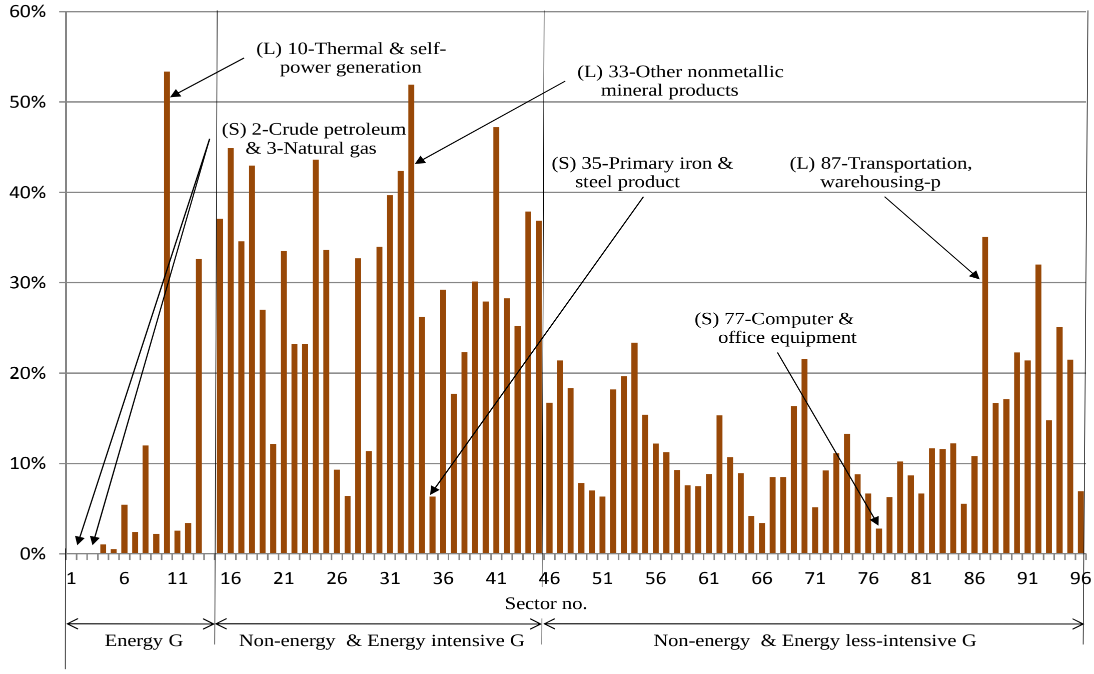


**Figure 3.4 Ratio of direct to total energy intensity.**

The ratio representing direct to total is important. Within each group, sector with the largest and the smallest ratio is marked (L) and (S) respectively. National energy policy maker should pay more attention to the behavior of (S) rather than (L). Because, even smaller ratio sectors do not reveal their energy consumption in conventional analysis but the sectors induce much more energy consumption of other sectors than larger one.

### 3.4.1.2 Energy intensity by energy source

The direct energy intensity and embodied energy intensity for each energy source in each group are shown in Figures 3.5 and 3.6, respectively

In the energy group, the consumption of coal (34.8%) and crude petroleum (27.3%) was the highest in terms of direct energy use; the consumption of coal (18.4%), crude petroleum (17.0%), and natural gas (11.7%) was the highest in terms of total energy use. In the energy-intensive group, the consumption of fuel oil (37.5%) and naphtha (16.5%) accounted for 54.0% of direct energy use, while the consumption of crude petroleum (24.6%) and fuel oil (18.3%) accounted for 43% of total energy use. Lastly, in the less energy-intensive group, the consumption of fuel oil (55.0%) and thermal and self-power generation (12.5%) accounted for 67.4% of direct energy use, and the consumption of crude petroleum (28.0%) and fuel oil (20.0%) contributed to 48.1% of total energy use.

In terms of direct energy use, the most frequently used energy source was found to be coal for the energy group and fuel oil for the non-energy group. On the other hand, there seems to be no predominantly used energy source in total energy use; however, the consumption of crude petroleum appears to make a significant contribution to the total energy use.

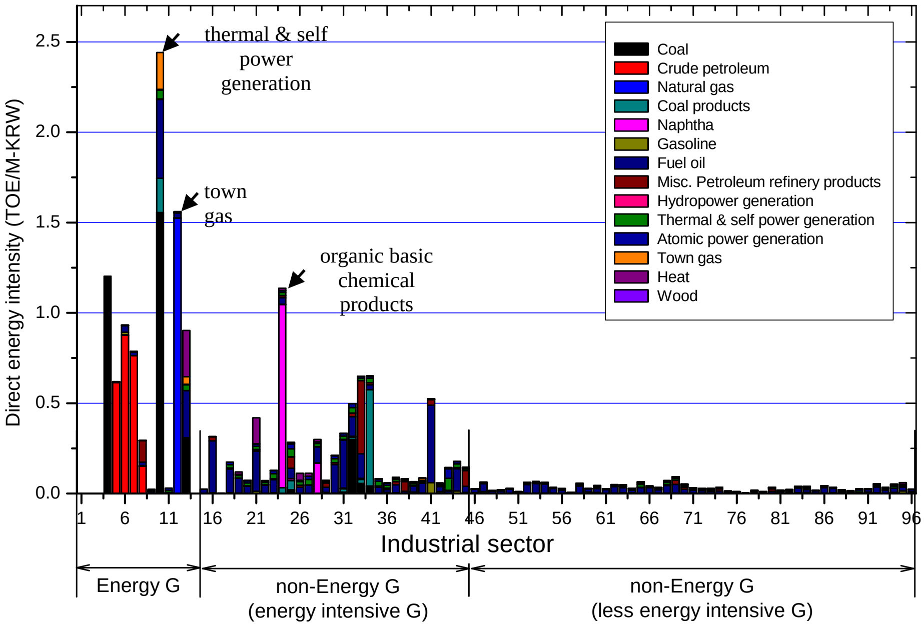


**Figure 3.5 Sectoral direct energy intensity by 14 energy sources.**

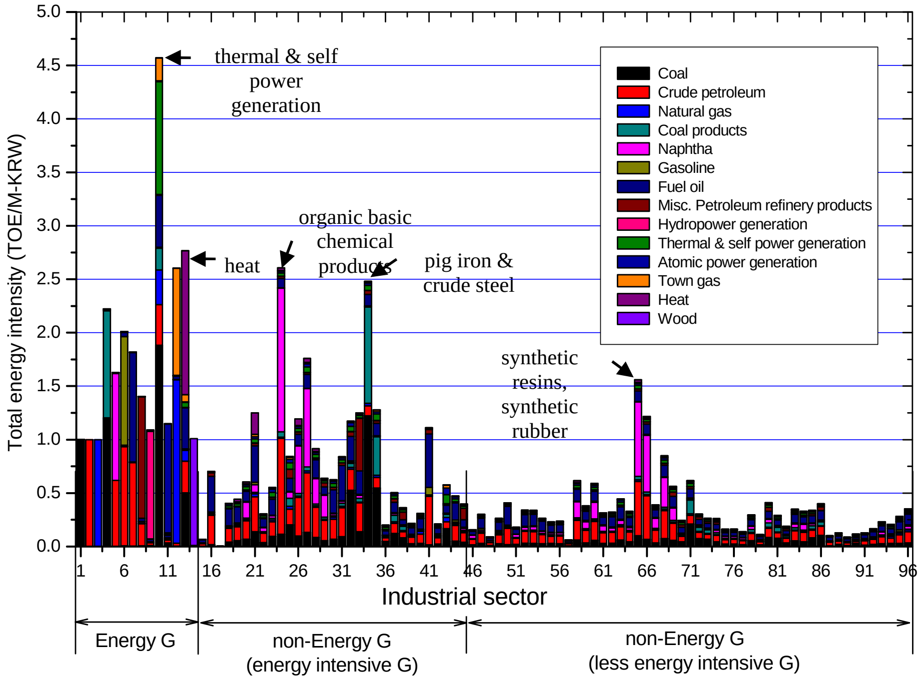


**Figure 3.6 Sectoral embodied energy intensity by 14 energy sources.**

### 3.4.2 GHG emission intensity analysis

#### 3.4.2.1 GHG emission intensity by industrial sector

The average ratios of direct GHG emission intensity to total emission intensity for the energy group, energy intensive group, and less energy intensive group were found to be 12.4%, 23.9%, and 10.7%, respectively.

The sectors with the largest direct GHG emission intensities in the energy group, energy intensive group, and less energy intensive group were sectors 10 (thermal and self-power generation; 8.611 t-$CO_2$-eq./M-KRW), 34 (pig iron and crude steel; 2.518 t-$CO_2$-eq./M-KRW), and 69 (rubber products; 0.176 t-$CO_2$-eq./M-KRW), respectively. The sectors with the largest embodied GHG emission in terms of total emission intensity in the energy group, energy intensive group, and less energy intensive group were sectors 10 (thermal and self power generation; 11.717 t-$CO_2$-eq./M-KRW), 34 (pig iron and crude steel; 9.007 t-$CO_2$-eq./M-KRW), and 65 (synthetic resins and synthetic rubber-p; 2.955 t-$CO_2$-eq./M-KRW), respectively, as shown in Figure 3.7.

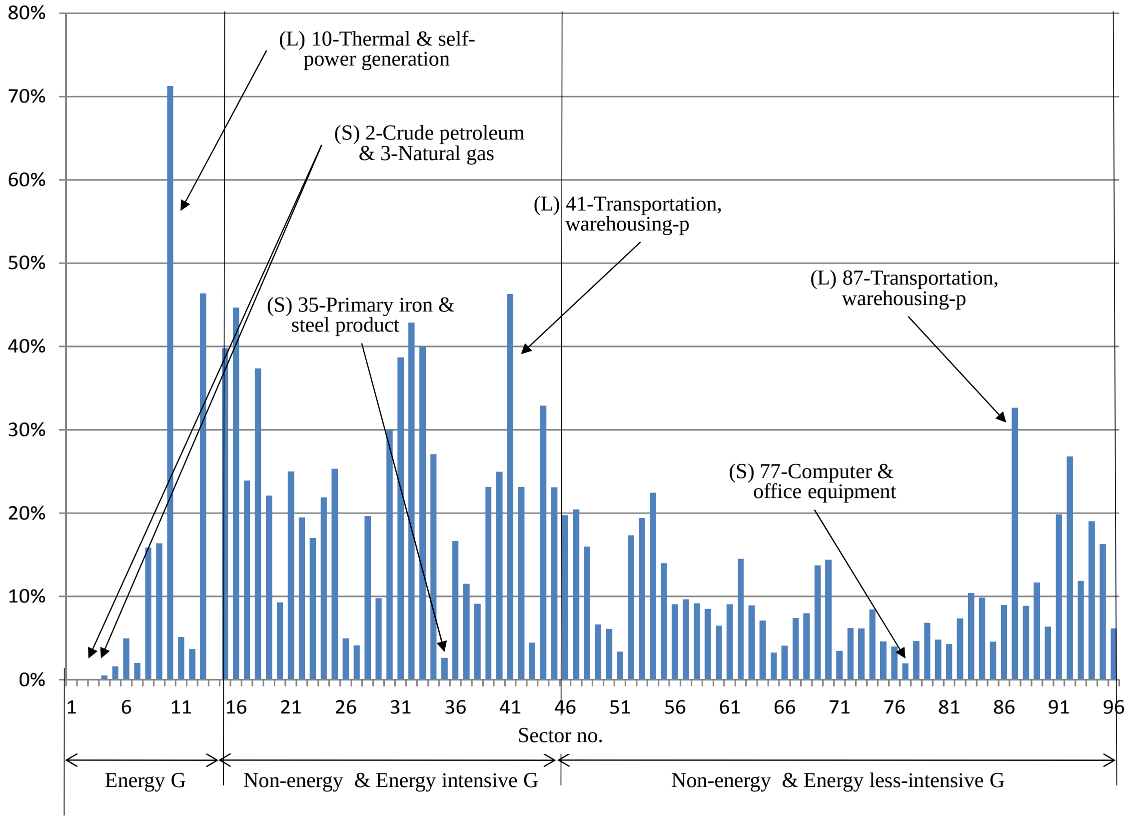


**Figure 3.7 Ratio of direct to total GHG emissions intensity.**

Figure 3.7 suggests that a policy for GHG emission reduction or control based on only the direct emissions or measurements from the end of pipe would be less effective. Therefore, it is very important to consider total emissions before framing a policy for GHG emission control. Especially considering total emission is more important in the strategic point of view. Because sectors such as sector 35(Primary iron & steel product) in energy intensive group and sector

77(Computer & office equipment) in energy less-intensive group, imply that they induce much more GHG emission than that sectors displayed longer blue bar.

By using the E-IO table, the direct and total GHG emissions caused by energy consumption in Korea in 2000 were found to be 512 Mt-$CO_2$-eq. and 1,378 Mt-$CO_2$-eq., respectively. The emissions from the energy group, energy intensive group, less energy intensive group, and final demand group were 61.0%, 22.4%, 0.5%, and 16.1% of the total emission, respectively. Table 3.5 shows direct and total emissions from 3 GHG materials for all groups. Since only the direct emissions can be calculated in the final demand group, indirect emissions are not included in the total emission of this group. The ratios of total to direct emission for the energy group, energy intensive group, and less energy intensive group were 280.9%, 342.6%, and 1,097.1%, respectively.

**Table 3.5 Estimation of GHG emissions in 2000**

| GHG emissions | $CO_2$ (kt-$CO_2$) | | $CH_4$ (kt-$CH_4$) | | $N_2O$ (kt-$N_2O$) | | Total (kt-$CO_2$-eq.) | |
|---|---|---|---|---|---|---|---|---|
| | Direct | Total | Direct | Total | Direct | Total | Direct | Total |
| Energy group | 310,749 | 873,316 | 6 | 27 | 4 | 10 | 312,182 | 876,958 |
| Non-energy groups | 116,118 | 416,433 | 14 | 41 | 2 | 6 | 117,036 | 419,056 |
| Final demand group | 81,826 | 81,826 | 15 | 15 | 0.6 | 0.6 | 82,339 | 82,339 |
| Total | 508,693 | 1,371,575 | 35 | 84 | 7 | 16 | 511,556 | 1,378,352 |

Remarks: Those in parenthesis under GHG represent their own unit

The values of the GHG emissions estimated in this study were compared with those obtained by KEEI [35] for the energy sector. (The KEEI report is regarded as an official national communication report in Korea.) The $CO_2$ and $N_2O$ emissions were overestimated by 16% and 137%, respectively, in our study, while $CH_4$ was underestimated by approximately 19%, as shown in Table 3.6.

The difference was considered to be within acceptable limits because of the following two reasons. Firstly, GHG emission, especially $N_2O$ emission is not yet fully understood in Korea and the national statistical data has great uncertainty. Secondly, the inherent limitations of the IO analysis, such as price distortion in unit conversion, aggregation error in setting sectors up, and missing necessary item in a sector, were found to persist in the E-IO analysis, too.

**Table 3.6 Comparison of GHG emissions in 2000 with the National Communication Report**

| Emissions | Direct | | | Total | | |
|---|---|---|---|---|---|---|
| GHG | $CO_2$ | $CH_4$ | $N_2O$ | $CO_2$ | $CH_4$ | $N_2O$ |
| Unit | kt-$CO_2$ | t-$CH_4$ | t-$N_2O$ | kt-$CO_2$ | t-$CH_4$ | t-$N_2O$ |
| E-IO(2008) (a) | 508,693 | 35,499 | 6,832 | 1,371,575 | 83,564 | 16,201 |
| Energy sector in National statistic(2003) (b) | 438,537 | 43,714 | 2,884 | NA | NA | NA |
| Comparison (a/b) | 116% | 81% | 237% | | | |

### 3.4.2.2 Sectoral GHG emission factor estimation by GHG species

The emission factor $EF_j$, which is the amount of GHG emission of the sector $j$ per consumed energy, can be calculated by

$$EF_j = \frac{\sum_{i=1}^{14}(E_{i,j} \times M_{i,j})}{\sum_{i=1}^{14} E_{i,j}}, \text{ for } \quad j = 1, 2, 3, \cdots, 96 \qquad (3.11)$$

where $E_{i,j}$ and $M_{i,j}$ represent energy consumption and the GHG emission factor pertaining to energy source $i$ in sector $j$, respectively.

Note that the total calculated emission consisted of $CO_2$, $CH_4$, and $N_2O$ emissions only.

The results of the analysis showed that the highest $CO_2$, $CH_4$, and $N_2O$ emissions were from sectors 10 (thermal and self-power generation; 3.407 t-$CO_2$/TOE), 13 (heat; 0.116 kg-$CH_4$/TOE), and 10 (thermal & self-power generation; 0.047 kg-$N_2O$/TOE), respectively, in the energy group. In the energy intensive group, sectors 34 (pig iron and crude steel; 3.722) and 32 (cement and concrete products; 3.047) had the highest $CO_2$ emission factors. In contrast, sector 43 (gas and water supply; 0.410) and 24 (organic basic chemical products; 0.895) had the lowest $CO_2$ emission factors in this group. Further, sectors 41 (transportation and warehousing-p; 0.471) and 15 (crops-p; 0.416) had the highest $CH_4$ emission factors, while sectors 35 (primary iron and steel products; 0.052) and 43 (gas and water supply; 0.054) had the lowest. Sectors 34 (pig iron & crude steel; 0.053) and 32 (cement & concrete products; 0.044) had the highest $N_2O$ emission factors, whereas sectors 43 (gas and water supply; 0.003) and 35 (primary iron and steel products; 0.014) had the lowest. Finally, in the less energy intensive group, sectors 46 (crops-p; 2.890) and 59 (apparel and accessories; 2.626) had the highest $CO_2$ emission factors. On the other hand, sectors 90 (real estate agencies and rental; 0.691) and 75 (electronic components and accessories; 1.243) had the lowest $CO_2$ emission factors. Furthermore, sector 46 (crops-p; 2.073) had a distinctively high $CH_4$ emission factor, while sectors 51 (polished grains, flour and milled cereals; 0.040) and 75 (electronic components and accessories; 0.057) had low $CH_4$ emission factors. Sectors 46 (crops-2p; 0.033) and 47 (livestock breeding; 0.029) had the highest $N_2O$ emission factors, and sector 90 (real estate agencies and rental; 0.005) had the lowest $N_2O$ emission factor, as shown in Figure 3.8.

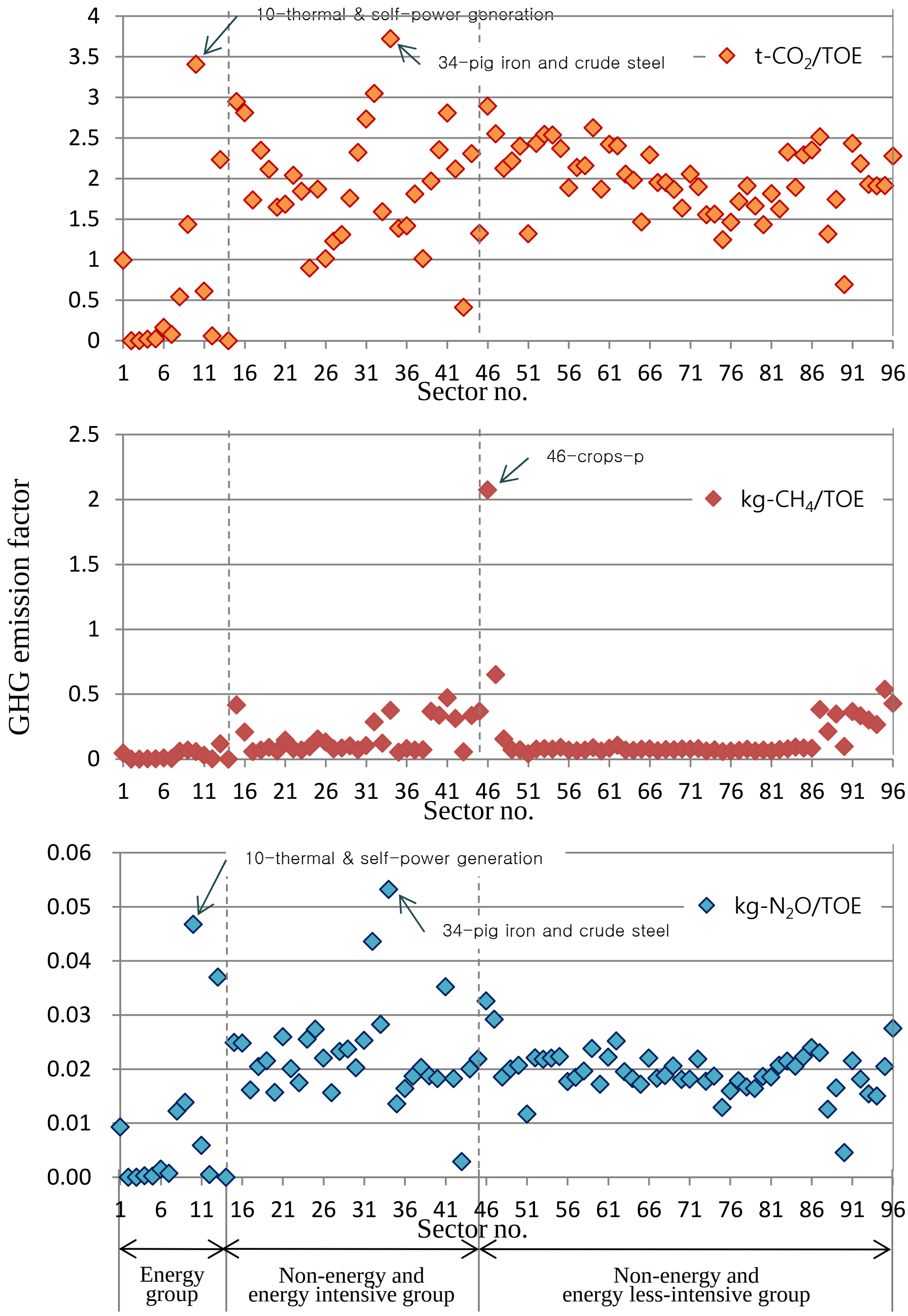


**Figure 3.8 GHG emission factors of 96 sectors.**

### 3.4.3 A concise representation of the results

In the case of direct energy use, the average values of direct energy intensity and GHG emission intensity of the 96 economic sectors were 0.186 TOE/M-KRW and 0.315 t-$CO_2$-eq./M-KRW, respectively. In the case of total energy use, the average values of total (or embodied) energy intensity and GHG emission intensity were estimated to be 0.640 TOE/M-KRW and 1.534 t-$CO_2$-eq./M-KRW, respectively.

Figures 3.9 and 3.10 show the relationship between energy intensity and GHG emission intensity for direct and total energy use, respectively. In Figures 3.9 and 3.10, the regression lines are plotted and the slopes indicate $CO_2$ elasticity of energy which is smaller than unity. If a sector is above the regression line in Figure 3.9 (for example, sector 34), its actual $CO_2$ emission factor will be larger than that predicted by the regression model, and the measures to reduce $CO_2$ emissions must be taken. Further, the average energy use and GHG emission intensities for all industrial sectors in 2000 are used as the origins of the coordinate system shown in these figures. The energy intensity of a sector that lies to the right of the ordinate axes is higher than the average value. On the other hand, the energy intensity of a sector that lies to the left of the ordinate axes is lower than the average value.

GHG emissions are in proportion to energy use in sectors that are located in quadrants I and III in Figures 3.9 and 3.10. Sectors with lower energy intensities but higher GHG emission intensities than the average are located in quadrant II. Such sectors are typically characterized by industries that use processes that are not eco-friendly in terms of energy use or carry out combustion process on a large scale. On the other hand, sectors with higher energy intensities but with lower GHG emission intensities than the average are located in quadrant IV. The sectors employ low GHG emitting energy use or employ combustion technology but consume much more energy than the other sectors. None of the sectors in non-energy group are located in quadrants II and IV.

Most sectors are located in quadrants I or III. Further, in Figures 3.9 and 3.10, the sectors largely remain in the same quadrants. However, some sectors showed a significant change. For example, sector 35 (primary iron and steel products) that is located in quadrant III in Figure 3.9 is located in quadrant I in Figure 3.10. Since this sector depends heavily upon coal or coal products which owe much energy and $CO_2$ at the indirect process, the embodied energy pertaining to this sector increases drastically. On the other hand, sectors 9 (hydropower generation) and 11 (atomic power generation) are below the regression line but are located in quadrant III in Figure 3.9 and quadrant IV in Figure 3.10. As these industries indulged in more indirect energy use, they are shifted to the right from quadrant III in Figure 3.9 to quadrant IV in Figure 3.10; further, because of their low dependence on fossil energy sources such as coal, crude petroleum, and coal products, these sectors remain below the horizontal average line for GHG emission intensity in Figure 3.10. The difference in the change of position of sectors 9 (hydropower generation) and 11 (atomic power generation) in Figure 3.10 can be explained by the fact that sector 11 uses more coal than sector 9.

The E-IO analysis provided not only speculative information on the total energy use and GHG emission but also some detailed practical information about each sector.

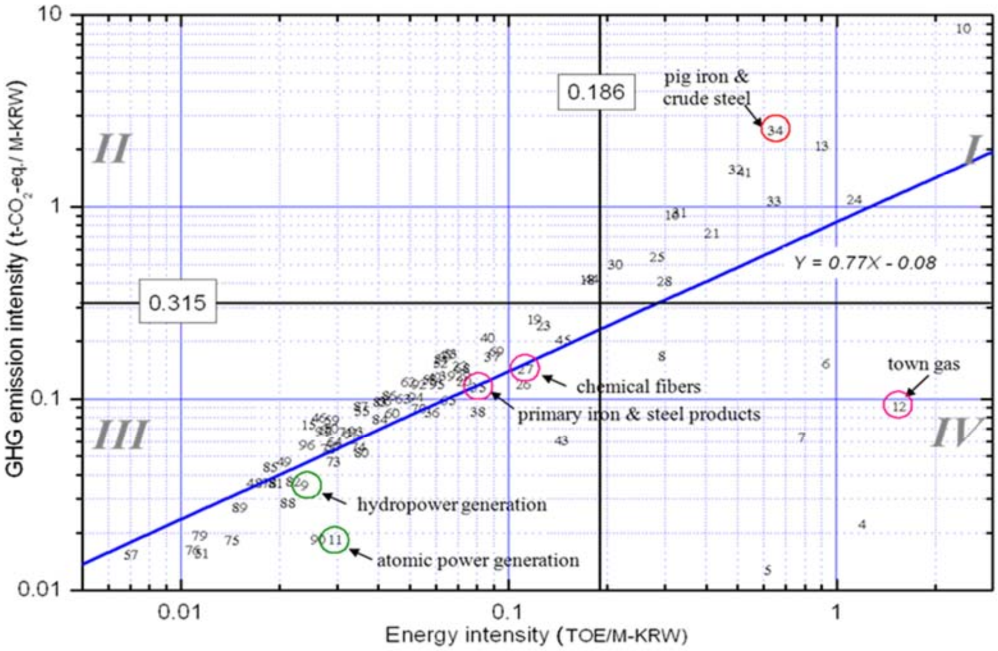


**Figure 3.9 Distribution of 96 sectors from direct energy use.**

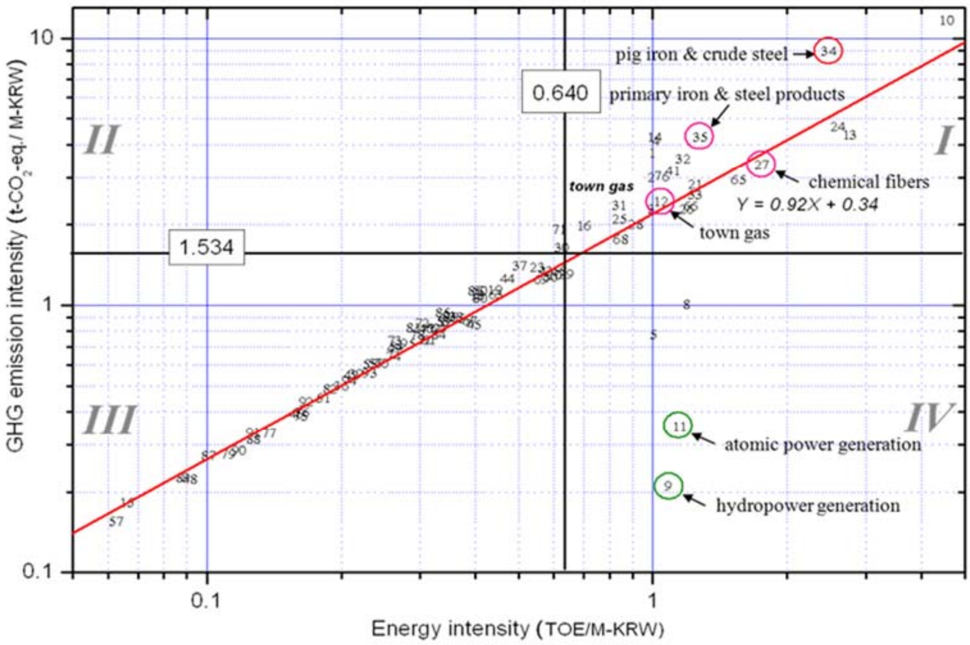


**Figure 3.10 Distribution of 96 sectors from embodied energy use.**

Korea's efforts to prevent the climate change in energy use are often planned based on the projection of 96 industries, plotted in Figures 3.9 and 3.10, onto the X, Y axis. It means that industrial policies are formulated by analyzing the characteristics of energy or GHG emission in a separate manner. This is equivalent to analyzing the industry in a one-dimensional straight line. However, in order for Korea's energy and environment countermeasure not to slow down the economic activity as well as achieve GHG reduction, both GHG emission and energy use characteristics of 96 industries must be taken into consideration at the same time. Moreover, each industry must be understood in a two-dimensional plane.

## 3.5 Conclusion

E-IO analysis was performed for 96 aggregated sectors including 14 energy sources and the energy intensities as well as GHG emission intensities of all the sectors were calculated.

We have elucidated the structure of energy use and GHG emission in each industrial sector in Korea. Sectors 27 (chemical fibers) and 35 (primary iron and steel products) were characterized by relatively low levels of both energy use and GHG emission intensity; however, in these sectors the induced effect of energy intensity and GHG emission intensity was observed to be higher than the direct effect. Therefore, sectors similar to sectors 27 and 35 can be regarded as superior to the rest in terms of direct emission intensity but inferior in terms of embodied emission intensity. In the energy group, sectors 9 (hydropower generation) and 11 (atomic power generation) are inferior to the rest of the sectors in terms of embodied energy intensity but are superior in terms of GHG emission intensity. Sector 12 (town gas) is inferior in terms of GHG emission intensity and is also characterized by a high embodied energy intensity.

The E-IO analysis used in this study has the following advantages and disadvantages compared to conventional IO analysis. The advantages are:

- Improvement in data accuracy: To employ conventional IO, it is necessary to collect reliable $x_{i,j}$ which is monetary amount of transaction. Each price that constitutes the amount of transaction already reflects the desire of market participants so it is vulnerable to market distortion. However, if IO table consisting of amount of physical units from the start, such distortion can be removed as prices are generally excluded.
- Easier to data handling: E-IO table excludes variations in space and time associated with prices and only sums up physical amount of usage so it is easier to data mining and manipulating the amount of energy use.
- Excellent use of policy application: The results of E-IO analysis appear in the form of energy and environment units so they can be easily understood for policy makers in this field.

Despite these advantages, the disadvantages of E-IO usually occur when estimating the E-IO table based on the conventional IO tables. The main disadvantages are:

- Drop in the accuracy of data: If E-IO table is formulated based on conventional IO after some time has passed, reliable energy prices, which are vulnerable to variations in time and sector, hard to get accurately analyzed. Hence such E-IO table will be fundamentally limited in terms of accuracy.

- Possibility of dispute over the validity of applied price as a proper representation: If same price is used for energy prices when estimating the amount of material (e.g., average price or midyear price), the value obtained can be represented statistically but not economically.

Nonetheless, E-IO can be precisely mapping to conventional IO if accurate energy price is analyzed and both can be converted to each other as illustrated in Chung [36].

Notwithstanding the merits of the E-IO analysis, our estimates are different from the values reported in the official national reports. The reason for this discrepancy needs to be studied further.

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# Chapter 4. A Time-series Energy Input-Output Analysis of Energy Use and Associated GHG Emissions in Korea

A time-series energy input-output analysis for building an infrastructure for the energy and environment policy in Korea, *Energy and Environment*, 2009;20(6): pp875-899

E-IO table in 2000 has been created in chapter 3. In this chapter, four sequential 96×96 hybrid units E-IO tables at five-year intervals from 1985 to 2000 are created based on the same methodology. Using these four sequential matrices, the energy intensities and the GHG emission intensities, caused by energy use, are estimated for each sector. Some recommendations are made to improve this model.

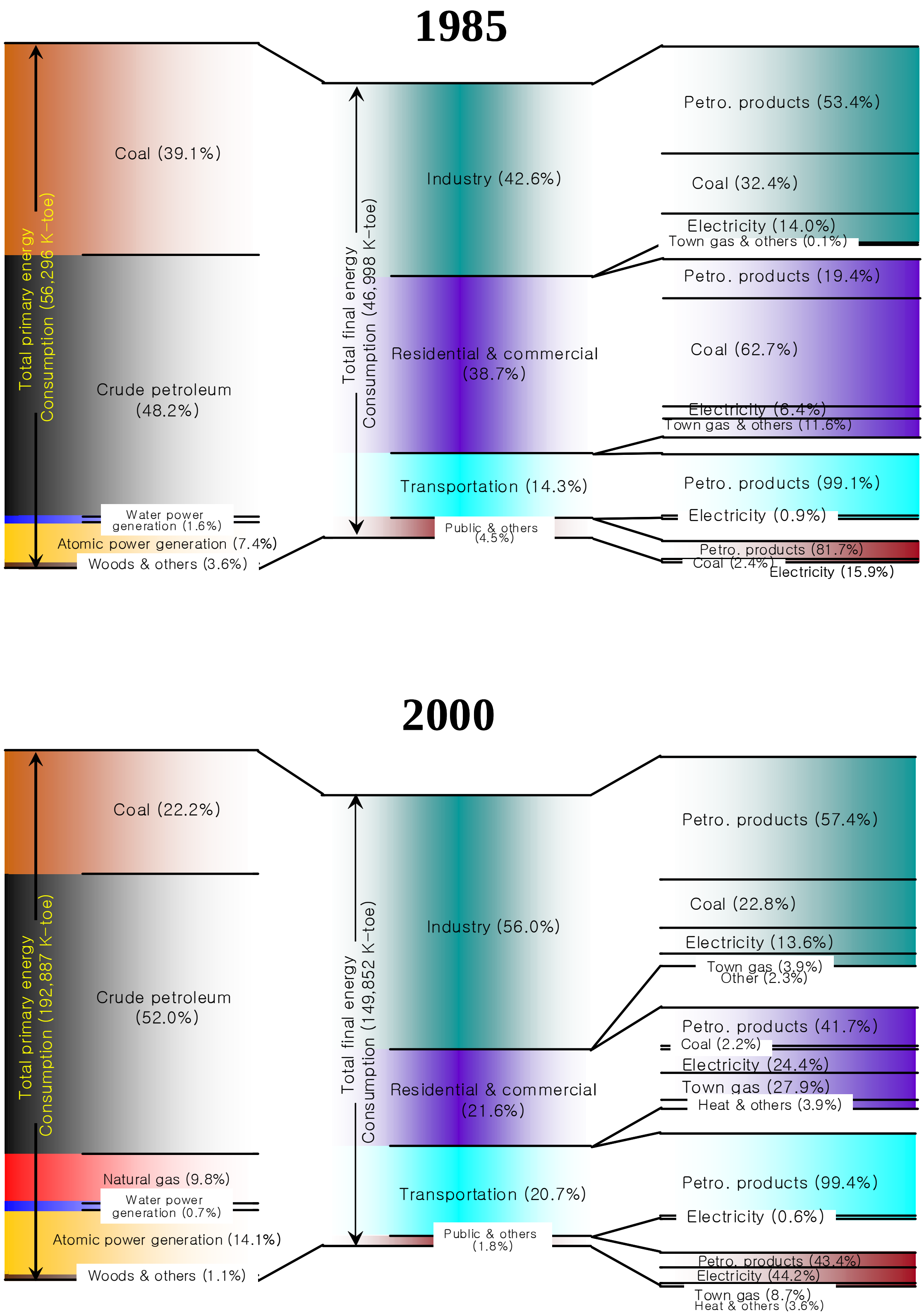
## 4.1 Introduction

### 4.1.1 Energy consumptions in Korea

Even after the Asian financial crisis in 1997–1998, which hit Korea particularly hard, Korea's primary energy consumption more than tripled during 1985–2000, i.e., from 54.7 million TOE in 1985 to 191.2 million TOE in 2000 [1]. This amounted to an average annual growth rate (AAGR) of 8.6% in primary energy consumption during that period. With regard to the energy source, the consumption of high carbon containing coal and oil changed from 40.3% to 49.6% in 1985 and from 22.4% to 52.5% in 2000 from their share of total primary energy consumption. In contrast, the shares of low carbon containing gas and renewable energies, including atomic and hydro power, increased from 0.0% to 10.1% in 1985 and from 9.9 % to 15.1% in 2000, respectively.

With regard to the energy type of the final energy consumption, petroleum products made up the largest share for each user group. Coal is the second most prevalent energy source, although its usage remained relatively static between 1985 and 2000 because the consumption of more environment-friendly town gas and carbon-free electricity increased, as shown in Figure 4.1.

According to KEEI [2], Korea's GHG emissions have increased gradually from 247.7 million tons of carbon dioxide (Mt-$CO_2$) in 1990 to 498.6 Mt-$CO_2$ in 2005, in the energy sector. Further, its share also increased from 81.1% in 1990 to 83.6% in 2005.




Source) Yearbook of energy statistics, KEEI, 1999 and 2006

**Figure 4.1 Korea's energy flow in 1985 and 2000.**

### 4.1.2 Greenhouse gas emissions in Korea

Korea's GHG emissions amounted to an AAGR of 4.8% in the energy sector during 1990–2005. Over this period, the GHG emissions from the energy industries and transport sectors increased by 10.6% and 5.8% per annum, respectively. However, the rate of GHG emissions has decreased for the energy industries (3.1%), manufacturing & construction industries (0.4%), and transport industries (1.2%) from 2000 until 2005 when compared with the entire period. (Table 4.1)

**Table 4.1 GHG emissions in Korea (Mt-$CO_2$ eq)**

| | 1990 | 1995 | 2000 | 2005 | AAGR (%) | |
|---|---|---|---|---|---|---|
| | | | | | 1990–2005 | 2000–2005 |
| From energy | 247.7 | 372.1 | 438.5 | 498.6 | 4.8 | 1.3 |
| 1) energy combustion | | | | | | |
| a. energy industries | 38.0 | 83.2 | 125.9 | 171.1 | 10.6 | 3.1 |
| b. manuf. & const. | 82.0 | 124.2 | 141.8 | 148.2 | 4.0 | 0.4 |
| c. transport | 42.4 | 77.2 | 87.1 | 98.2 | 5.8 | 1.2 |
| d. others | 79.9 | 84.3 | 79.3 | 75.2 | –0.4 | –0.5 |
| subtotal | 242.3 | 368.9 | 434.1 | 492.7 | 4.8 | 1.3 |
| 2) fugitive emissions | | | | | | |
| a. coal | 4.8 | 1.6 | 1.2 | 0.8 | –11.3 | –4.0 |
| b. oil & natural gas | 0.6 | 1.6 | 3.2 | 5.1 | 15.3 | 4.8 |
| subtotal | 5.4 | 3.2 | 4.4 | 5.9 | 0.6 | 3.0 |
| From non-energy | 26.0 | 58.6 | 51.9 | 59.6 | 5.7 | 1.4 |
| National total | 273.7 | 430.7 | 490.4 | 558.2 | 4.9 | 1.3 |

Remarks: The figures are amended in the latest version.
Source: http://www.gihoo.or.kr/portal/01_General_Info/04_ST01_02.jsp.

According to WRI [3], Korea ranked 1st in the world for its GHG emissions growth rate during 1990–2002. Further, for the percentile changes in non-$CO_2$ GHG emissions during the same period, Korea ranked 2nd in the world with a growth rate of 49%. As of 2000, only Saudi Arabia, the largest petroleum exporting country, emitted more non-$CO_2$ GHGs than Korea in the world.

Korea is a non-Annex I country under the Kyoto Protocol and thus is not committed to reducing its GHG emissions. Nevertheless, Korea has devoted its efforts to reduce its GHG emissions. For instance, the Presidential Commission on Sustainable Development of the Republic of Korea has issued a report, "National strategy for sustainable development of the Republic of Korea, 2006~2010," in October 2006, in which the major goals in energy and global environmental conservation area are proclaimed as follows:

- Improve the stable energy provision
- Convert into a low energy-consumption economy
- Build an environment-friendly energy supply system

- Upgrade energy technology and an R&D system
- Build a foundation for implementing agreements
- Carry out GHG reduction project for important sector
- Establish a foundation that adapts to climate change

The various policy action items that have been executed until now were insufficient to substantially reduce the GHG emissions from Korea's energy use. The Annex I countries no longer exempt Korea from GHG emissions policy. In order to prevent an international paradigm such as a post-Kyoto Regime, Korea must launch specific action items. Currently, Korea having a 4% GHG emissions reduction target by 2020 from a 2005 baseline is eager to substitute the policies that were based on a rule of thumb as well as social distortion and search for effective and efficient policies.

For the first step to establish an efficient policy in energy conservation and mitigating GHG emissions, it is important to understand the interrelations among economic activities, energy use, and GHG emissions in Korea. Furthermore time-series analysis of economy, energy and GHG emission data is useful to determine how the trends were changed and what factors impacted.

For such purposes, a time series E-IO analysis was conducted on the basis of monetary input-output (IO) tables from 1985 to 2000 in Korea. Through E-IO analysis, the interrelations among economy, energy, and GHG emissions were analyzed. It is to be noted that the IO tables used in this study were issued by the BOK. The benchmark IO table of 2000 was the newest one in Korea at the submission stage to the journal of Energy and Environment.

## 4.2 Preceding study review

There are many studies in the world regarding an energy analysis and/or an environmental analysis with an IO approach. Previous studies of energy or environmental IO analysis have already been reviewed in chapter 1 and the studies are summarized in Table 1.6.

### 4.2.1 Composition of the E-IO table

#### 4.2.1.1 Composition of the E-IO table with hybrid units

The E-IO tables were composed on the basis of the corresponding IO table issued by the BOK every five years. In the E-IO table, energy sectors are expressed in units of a ton of oil equivalent (TOE), while the other sectors follow the conventional IO table approach and are expressed in monetary units (Korean Won, KRW). Therefore, if viewed column-wise, the table consists of values with different units, i.e., TOE and KRW, while row-wise the values are of the same unit. Therefore, for the energy sectors, the row values show the energy distribution structure for each sector and their sum equals the total output of the corresponding energy sector. Meanwhile, for the non-energy sectors, the row values signify the distribution structure of the total output. Detailed composition was described in chapter 3.

#### 4.2.1.2 Expansion to linked E-IO tables

To create linked E-IO tables, each year's E-IO table, which is based on the current price, must be converted so that it is based on the constant price. The target of conversion should be the monetary amount reflected in the transactions between industrial sectors and their final demand. The rows already substituted by energy units do not go through any conversion. In the case of BOK, in order to create linked IO tables, the constant price is not computed by converting the current value added for each cell, but instead the double deflation method is used for constant price with respect to the total value added. This research used the method of BOK. Double deflation is a useful method in calculation of real GDP, which deflates nominal price of intermediate transactions and output using proper price index and subtract real intermediate input from real output. The method has been applied in the system of national accounts of 1993 (SNA 93).

### 4.2.2 Validation of the composed E-IO table

#### 4.2.2.1 Appropriateness of the energy data

Energy statistics in Korea are composed by the Korea Energy Economy Institute (KEEI). The E-IO table must be composed on the basis of professional statistics on energy. This study, however, composed energy quantity data on the basis of annual average price data issued by the BOK because the statistics, the classification standard of the sectors, and the aggregated items presented in the energy balance sheets included in the Energy Statistics 2000 issued by KEEI and BOK are not consistent.

This study composed quantity data of the energy sources by the following steps:

1) Calculate unit prices for each energy source from the supplementary table in the IO table from the BOK
2) In the case of many energy products in one sector (e.g., oil products include various kinds of lubricants and refined petroleum products), a weighted average was considered as a unit price
3) Convert various kinds of energy units (e.g., metric ton for primary coal, kilo liters for gasoline, and barrel for crude petroleum) into TOE
4) Calculate the total energy used from the original transaction matrix

This approach is comparatively accurate because it uses averaged national values for the energy sources when the sectoral price variation of the energy sources is small. However, when the sectoral price variation of the energy sources is large, this approach is not accurate. The sectoral price variation for an energy source except electricity was small at the corresponding year in Korea [1].

In this study, each sector was aggregated into three groups which have similar energy consumption behavior. The grouping was necessary in order to maximize utilization of results for the energy and GHG policy. Table 4.2 shows the aggregated results of the differences between the energy consumption data calculated by this study (E-IO) and the data from the census of the national energy statistics as compared to the primary energy consumption by KEEI.

**Table 4.2 Comparison of the primary energy consumption**

(unit: M-TOE)

| Energy source | 1985 | | | 1990 | | | 1995 | | | 2000 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | E-IO | KEEI | % | E-IO | KEEI | % | E-IO | KEEI | % | E-IO | KEEI | % |
| *Coal* | *23.0* | *22.0* | *105* | *23.5* | *24.4* | *96* | *31.9* | *28.1* | *114* | *43.9* | *42.9* | *102* |
| Crude petroleum | 27.7 | 27.1 | 102 | 42.0 | 50.2 | 84 | 85.5 | 94.0 | 91 | 121.9 | 100.3 | 122 |
| Natural gas | 0 | 0 | - | 2.9 | 3.0 | 96 | 8.8 | 9.2 | 95 | 19.8 | 18.9 | 105 |
| Water power generation | 0.3 | 0.9 | 34 | 0.5 | 1.6 | 34 | 0.5 | 1.4 | 34 | 0.5 | 1.4 | 35 |
| Thermal & self-power generation | 3.6 | 8.6. | 43 | 5.0 | 11.4 | 44 | 10.5 | 24.7 | 43 | 14.5 | 32.3 | 45 |
| Atomic power generation | 1.4 | 4.2 | 34 | 4.4 | 13.2 | 34 | 5.8 | 16.8 | 34 | 9.4 | 27.2 | 34 |

As shown in Table 4.2, the values in the E-IO and energy balance sheet of KEEI are not always acceptable. The differences are mainly from the following two reasons.

First, they have a fundamental difference for aggregating accounts. For example, the energy balance sheet of the KEEI includes transformation, stock change, and exports but excludes international bunkers. The E-IO includes these items; if these accounts are eliminated from the E-IO, the original differences could reduce as described in chapter 3.

Next, the aggregated standards are different. For example, errors are generated in the power generation technologies because the KEEI’s values were surveyed on the basis of an energy input to a power station, but the E-IO's values were aggregated by electricity produced by power stations. Because of these reasons, energy consumption data, used as a power sector among the 14 energy sources in the E-IO table, are expressed as energy input to generated electricity. Therefore, thermal power reveals a 43-45% error and water and atomic energy reveal 34-35% errors, which are nearly equal to power generation efficiency.

Additionally, this study assumed the use of only wood energy and so it must separate the consumption data from renewable energies in the KEEI statistics. This study, however, did not include wood energy because of lack of reliable data for wood consumption as primary energy.

#### 4.2.2.2 Confirmation of the necessary conditions

The E-IO tables from 1985 to 2000 used in this study were verified to satisfy the following two conditions.

- In terms of an energy balance, the total primary energy intensity of a product should be equal to the total secondary energy intensity of the product plus the amount of energy lost in energy conversion. This signifies that it should satisfy the energy conservation condition.

- In terms of linear algebra, conditions ensuring a non-negativity of the total outputs computed in the Leontief inverse matrix and producibility in economics. This signifies that it should satisfy the Hawkins-Simon (H-S) condition [28].

Among these, the energy conservation condition can usually be compensated by the laws of thermodynamics. Since the power generation sector has a thermal efficiency of 45% in the case of thermal & self-power generation and a thermal efficiency of 35% in the case of atomic power generation, their energy loss can be compensated artificially applying the energy concept in an E-IO table. However, this study did not have to compensate because the original IO table announced by BOK had been composed based on transaction amount of electricity not based on energy input.

Next, Miller and Blair [7] introduced an H-S condition to obtain a non-negative solution in a Leontief model, so that a non-negative output will result from a given non-negative final demand. This condition was checked in this study by the following steps:

- For the **(I-A*)** coefficients matrix to satisfy the H-S conditions, it can be checked by the following two steps. First, all the diagonal elements of the matrix must be positive and all the non-diagonal elements of the matrix must meet a precondition, which is non-positive. The E-IO table from 1985 to 2000 used in this study satisfies the precondition.

- Next, the results of the calculation of the determinants values for all the leading principle sub-matrices of the **(I-A*)** for each table showed that all the minors were positive, which means all the **(I-A*)** matrices composed in this study satisfy the H-S condition.

- Therefore, the Leontief inverse matrix, $\mathbf{(I-A^*)^{-1}}$, was found to satisfy the H-S conditions, as well.

### 4.2.3 Selection of the GHGs

As described in chapter 3, we have selected three GHGs of carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$), which cause a direct greenhouse effect in IPCC (1996). The emission coefficients for these compounds are calculated by considering the average calorific values of 14 energy sources used in Korea. GHG emissions from each sector were determined by the same procedures in chapter 3.

## 4.3 Methodology

### 4.3.1 E-IO analysis procedure

An estimation of the energy and GHG emissions intensities from energy use with an E-IO analysis has a few differences when compared to using a conventional IO analysis. Generally, the analysis begins with three components. (Figure 4.2)

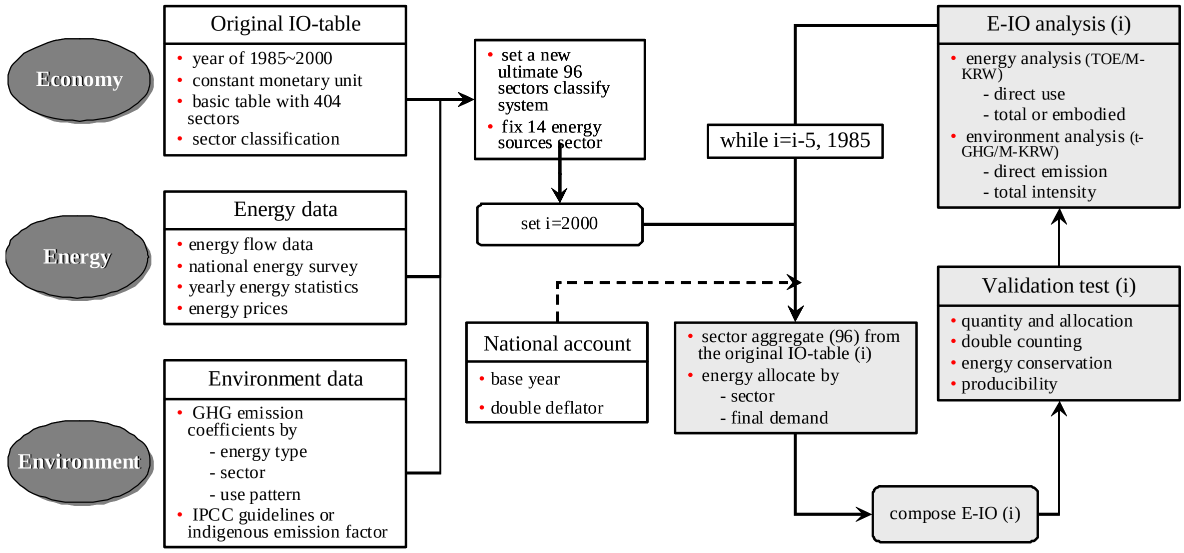



**Figure 4.2 Process of time-series E-IO analysis.**

The method for obtaining an energy intensity and GHG emissions intensity through an E-IO table was already presented in detail in chapter 3. Hereafter the computation procedure is summarized.

The input coefficient matrix consists of four elements of heterogeneous characteristics, as shown in Eq. (4.1).

$$A^* = Z^* (\widehat{X^*})^{-1} = \begin{bmatrix} {}^{toe}/_{toe} & {}^{toe}/_{\$} \\ {}^{\$}/_{toe} & {}^{\$}/_{\$} \end{bmatrix} \qquad (4.1)$$

Here, **Z*** is a new transaction matrix because *k* energy sectors in a conventional input-output table has changed row-wise from monetary price to energy unit. **X*** represents a total output vector that is mixed with monetary units and energy units according to sectors as well. The hat (^) that is shown here represents that the elements of a vector is changed into a diagonal matrix. The superscript (*) on the matrix implies that the energy sectors consist of an energy unit and the non-energy sectors consist of a monetary unit.

Direct energy coefficients ($\mathbf{EI_\delta}$) and total or embodied energy coefficients ($\mathbf{EI_\alpha}$) can be found using Eqs. (4.2) and (4.3).

$$\mathbf{EI}_\delta = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} \mathbf{A}^* \tag{4.2}$$

$$\mathbf{EI}_\alpha = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} (\mathbf{I} - \mathbf{A}^*)^{-1} \tag{4.3}$$

**F*** is an artificial vector that remains energy rows in a matrix. $(\mathbf{I}\text{-}\mathbf{A}^*)^{-1}$ matrix has the same characteristic as **A*** shown in Eq. (4.1). **A*** and $(\mathbf{I}\text{-}\mathbf{A}^*)^{-1}$ matrices represent an input or technical coefficients matrix and a Leontief inverse matrix, such as the conventional IO, respectively.

Here, both **F** and **X** are vectors and each are defined as the total energy consumption for an economy (the elements of non-energy sectors consist of 0) and the total output (non-energy sectors consist of money and energy sectors consist of amount of consumption), respectively.

Direct or total emission intensity of a GHG is denoted as **GI**; the **GI** of the intermediate transaction sectors by energy use is shown in Eqs. (4.4) and (4.5); $\mathbf{GI_\delta}$ and $\mathbf{GI_\alpha}$ are matrices of the $k \times n$ that designate the GHG emissions intensity caused by direct energy use and total energy use, respectively.

$$\mathbf{GI}_\delta = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} \mathbf{M}\mathbf{A}^* \tag{4.4}$$

$$\mathbf{GI}_\alpha = \hat{\mathbf{F}}^* (\hat{\mathbf{X}}^*)^{-1} \mathbf{M}(\mathbf{I} - \mathbf{A}^*)^{-1} \tag{4.5}$$

Here, **M** is an $n \times n$ dimensional symmetric matrix and it was modified to incorporate Korea's situation on the basis of IPCC (1996). The elements of the matrix represent the coefficients of the GHG ($CO_2$, $CH_4$, and $N_2O$) emissions associated with energy consumption in each industry. The unit of the elements is the emissions of each GHG under evaluation per unit energy consumption (e.g., t-$CO_2$/TOE or g-$CH_4$/J).

### 4.3.2 Modification of the GHG emission factor

For the assessment of GHG emissions caused by energy consumption, the emission factors of the IPCC Guidelines revised in 1996 were used. This study, however, partly modified the factors on the basis of IPCC [29] by considering the specific conditions in Korea as described in chapter 3. The modification was performed according to the recommendations of the IPCC [29] for two aspects. One was to consider the fraction of carbon stored and the fraction of carbon oxidized for each energy source to reflect a different use pattern for the 14 energy sources. The other was that since the energy sources were combined into 14 sectors, the emission factors were modified by a weighted average for a component rate of the included energy sources. The modification results as a result of reflecting the time series situation of each E-IO table are summarized in Table 4.3. We need to treat $CO_2$ emissions factor for three power generation sectors to zero to prevent double calculation in both at power generation stage and at electricity usage stage.

In 2007, IPCC [31] issued an updated guideline report on an emission coefficient in "IPCC 2006 Guidelines for National Greenhouse Gas Inventories," which was not formally applied for national report. Key World Energy Statistics 2007 [18] still used the IPCC Guidelines 1996, which was not used internally. This provides consistent viewpoints on the previous GHG emissions statistics of Korea. According to these backgrounds, this study will use the emissions coefficients of the IPCC Guidelines 1996.

**Table 4.3 Modification of the $CO_2$ emission factors by energy source**

| Name of sector | Emission factor (t-$CO_2$/TOE) | | | | Included fuels |
|---|---|---|---|---|---|
| | 1985 | 1990 | 1995 | 2000 | |
| Coal | 3.758 | 3.733 | 3.718 | 3.708 | |
| Crude petroleum | 3.009 | 3.009 | 3.009 | 3.009 | |
| Natural gas | 2.298 | 2.298 | 2.298 | 2.298 | |
| Coal products | 4.077 | 4.077 | 4.077 | 4.077 | BKB & Patent fuel, Coke, Coal briquette, etc. |
| Naphtha | 0.752 | 0.752 | 0.752 | 0.752 | |
| Gasoline | 2.842 | 2.842 | 2.842 | 2.842 | Jet oil A-1, P-4 |
| Fuel oil | 3.057 | 3.026 | 3.011 | 2.974 | Kerosene, Diesel, Bunker A~C, LPG |
| Misc. petroleum refinery products | 0.775 | 0.775 | 0.775 | 0.775 | Asphalt, Lubricant, Paraffin wax, etc. |
| Water power generation | 0.000 | 0.000 | 0.000 | 0.000 | |
| Thermal and self-power generation | 0.000 | 0.000 | 0.000 | 0.000 | |
| Atomic power generation | 0.000 | 0.000 | 0.000 | 0.000 | |
| Town gas | 2.677 | 2.423 | 2.400 | 2.334 | Naphtha, Propane, LNG |
| Heat | 0.000 | 0.000 | 0.000 | 0.000 | LNG, LSWR, Bunker C, Waste burning |
| Wood | 4.178 | 4.178 | 4.178 | 4.178 | |

### 4.3.3 Validation of estimated GHG emissions

The amounts of GHG emissions estimated in this study were compared with those of KEEI [32]. $N_2O$ was overestimated by 137%. $CO_2$ was converted from an underestimated value to an overestimated value in 2000, while $CH_4$ exhibited an opposite trend in 1995. (Table 4.4)

In this study, the error was considered to be acceptable and no further analyses were made due to the two grounds. At first, there is an uncertainty involved in deciding whether the E-IO table in this study or KEEI [32] that would be the most likely estimate for the value, which was estimated by most of the Annex-I parties. Secondly, even the inherent limitations of the IO analysis still remain in an E-IO analysis, such as price distortion in a unit conversion, aggregation error in setting up a sector, and missing a necessary item in a sector. Both estimations do not put in an awkward position but in a mutually complementary role.

**Table 4.4 Comparison of the estimation tendency for the GHG emissions**

| Year | Element | E-IO (2008) | | | KEEI (2003) | | Comparison (a/b) |
|---|---|---|---|---|---|---|---|
| | | total | direct (a) | unit | actual (b) | unit | |
| 1985 ** | $CO_2$ | 413 | 158 | Mt-$CO_2$ | 229 | Mt-$CO_2$ | 69% |
| | $CH_4$ | 137,643 | 124,588 | t-$CH_4$ | 1,895 | kt-$CO_2$ eq | 138% |
| | $N_2O$ | 5,029 | 2,136 | t-$N_2O$ | 353 | kt-$CO_2$ eq | 188% |
| 1990 | $CO_2$ | 533 | 186 | Mt-$CO_2$ | 248 | Mt-$CO_2$ eq | 75% |
| | $CH_4$ | 135,260 | 116,781 | t-$CH_4$ | 1,503 | kt-$CO_2$ eq | 163% |
| | $N_2O$ | 6,204 | 24,05 | t-$N_2O$ | 480 | kt-$CO_2$ eq | 155% |
| 1995 | $CO_2$ | 1,022 | 349 | Mt-$CO_2$ | 372 | Mt-$CO_2$ | 94% |
| | $CH_4$ | 76,519 | 37,724 | t-$CH_4$ | 992 | kt-$CO_2$ eq | 80% |
| | $N_2O$ | 11,772 | 4,453 | t-$N_2O$ | 714 | kt-$CO_2$ eq | 193% |
| 2000 | $CO_2$ | 1,372 | 509 | Mt-$CO_2$ | 439 | Mt-$CO_2$ | 116% |
| | $CH_4$ | 83,565 | 35,499 | t-$CH_4$ | 918 | kt-$CO_2$ eq | 81% |
| | $N_2O$ | 16,201 | 6,832 | t-$N_2O$ | 894 | kt-$CO_2$ eq | 237% |

Remarks: Figures in column KEEI (2003) is extrapolated for this study

## 4.4 Results

Since intensity denotes a total amount of input required for a unit value-added production (million Korean Won (M-KRW) in this study), it can be applied to both direct energy use and total or embodied energy use. In this study, however, to avoid any confusion, “factor” refers to direct energy use and “intensity” refers to total or embodied energy use.

Energy consumption factors and GHG emission factors of direct energy use will be shown as a whole, while energy intensities and GHG emissions intensities of total energy use will be explained in more detail compared to direct use..

### 4.4.1 Energy use and GHG emission factors

The analysis of energy use and GHG emissions from direct energy use was performed using Eqs. (4.2) and (4.4). The results obtained from direct energy use during 1985–2000 are summarized as follows (Table 4.5):

- When we look at the energy use factors with respect to the average annual values (0.166 (1985), 0.142 (1990), 0.135(1995), and 0.132 (2000)), gradual improvements have been shown since 1985. The GHG emissions factors were 0.429 (1985), 0.344(1990), 0.310 (1995), and 0.306 (2000) and steady improvement was seen during 1985–2000.

- Sector 10 (thermal & self-power generation) showed the highest factors of energy use and GHG emissions throughout the entire period.

# Table 4.5 Sectoral energy use factor and its GHG emissions factor

| Group | Sector code | Energy use factor (TOE/M-KRW) | | | | GHG emission factor (t-$CO_2$-eq./M-KRW) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1985 | 1990 | 1995 | 2000 | 1985 | 1990 | 1995 | 2000 |
| Energy group | 1 | 0.0056 | 0.0034 | 0.0012 | 0.0007 | 0.0089 | 0.0031 | 0.0012 | 0.0007 |
| | 2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 4 | 0.0047 | 0.0127 | 0.0207 | 0.0105 | 0.0126 | 0.0252 | 0.0482 | 0.0216 |
| | 5 | 0.0172 | 0.0114 | 0.0065 | 0.0054 | 0.0487 | 0.0297 | 0.0165 | 0.0126 |
| | 6 | 0.0305 | 0.0227 | 0.0499 | 0.0586 | 0.0877 | 0.0593 | 0.1362 | 0.1504 |
| | 7 | 0.0239 | 0.0182 | 0.0235 | 0.0251 | 0.0686 | 0.0473 | 0.0646 | 0.0617 |
| | 8 | 0.3994 | 0.2211 | 0.1693 | 0.1430 | 0.6386 | 0.2735 | 0.1824 | 0.1602 |
| | 9 | 0.0135 | 0.2856 | 0.1685 | 0.0241 | 0.0351 | 0.0394 | 0.0420 | 0.0347 |
| | 10 | 2.4418 | 2.1166 | 2.2400 | 2.4401 | 8.3281 | 6.8555 | 7.2879 | 8.3515 |
| | 11 | 0.0114 | 0.0652 | 0.0737 | 0.0297 | 0.0312 | 0.0320 | 0.0313 | 0.0181 |
| | 12 | 1.1276 | 0.4310 | 0.2174 | 0.0360 | 1.9930 | 1.2625 | 0.6377 | 0.0905 |
| | 13 | 1.2285 | 0.7635 | 0.6347 | 0.9027 | 3.7477 | 2.3353 | 1.1938 | 2.0277 |
| | 14 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Non-energy & energy intensive group | 15 | 0.0004 | 0.0505 | 0.0668 | 0.0245 | 0.0006 | 0.1533 | 0.2008 | 0.0727 |
| | 16 | 0.1935 | 0.3019 | 0.3245 | 0.3154 | 0.5926 | 0.8911 | 0.9350 | 0.8896 |
| | 17 | 0.0290 | 0.0077 | 0.0052 | 0.0014 | 0.0482 | 0.0090 | 0.0115 | 0.0024 |
| | 18 | 0.1487 | 0.1946 | 0.1850 | 0.1737 | 0.3387 | 0.3750 | 0.4428 | 0.4087 |
| | 19 | 0.1489 | 0.1512 | 0.1115 | 0.1197 | 0.4151 | 0.4231 | 0.2935 | 0.2539 |
| | 20 | 0.0759 | 0.0749 | 0.0641 | 0.0734 | 0.1287 | 0.1396 | 0.1240 | 0.1211 |
| | 21 | 0.4059 | 0.3003 | 0.4190 | 0.4185 | 1.1337 | 0.8056 | 0.9217 | 0.7079 |
| | 22 | 0.0561 | 0.0450 | 0.0503 | 0.0713 | 0.1422 | 0.0975 | 0.1081 | 0.1459 |
| | 23 | 0.1687 | 0.1430 | 0.1197 | 0.1284 | 0.4100 | 0.3400 | 0.2474 | 0.2371 |
| | 24 | 0.8973 | 0.8077 | 1.1500 | 1.1368 | 1.1484 | 0.8023 | 1.0570 | 1.0284 |
| | 25 | 0.5380 | 0.3507 | 0.2560 | 0.2839 | 1.5955 | 1.0137 | 0.6250 | 0.5333 |
| | 26 | 0.1520 | 0.0449 | 0.0818 | 0.1113 | 0.0966 | 0.0069 | 0.1088 | 0.1137 |
| | 27 | 0.2703 | 0.1982 | 0.1280 | 0.1128 | 0.5551 | 0.3511 | 0.2083 | 0.1391 |
| | 28 | 0.6546 | 0.5510 | 0.4649 | 0.2996 | 0.8282 | 0.6481 | 0.5430 | 0.3948 |
| | 29 | 0.0751 | 0.0861 | 0.0671 | 0.0727 | 0.1565 | 0.1718 | 0.1232 | 0.1283 |
| | 30 | 0.3830 | 0.4019 | 0.2411 | 0.2125 | 1.0732 | 1.0712 | 0.6129 | 0.4947 |
| | 31 | 0.4379 | 0.3971 | 0.3723 | 0.3342 | 1.3220 | 1.1396 | 1.0585 | 0.9167 |
| | 32 | 1.0640 | 0.6887 | 0.4891 | 0.4963 | 3.6693 | 2.3072 | 1.5287 | 1.5219 |
| | 33 | 0.5917 | 0.6835 | 0.6814 | 0.6488 | 1.3178 | 1.1320 | 1.0817 | 1.0388 |
| | 34 | 0.7027 | 0.5989 | 0.6379 | 0.6511 | 2.6371 | 2.1717 | 2.3825 | 2.4390 |
| | 35 | 0.0978 | 0.0854 | 0.0754 | 0.0810 | 0.2411 | 0.1936 | 0.1398 | 0.1125 |
| | 36 | 0.1928 | 0.1163 | 0.0800 | 0.0586 | 0.5755 | 0.3259 | 0.1840 | 0.0833 |
| | 37 | 0.0737 | 0.0539 | 0.0845 | 0.0892 | 0.1547 | 0.0851 | 0.1547 | 0.1621 |
| | 38 | 0.0459 | 0.0304 | 0.0562 | 0.0808 | 0.0948 | 0.0364 | 0.0597 | 0.0823 |
| | 39 | 0.0989 | 0.1010 | 0.0993 | 0.0652 | 0.2799 | 0.2652 | 0.2511 | 0.1291 |
| | 40 | 0.1235 | 0.1180 | 0.0823 | 0.0866 | 0.3383 | 0.3281 | 0.1968 | 0.2048 |
| | 41 | 0.3953 | 0.4881 | 0.5471 | 0.5244 | 1.1646 | 1.3721 | 1.5601 | 1.4817 |
| | 42 | 0.0977 | 0.0868 | 0.0741 | 0.0596 | 0.2649 | 0.2272 | 0.1715 | 0.1269 |
| | 43 | 0.1645 | 0.1357 | 0.1423 | 0.1454 | 0.0262 | 0.0266 | 0.0530 | 0.0599 |
| | 44 | 0.1270 | 0.2376 | 0.1898 | 0.1790 | 0.2682 | 0.5540 | 0.4715 | 0.4150 |
| | 45 | 0.0468 | 0.0764 | 0.1670 | 0.1467 | 0.1106 | 0.1624 | 0.2519 | 0.1960 |
| Non-energy & energy less-intensive group | 46 | 0.0099 | 0.0156 | 0.0202 | 0.0265 | 0.0374 | 0.0464 | 0.0603 | 0.0779 |
| | 47 | 0.0501 | 0.0494 | 0.0662 | 0.0644 | 0.1711 | 0.1237 | 0.1776 | 0.1657 |
| | 48 | 0.0011 | 0.0108 | 0.0076 | 0.0168 | 0.0032 | 0.0229 | 0.0166 | 0.0358 |
| | 49 | 0.0231 | 0.0236 | 0.0246 | 0.0207 | 0.0583 | 0.0549 | 0.0571 | 0.0460 |
| | 50 | 0.0548 | 0.0338 | 0.0305 | 0.0288 | 0.1242 | 0.0785 | 0.0726 | 0.0692 |
| | 51 | 0.0059 | 0.0086 | 0.0098 | 0.0116 | 0.0089 | 0.0130 | 0.0161 | 0.0153 |
| | 52 | 0.0676 | 0.0608 | 0.0555 | 0.0620 | 0.1822 | 0.1537 | 0.1359 | 0.1513 |
| | 53 | 0.1146 | 0.0848 | 0.0602 | 0.0665 | 0.2973 | 0.2125 | 0.1473 | 0.1696 |
| | 54 | 0.0724 | 0.0740 | 0.0686 | 0.0621 | 0.2005 | 0.2032 | 0.1729 | 0.1579 |
| | 55 | 0.0654 | 0.0463 | 0.0413 | 0.0357 | 0.1764 | 0.1217 | 0.1021 | 0.0849 |
| | 56 | 0.0097 | 0.0157 | 0.0247 | 0.0291 | 0.0167 | 0.0351 | 0.0465 | 0.0550 |
| | 57 | 0.0056 | 0.0070 | 0.0068 | 0.0070 | 0.0131 | 0.0182 | 0.0145 | 0.0151 |
| | 58 | 0.0602 | 0.0713 | 0.0652 | 0.0573 | 0.1170 | 0.1459 | 0.1544 | 0.1241 |
| | 59 | 0.0400 | 0.0446 | 0.0316 | 0.0289 | 0.0851 | 0.0950 | 0.0801 | 0.0761 |
| | 60 | 0.0407 | 0.0467 | 0.0505 | 0.0443 | 0.0914 | 0.1038 | 0.1143 | 0.0831 |
| | 61 | 0.0238 | 0.0254 | 0.0253 | 0.0279 | 0.0562 | 0.0582 | 0.0607 | 0.0677 |
| | 62 | 0.0578 | 0.0668 | 0.0510 | 0.0495 | 0.1552 | 0.1578 | 0.1282 | 0.1195 |
| | 63 | 0.0598 | 0.0543 | 0.0379 | 0.0478 | 0.1539 | 0.1327 | 0.0847 | 0.0984 |
| | 64 | 0.0174 | 0.0168 | 0.0243 | 0.0294 | 0.0378 | 0.0380 | 0.0524 | 0.0585 |
| | 65 | 0.1089 | 0.1315 | 0.0658 | 0.0655 | 0.1367 | 0.1435 | 0.1204 | 0.0963 |
| | 66 | 0.0294 | 0.0250 | 0.0409 | 0.0418 | 0.0689 | 0.0608 | 0.0943 | 0.0959 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 67 | 0.0392 | 0.0320 | 0.0338 | 0.0331 | 0.0920 | 0.0701 | 0.0765 | 0.0647 |
| 68 | 0.0711 | 0.0592 | 0.0805 | 0.0722 | 0.1374 | 0.1121 | 0.1809 | 0.1413 |
| 69 | 0.1078 | 0.0780 | 0.0765 | 0.0920 | 0.2382 | 0.1633 | 0.1533 | 0.1722 |
| 70 | 0.0852 | 0.1007 | 0.0809 | 0.0533 | 0.1946 | 0.1766 | 0.1449 | 0.0876 |
| 71 | 0.0577 | 0.0313 | 0.0298 | 0.0320 | 0.1298 | 0.0567 | 0.0638 | 0.0659 |
| 72 | 0.0230 | 0.0265 | 0.0218 | 0.0281 | 0.0532 | 0.0515 | 0.0401 | 0.0536 |
| 73 | 0.0282 | 0.0157 | 0.0205 | 0.0293 | 0.0666 | 0.0268 | 0.0358 | 0.0458 |
| 74 | 0.0345 | 0.0478 | 0.0314 | 0.0349 | 0.0682 | 0.0735 | 0.0557 | 0.0546 |
| 75 | 0.0359 | 0.0298 | 0.0247 | 0.0143 | 0.0589 | 0.0379 | 0.0334 | 0.0179 |
| 76 | 0.0167 | 0.0202 | 0.0119 | 0.0109 | 0.0297 | 0.0297 | 0.0213 | 0.0160 |
| 77 | 0.0221 | 0.0145 | 0.0055 | 0.0039 | 0.0396 | 0.0154 | 0.0098 | 0.0066 |
| 78 | 0.0337 | 0.0257 | 0.0203 | 0.0187 | 0.0766 | 0.0534 | 0.0387 | 0.0358 |
| 79 | 0.0138 | 0.0087 | 0.0101 | 0.0114 | 0.0277 | 0.0130 | 0.0159 | 0.0190 |
| 80 | 0.0419 | 0.0386 | 0.0320 | 0.0356 | 0.0994 | 0.0686 | 0.0487 | 0.0512 |
| 81 | 0.0224 | 0.0171 | 0.0151 | 0.0194 | 0.0424 | 0.0389 | 0.0285 | 0.0354 |
| 82 | 0.0184 | 0.0161 | 0.0170 | 0.0221 | 0.0437 | 0.0257 | 0.0311 | 0.0360 |
| 83 | 0.0393 | 0.0462 | 0.0376 | 0.0406 | 0.0832 | 0.1090 | 0.0905 | 0.0946 |
| 84 | 0.0406 | 0.0345 | 0.0358 | 0.0404 | 0.0959 | 0.0821 | 0.0769 | 0.0768 |
| 85 | 0.0126 | 0.0144 | 0.0140 | 0.0188 | 0.0292 | 0.0304 | 0.0353 | 0.0431 |
| 86 | 0.0682 | 0.0699 | 0.0377 | 0.0433 | 0.1427 | 0.1446 | 0.1017 | 0.1021 |
| 87 | 0.0410 | 0.0832 | 0.0410 | 0.0354 | 0.1036 | 0.2225 | 0.1111 | 0.0895 |
| 88 | 0.0632 | 0.0422 | 0.0301 | 0.0212 | 0.1114 | 0.0636 | 0.0429 | 0.0281 |
| 89 | 0.0268 | 0.0276 | 0.0186 | 0.0151 | 0.0500 | 0.0569 | 0.0367 | 0.0266 |
| 90 | 0.0294 | 0.0262 | 0.0340 | 0.0263 | 0.0464 | 0.0303 | 0.0319 | 0.0183 |
| 91 | 0.0426 | 0.0390 | 0.0392 | 0.0272 | 0.1043 | 0.0933 | 0.1026 | 0.0666 |
| 92 | 0.0282 | 0.0334 | 0.0407 | 0.0535 | 0.0841 | 0.0920 | 0.0979 | 0.1175 |
| 93 | 0.0628 | 0.0461 | 0.0432 | 0.0343 | 0.1658 | 0.1141 | 0.1003 | 0.0665 |
| 94 | 0.1001 | 0.0752 | 0.0632 | 0.0523 | 0.2158 | 0.1472 | 0.1260 | 0.1003 |
| 95 | 0.0778 | 0.0685 | 0.0390 | 0.0607 | 0.1892 | 0.1893 | 0.0981 | 0.1172 |
| 96 | 0.0158 | 0.0159 | 0.0208 | 0.0244 | 0.0582 | 0.0561 | 0.0686 | 0.0559 |

- Among the 96 sectors, sector 12 (town gas) showed the largest improvement in terms of the energy use factor and the GHG emissions factor; on the other hand, sector 15 (Crops-p) showed the largest deterioration for both factors. The improvement in sector 12 was because the input fuel was changed from petroleum gas in 1985 to natural gas in 2000, and the deterioration in sector 15 was due to the spread of agricultural facilities and a rapid growth in the demand of electricity for the facilities.

### 4.4.2 Energy and GHG emission intensities from total energy use

Total energy use is an IO concept that incorporates direct energy use and indirect energy use. The evaluation of energy use and GHG emissions was performed using Eqs. (4.3) and (4.5). Time series characteristics are explained by dividing 96 sectors into 3 predetermined groups.

In Figures 4.3 through 4.6, the blue column means that the energy or GHG emission intensity was improved in the final year 2000 as compared to the start year 1985. Red bar means that the index was even or worse in 2000 than 1985. And the line segment attached to the column shows outlier between 1985 and 2000.

#### 4.4.2.1 Embodied energy intensity

The estimated values showed the following characteristics. The unit is TOE/M-KRW (Figure 4.3).

- Energy group (sector-1 through -14, see (a) in Figure 4.3)

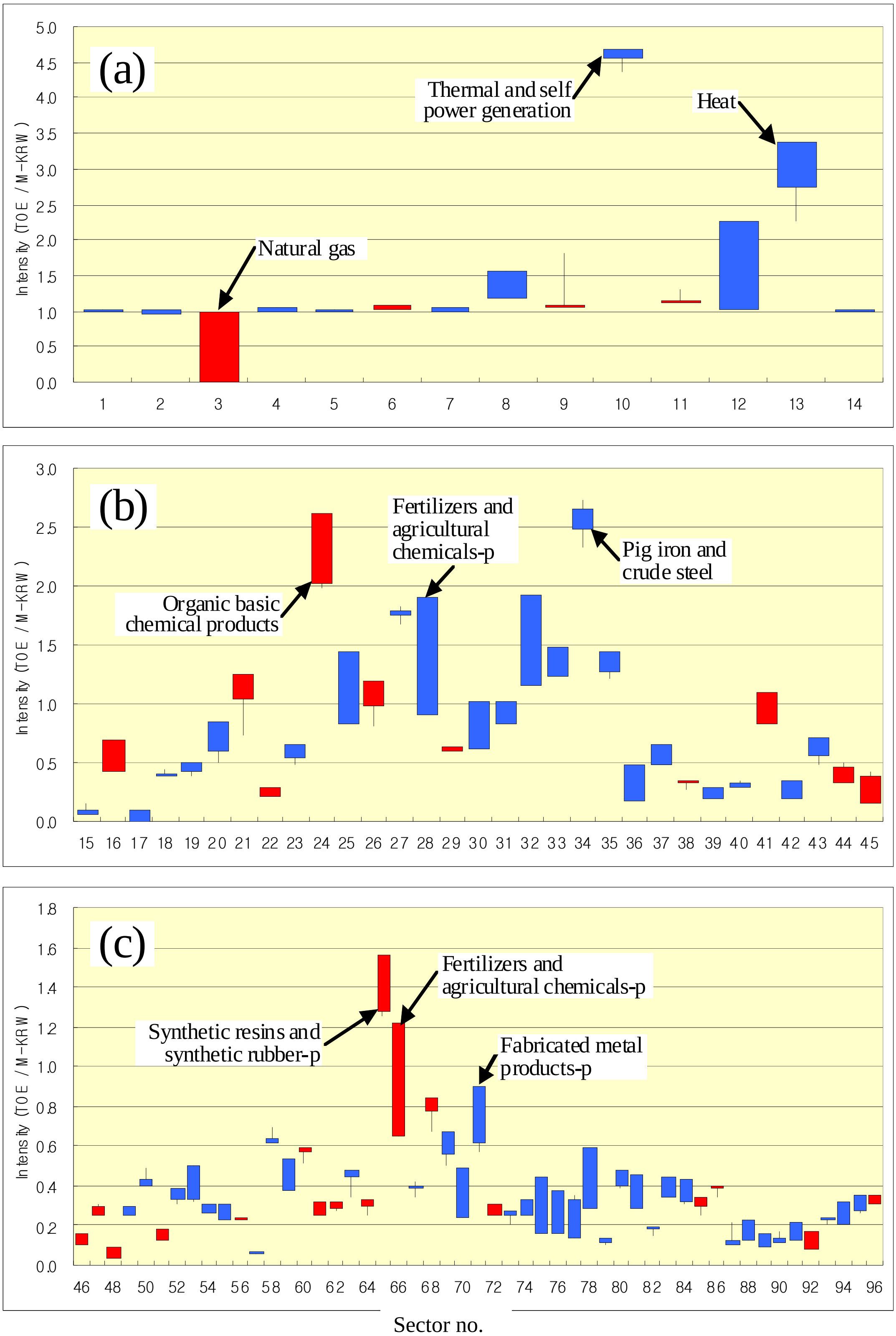



**Figure 4.3 Embodied energy intensity for three separate groups.**

Most sectors showed improvement between 1985 and 2000 and the annual averages of these 14 sectors were 1.514 (1985), 1.466 (1990), 1.442 (1995), and 1.426 (2000); the values decreased gradually. The most notable feature was deterioration in sector 3 (natural gas) that was introduced in 1986 and an improvement in sector 12 (town gas).

- Energy intensive group in the non-energy group (sector-15 through -45, see (b) in Figure 4.3)
  There were more sectors showing improvement than those showing deterioration and the annual averages of these 31 sectors were 0.876 (1985), 0.768 (1990), 0.798 (1995), and 0.784 (2000); the values decreased gradually. The notable sector was sector 28 (Fertilizers and agricultural chemicals-p), which showed an improvement of more than double.

- Energy less-intensive group in the non-energy group (sector-46 through -96,see (c) in Figure 4.3)
  There were more sectors showing improvement than those showing deterioration and the annual averages of the 51 sectors were 0.372 (1985), 0.338 (1990), 0.333 (1995), and 0.336 (2000); the values decreased gradually. The notable sector was sector 66 (fertilizers and agricultural chemicals-p), which showed a considerable deterioration of more than double. This is contrary to the improvement for this sector mentioned in the previous paragraph. This implies that the fertilizers and agricultural chemicals sectors are divided into two extremes in terms of their efficiency.

#### 4.4.2.2 Embodied GHG emission intensity

**1) $CO_2$ emission intensity**

The decreasing trend in the $CO_2$ emission intensity was shown for the 96 sectors (Figure 4.4). The annual averages were 1.844 (1985), 1.578 (1990), 1.548 (1995), and 1.525 (2000); the values appeared to be decreasing gradually. Sector 10 (thermal and self-power generation) and sector 34 (pig iron and crude steel) showed rapid improvements, while sector 3 (natural gas) denoted red column since it was used from 1986 in Korea.

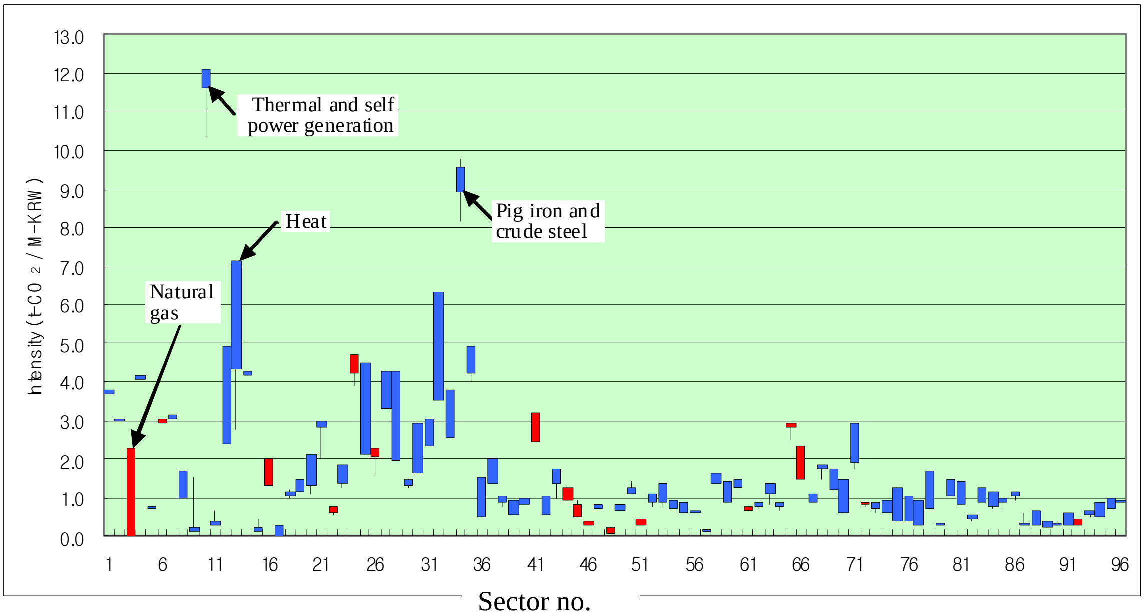



**Figure 4.4 Change of the $CO_2$ emission intensities during 1985-2000.**

## 2) $CH_4$ emission intensity

The $CH_4$ emission intensity showed decreasing trend for the 96 sectors (Figure 4.5). The annual averages were 0.150 (1985), 0.120 (1990), 0.134 (1995), and 0.123 (2000); the values decreased gradually. Sector 13 (heat) and sector 47 (livestock breeding) showed rapid improvements, while sector 41 (transportation and warehousing-p) got worse.

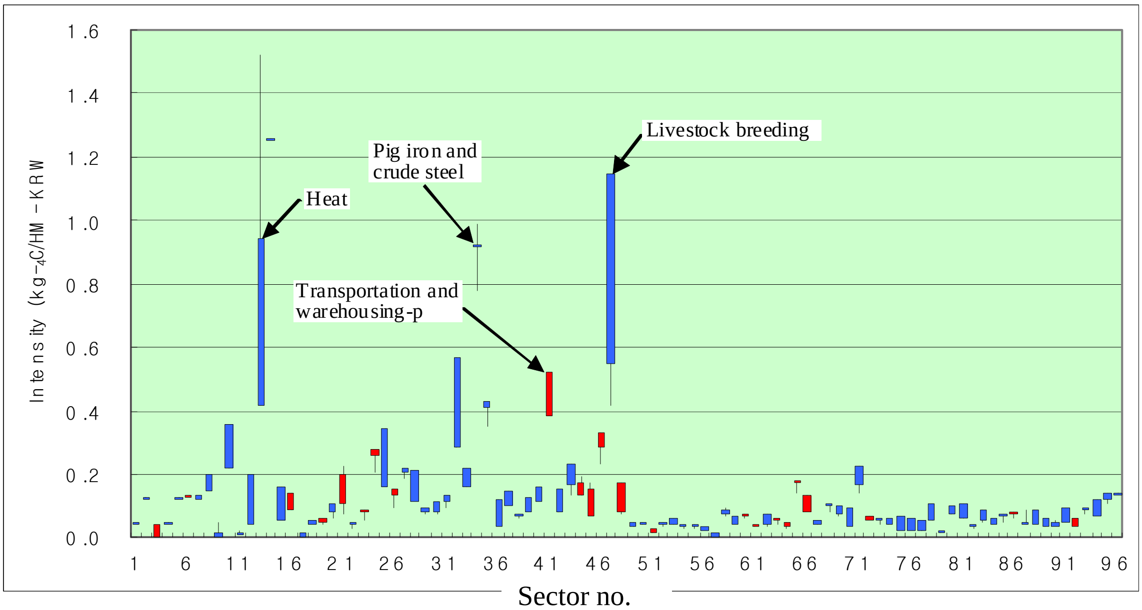



**Figure 4.5 Change of the $CH_4$ emission intensities during 1985-2000.**

### 3) $N_2O$ emission intensity

The $N_2O$ emission intensity decreased for the 96 sectors (Figure 4.6). The annual averages were 0.024 (1985), 0.020 (1990), 0.022 (1995), and 0.020 (2000); the values remained about the same. However, two sectors showed rapid improvements—sector 13 (heat) and sector 34 (pig iron and crude steel). On the other hand, sector 10 (thermal and self-power generation) went through deterioration along with large emissions.

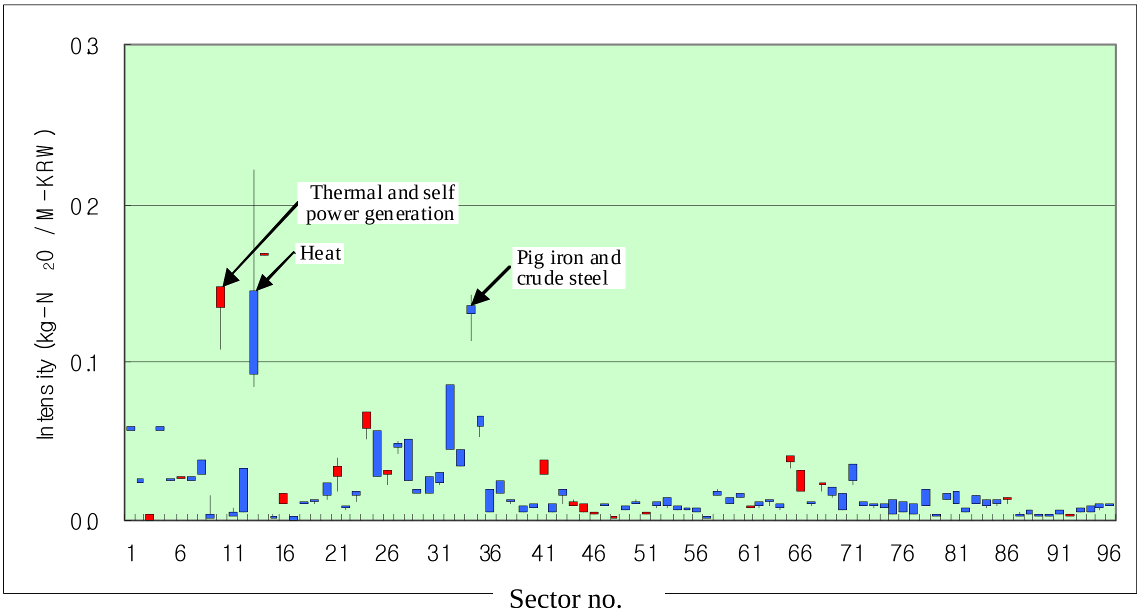



**Figure 4.6 Change of the $N_2O$ emission intensities during 1985-2000.**

### 4.4.2.3 Scattering patterns and linear fittings

The distribution patterns of the time-series energy and GHG emission intensities for each group are shown in Figure 4.7. The scattered numbers for each graph represent the numbers for the 96 sectors and the slanting red solid line represents the result of the linear fitting that passes through the point of origin, which enables us to examine the relationship between the embodied energy consumption intensity (TOE/M-KRW, shown at the X-axis) and the embodied GHG emissions intensity (g-$CO_2$-eq./M-KRW, shown at the Y-axis).

The changes in the slope of this line signify the rate of change in GHG emissions intensity with respect to a change in the energy intensity. Therefore, if the value of the slope decreases with time, it means that the corresponding group's GHG emissions intensity has been improved. In contrast, an increasing value of the slope implies that the GHG emission intensity has been degraded. Both the energy intensive group and the energy less-intensive group, including the non-energy sector, showed a gradual improvement during 1985–2000. On the other hand, the energy group went through a lot of improvements between 1985 and 1990, but its GHG emissions intensity increased between 1990 and 2000. This shows that the GHG emissions from the energy sectors, especially in sector 10(thermal and self-power generation), contributed to increase of Korea's GHG emissions significantly. (Figure 4.8) It varied depending on the ratio of coal usage in sector 10 of transformation sector. The share of thermal power generation rose gradually in the 57.5% in 2005 from 45.0% in 1990 in Korea.

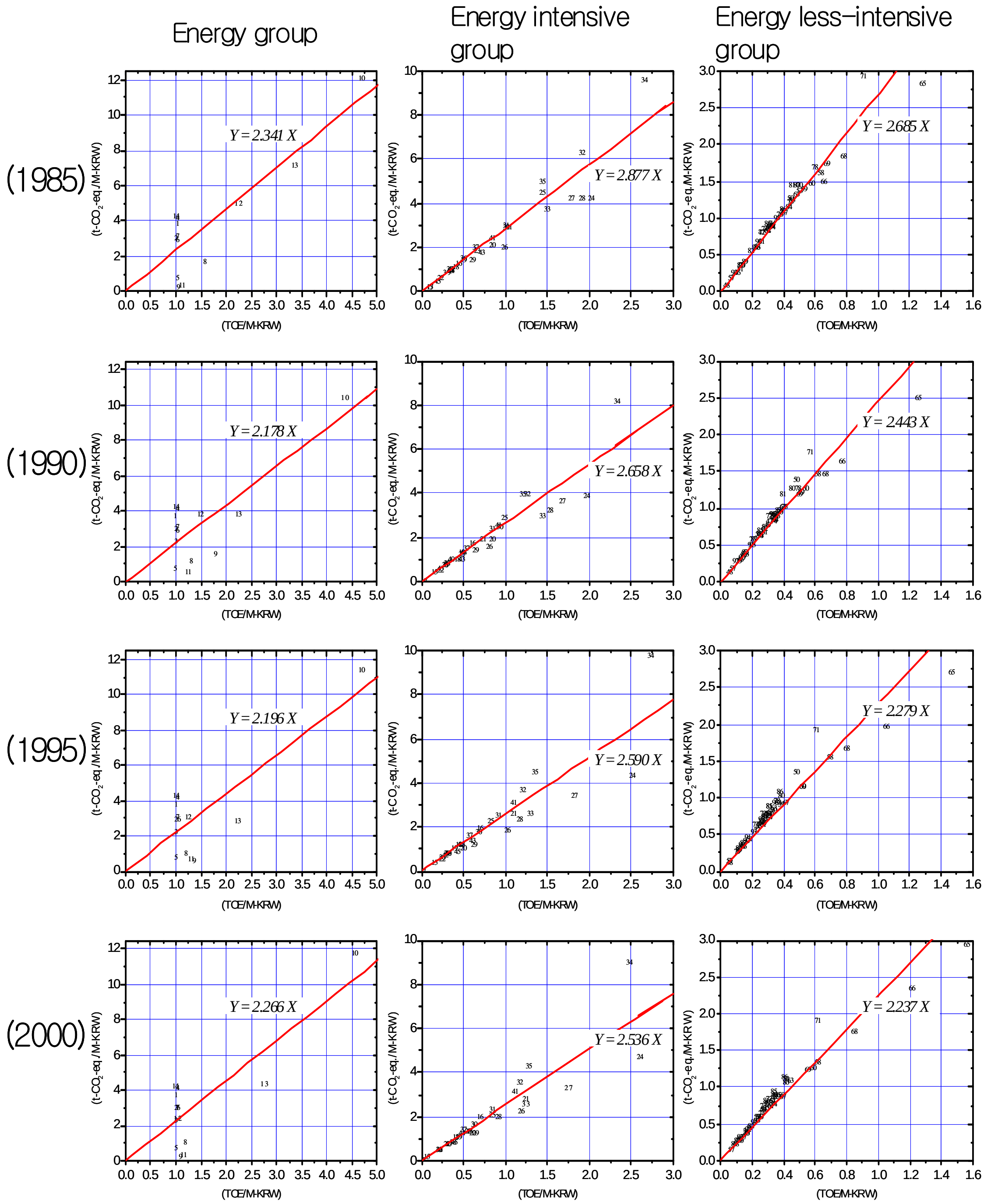



**Figure 4.7 Temporal distribution changes in total intensities in each group.**

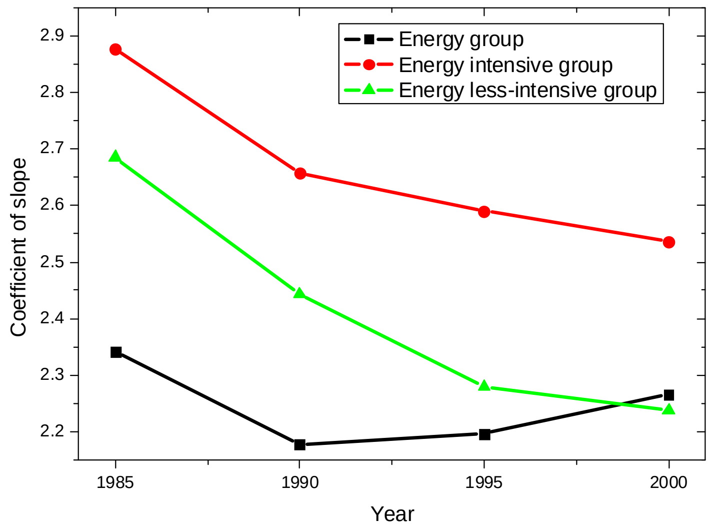



**Figure 4.8 Changes in coefficients of slope for each group.**

## 4.5 Summary and policy recommendations

E-IO analysis was performed on the basis of 96 aggregated sectors, including 14 energy sources, and their total (embodied) energy and GHG emission intensities were calculated. The results imply that if the major goal is to save expense for energy imports, then sectors with high energy consumption intensity have to be regulated; if the goal is to meet Korea's declaration to the GHG emission abatement, then sectors with high GHG emission intensity would have to be regulated; and if both these goals are important simultaneously, then sectors located far from the point of origin would have to be regulated as shown in Figure 4.7.

A metric model to describe a climate change must include not only direct emissions of a pollution source but also induced indirect emissions. An assessment that incorporates indirect emissions is a task that should be considered carefully during the discussions for a new regime such as a post-Kyoto Protocol that encourages the participation of developing countries. This is because it is difficult to expect an actual worldwide or nationwide decrease in pollutant emissions if countries or industries simply transfer emissions from one to another. Moreover, not only does a national climate change countermeasure decrease a pollutant's emissions, but it also directly affects the sustainable growth of an economy. Since the enforcing of environmental policies has a profound effect upon an economic progress, a metric analysis of the relationship among economy, energy, and environment is essential.

The results of this analysis can be applied to the measurement of load sharing in terms of energy and GHG emissions between entities in intra-industry assessment, and direction of structural changes in inter-industry policy as well,

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# Chapter 5. Index Decomposition Analysis of Changes in Energy-related Sectoral GHG Emissions in Korea

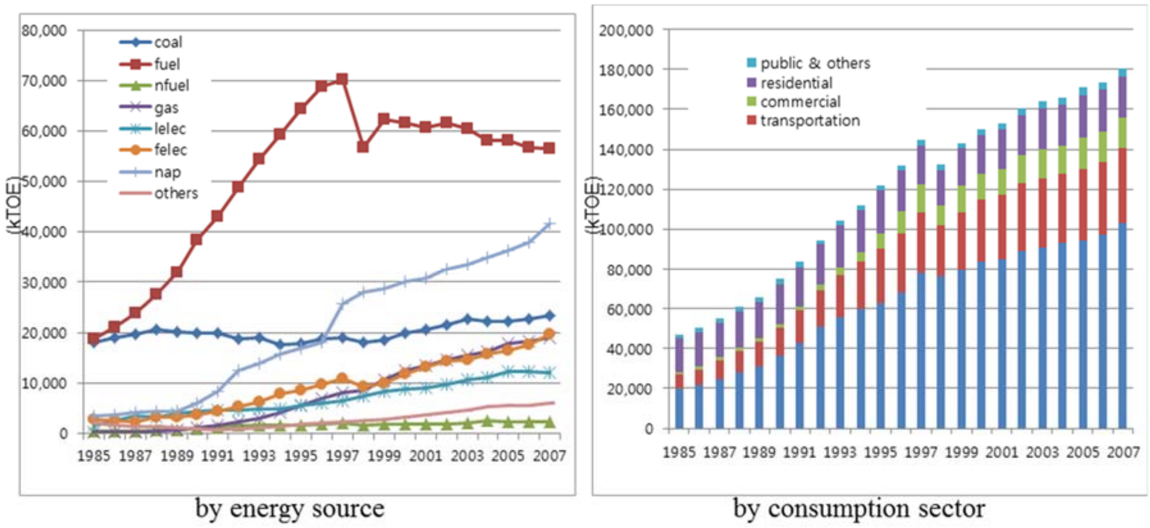
Socio-Technological Impact Analysis using an Energy IO Approach to GHG Emissions Issues in Korea, *Applied Energy*, 2011; 88: pp.3747-3758.

Through E-IO analyses from 1985 to 2005, the changes in three factors affecting GHG emissions in Korea are analyzed. Based on the E-IO results, the changes in the direct and total (embodied) GHG emissions from the pertinent sectors are decomposed into three factors—the energy consumption effect, the social effect, and the technological effect—using the Sato-Vartia index for the three periods of 1985-1995, 1995-2000, and 2000-2005.

## 5.1 Introduction

### 5.1.1 State of Korea's energy and environment

According to the energy statistics of Korea [1], Korea accomplished rapid industrial growth after the 1980s. It was this period when the nation's energy consumption and greenhouse gas (GHG) emissions from the industrial sector increased dramatically. According to the official government statistics, the annual final energy consumption increased from 46,998 kTOE in 1985 to 180,543 kTOE in 2007, representing an annual average rate of 7.0%, as shown in Figure 5.1. Energy was grouped into the following eight categories: Coal, Fuel, non-fuel oil (Nfuel), Gas, low-carbon electricity generation (Lelec), fossil fuel electricity generation (Felec), naphtha (Nap) and district heating (Heat).




Remarks: "Coal" includes coal and coal products; "Fuel" includes gasoline, fuel oil, and LPG; "Nfuel" includes non-fuel oil—crude oil, lubricants, and others; "Gas" comprises natural gas and city gas. "Lelec" represents low-carbon electricity generation, which includes hydro power generation and atomic power generation. "Felec" denotes fossil fuel electricity generation, which includes thermal power generation. "Nap" stands for naphtha. "Heat" includes thermal energy for district heating.
Source: KEEI, Yearbook of Energy Statistics

**Figure 5.1 Trend in final energy consumption in Korea.**

In the final energy consumption structure of Korea, the relative importance of the consumption of Coal and Fuel were reduced from their 1985 levels of 38.2% and 39.9%, respectively, to 13.0% and 31.3% in 2007. On the other hand, the relative importance of the consumption of Nfuel, Gas, Lelec, and Felec during the same period increased to 24.4%, 10.4%, 6.6%, and 10.9% in 2007 from 8.1%, 0.2%, 3.3%, and 6.0%, respectively, in 1985. The growth rate of the final energy consumption was higher than that of the GDP through the period between 1985 and 2005, as shown in Table 5.1[2]. During this period, the energy use environment of Korea was marked by the rapid spread of automobiles and distinctive changes in industrial structures. The change in the industrial structures, that is, the increase in the relative importance of the service industry as well as the increases related to automobiles and semiconductors, petrochemicals, steel, and high-value-added consumption materials led to an increasing demand for clean energy sources such as electricity and gas. The increased demand for clean energy sources also resulted in a decrease in the relative importance of lower-value-added and labor-intensive manufacturing industries such as textiles, shoes, and container manufacturing.

**Table 5.1 Status of Korean economy, energy use, and GHG emissions**

| Item | GDP (in 2000 price) | | Final energy consumption | | GHG emissions in energy use | | Share of intermediate sectors in energy use |
|---|---|---|---|---|---|---|---|
| Unit | Billion-KRW | AAGR(%) | kTOE | AAGR(%) | Mt-$CO_2$ | AAGR(%) | Share(%) |
| 1985 | 202,408.0 | - | 46,998.0 | - | na | - | 86.3 |
| 1990 | 320,696.4 | 9.6 | 75,107.0 | 9.8 | 239.0 | - | 88.6 |
| 1995 | 467,099.2 | 8.7 | 121,962.0 | 10.0 | 366.9 | 9.0 | 85.3 |
| 2000 | 578,664.5 | 7.3 | 149,852.0 | 8.0 | 432.2 | 6.1 | 81.7 |
| 2005 | 723,126.8 | 6.6 | 170,854.0 | 6.7 | 490.5 | 4.9 | 84.8 |

Remarks: KRW represents monetary unit of Korean Won and AAGR denotes average annual growth rate.

GHG emissions associated with energy use stood at 490.5 Mt-$CO_2$ in 2005, showing an increase of 4.9% in AAGR (Average Annual Growth Rate), which was lower than that of the final energy consumption between 1990 and 2005. Among the countries in the Organization for Economic Cooperation and Development (OECD), Korea was rated as the sixth-highest country in terms of total GHG emissions in 2004. Between 1990 and 2005, the country’s carbon dioxide ($CO_2$) emissions doubled, increasing by 105.2 %. This growth rate is the highest among OECD members according to the data from the Ministry of the Environment [3].

Although Korea does not have any binding targets under the Kyoto Protocol, the country nevertheless declared a voluntary mitigation target in November, 2009. However, for countries such as Korea, which belong to the non-Annex 1 group, it is more important to have the capability to analyze the emission characteristics of each industrial sector rather than to engage in declarations pertaining to a reduction in total emissions, so that they may be in a better position to prevent a decline in economic competitiveness in the post-Kyoto era.

The intermediate demand sector comprises approximately 85% of the final energy consumption of Korea. The energy used by the intermediate demand sector plays a very important role in the cyclical structure of the national economy because it creates added value as a direct input. Moreover, in the discussions on application of a sectoral approach to reduce GHG emissions, each country must have the capability to analyze the characteristics of the GHG emissions from its various industrial sectors. Therefore, it is important to reveal the characteristics of the energy use and environmental emissions associated with the activities of the intermediate demand sector and to analyze the socio-technological impact on these factors associated with Korean policies to reduce GHG emissions.

### 5.1.2 Decomposition methods

The concept of decomposition analysis was originally a basic tool in positive economics because a majority of economic data is prepared based on the concept of an economic differential and/or an index. Structural decomposition analysis (SDA) and index decomposition analysis (IDA) are typically used as preferred methods of decomposition analysis. In general, SDA uses information from IO tables, while IDA uses aggregate data at the sector level [4]. Moreover, among all decomposition analysis methods, IDA is suitable for examining and measuring production, social, technological effects using national-level data; thus, it is widely used in energy and environmental analysis, especially in the energy sector as shown in Table 5.2. Hence, IDA is considered as a type of energy decomposition analysis [4].

### 5.1.3 Literature review of the decomposition analysis of energy and the environment

Arithmetic mean Divisia index (AMDI) and log mean Divisia index (LMDI) methods are applicable in terms of weight function. However Ang [6] pointed out that AMDI method has two shortcomings. One of the shortcomings of the AMDI method is that it fails when the data set contains zero values, e.g. when an energy source begins or ceases to be used in a sector in the study period. The LMDI can be shown to converge when the zero values in the data set are replaced by a small positive number but the AMDI does not have this convergence property. In any of the above-mentioned situations, the LMDI method is the preferred index decomposition method from both the theoretical and application viewpoints. The results given by multiplicative decomposition and additive decomposition are related by a simple formula and interchangeable.

The most common application areas of the LMDI analysis are energy demand and supply as well as energy-related GHG emissions (Table 5.2).

Most existing studies concentrate on the decomposition of national $CO_2$ emissions and emission intensities of the industrial and power sectors.

Examples of decomposition studies on national $CO_2$ emissions (or emission intensities) include Wang et al. (2005) and Ma and Stern(2008) of China, Lin et al. (2006) of Taiwan, Hatzigeorgiou (2007) of Greece, O’ Mahony et al. (2008) of Ireland, Löfgren and Muller (2008) of Sweden, Sands and Schumacher (2009) of Germany, Bacon and Bhattacharya (2007) on behalf of 70 countries, Bataille et al. (2007) representing the G7 countries, Zhang (2008) representing 18 countries in the Middle East and North Africa, and Böhm (2009) representing 13 countries and 2 regions. Most of the studies decomposed the national $CO_2$ emissions growth into economic growth, fuel switching, and changes in emission intensity [7-17].

**Table 5.2 Recent decomposition cases with the LMDI method**

| Researcher | Year of publish | Country/ Region | LMDI | | Time span | Applied on |
|---|---|---|---|---|---|---|
| | | | I/II | Calc. | | |
| Bhattacharyya & Ussanarassamee | 2005 | Thai | I | multi | 1981-2000 | energy intensity |
| Wang et al. | 2005 | China | I | add | 1957–2000 | $CO_2$ emissions |
| Lin et al. | 2006 | Taiwan | I | add | 1991-2001 | $CO_2$ emissions |
| Ang & Liu | 2007 | USA | I / II | add | 1985-2000 | energy consumption |
| Bacon & Bhattacharya | 2007 | worldwide 71 countries | I | add | 1994-2004 | $CO_2$ emissions |
| Bataille et al. | 2007 | G7 countries | I | add | 1990-2002 | GHG emissions |
| Hatzigeorgiou et al. | 2007 | Greece | I | add | 1990-2002 | $CO_2$ emissions |
| He et al. | 2007 | Liaoning province in China | I | add | 1995-2005 | energy intensity |
| Liu et al. | 2007 | China | I | add | 1998–2005 | $CO_2$ emissions |
| Löfgren & Muller | 2008 | Sweden | I | add | 1993-2004 | carbon emissions |
| Ma & Stern | 2008 | China | I | add | 1994–2003 | energy intensity |
| O'Mahony et al. | 2008 | Ireland | I | add | 1990-2006 | $CO_2$ emissions |
| Sandu & Syed | 2008 | Australia | I | add | 1989-2006 | energy consumption |
| Zhang | 2008 | 18 countries in Middle East & North Africa Region | I | add | 1995-2005 | $CO_2$ emissions |
| Zhao & Ouyang | 2008 | China | I | add | 1998-2006 | $SO_2$ emission intensity |
| Böhm | 2009 | 13 countries, 2 regions | I | add | 1971-2005 | $CO_2$ emissions |
| Cahill & Gallachóir | 2009 | Irish | I | multi | 1995-2007 | energy consumption |
| Malla | 2009 | Australian, Canada, China, India, Japan, Korea, USA | I | add | 1990–2005 | $CO_2$ emissions |
| Sands & Schumacher | 2009 | Germany | I | add | 1995-2006 | GHG emissions |
| Timilsina & Shrestha | 2009 | 25 Latin American & Caribbean countries | I | multi | 1980-2005 | $CO_2$ emissions |

At the sectoral level, more studies are focused on the industrial sector than any other sectors. Liu et al. [18] decomposed $CO_2$ emissions growth in 36 industrial sectors in China over the period of 1998-2005. Changes in the industrial $CO_2$ emission are decomposed into carbon emissions coefficients of heat and electricity, energy intensity, industrial structural shift, industrial activity and final fuel shift. Zhao and Ouyang [19] analyzed $SO_2$ emissions from industry in China between 1998 and 2006 to identify the structure, GHG intensity, and the effect of government control. Sandu and Syed [20] examined energy consumption in industry in Australia during 1989-2006 to analyze the decomposition effect on economic activity, on structural, and on inter-fuel substitution. Cahill and Gallachóir [21] decomposed energy consumption in the Irish industry over the period 1995-2007 to examine the fuel mix and the energy intensity effect.

Some studies have concentrated on a particular industry instead of the industry sector as a whole for their decomposition analyses: Malla [22], on the electricity generation industry in seven Asia-Pacific and North American countries (Australian, Canada, China, India, Japan, Korea, USA); Ang and Liu [23], on the manufacturing and transportation sectors in the USA using both the LMDI-I and LMDI-II; and Timilsina and Shrestha [24], on the transportation industry in the Latin American and Caribbean countries.

### 5.1.4 Decomposition features

In the present work, IDA is used to analyze time-series changes of GHG emissions from individual sectors. IDA is considered to be suitable for analyzing time-series changes because it does not leave decomposition residual [5, 6]. This might be a rare case in analyzing GHG emissions effects from time series IO tables with IDA. Only the Lin et al. [9] and Sands and Schumacher [13] are unique studies in terms of recursive form as listed in Table 5.2.

To reveal the characteristics of the energy use and GHG emissions of the intermediate demand sector and determine the socio-technological impact on the changes of GHG emissions in Korea, a Divisia decomposition analysis was conducted using original data procured through a hybrid E-IO table. The results of the analysis were interpreted by dividing the time frame into Phase I (1985-1995), Phase II (1995-2000) and Phase III (2000-2005) based on the times when Korea began considering the climate change factor in its energy policy.

We attempt to represent the direct and total GHG emissions from each industry sector using the E-IO table. This approach must be useful in building essential data for each sector to cope with a Post-Kyoto protocol. While an analyst tries to measure the indirect demand effects of energy use, only decompositions with IO tables are possible because the Divisia decomposition analysis uses aggregate data.

The analysis conducted in this study is summarized as follows:

- Disaggregation of intermediate sectors: Economic activities in Korea were divided into 90 industries and products spanning 8 energy sources. According to change of the BOK's aggregation principle in energy sector e.g., woods, and to focus on the decomposition analysis of final energy sources, sectors was classified in this number. Classification rule for the rest of 82 sectors in non-energy group was maintained as previous chapters.
- Decomposition analysis method: The Divisia index decomposition analysis method, which is known to provide useful results with a simple operation (and is thus preferred among various decomposition analysis methods), was applied. Specifically, the LMDI-II multiplicative method, which can guarantee very accurate results in terms of linear homogeneity, was adopted [25].
- Base year of the analysis: Fixed base year makes it difficult to avoid accumulating effects as regards the appearances and extinctions of energy types in the course of serial decomposition activities, then our study used a rolling base year to eliminate this effect.
- Objects of decomposition analysis: As our analysis was carried out based on an E-IO table, it can also be applied to a direct input matrix and to a Leontief's matrix. This implies that the direct GHG emissions from the former matrix (hereinafter referred to the direct emission matrix) and the embodied GHG emissions from the latter matrix (hereinafter referred to the total emission matrix) can be estimated easily.
- Description of the analysis result: The objective function is the change in GHG emissions from energy consumption.

## 5.2 Model for the index decomposition method and data pertaining to energy and GHG emissions in Korea

### 5.2.1 Model description

We use the decomposition index (LMDI-II) in a multiplicative form (due to its linear weighted homogeneity) to analyze the changes in the GHG emissions of Korean industries. The method discussed below closely follows that in an earlier study [25].

We define the following variables:

$i$ = energy type, $i$= 1, 2, 3, …, 8, referring to Coal, Fuel, Nfuel, Gas, Lelec, Felec, Nap, and Heat, respectively.

$j$ = industrial sector, $j$= 1, 2, 3, …, 90

$t$ = observation year, $t$ = 1985, 1990, 1995, 2000, 2005

$GHG_i$ = GHG ($CO_2$, $CH_4$ and $N_2O$) emission by energy type $i$ (Mt-$CO_2$-eq.)

$GHG_{i,j}$ = GHG emission in sector $j$ for energy type $i$ (Mt-$CO_2$-eq.)

The variables below are determined for each energy type, but the suffix $i$ is dropped.

$E$ = total industrial energy consumption (TOE)

$E_j$ = energy consumption in sector *j* (TOE)

$S_j$ = structure of energy consumption in sector *j* (= $E_j / E$)

$G_j$ = GHG emission intensity in sector *j* (= $GHG_j / E_j$, Mt-$CO_2$-eq. /TOE)

The aggregate GHG emission due to the use of energy type *i* from the predetermined 90 industrial sectors *j* can be expressed as follows:

$$GHG_i = \sum_j GHG_{i,j} \tag{5.1}$$

Eq. (5.1) can be rewritten as

$$GHG_i = \sum_j E \cdot \frac{E_j}{E} \cdot \frac{GHG_{i,j}}{E_j} \tag{5.2}$$

Eq. (5.2) is equivalent to

$$GHG_i = \sum_j E \cdot S_j \cdot G_{i,j} \tag{5.3}$$

The ratio of the aggregate GHG emission of year *t* to that of year *t*-1 is termed the aggregate energy intensity index. It is written as follows:

$$D_{GHG,i} = \frac{GHG_i^t}{GHG_i^{t-1}} \tag{5.4}$$

Decomposition is carried out based on this index.

Assuming that all the variables in Eq. (5.3) are continuous in time *t* and applying the theorem of an instantaneous growth rate to Eq. (5.3) leads to

$$d\frac{\ln(GHG_i^t)}{dt} = \sum_j \omega_j^t \left[ d\frac{\ln(E^t)}{dt} + d\frac{\ln(S_j^t)}{dt} + d\frac{\ln(G_j^t)}{dt} \right] \tag{5.5}$$

Where $\omega_j^t = {GHG_j^t}/{\sum_j GHG_j^t}$ is the sector's share of GHG emissions; it is known as the weight of the sector in the summation. Integrating over time from *t*-1 to *t* and rearranging the terms, we get:

$$\ln\left(\frac{GHG_i^t}{GHG_i^{t-1}}\right) = \int_{t-1}^{t} \sum_j \omega_j^t \left[ d\frac{\ln(E^t)}{dt} dt \right] + \int_{t-1}^{t} \sum_j \omega_j^t \left[ d\frac{\ln(S_j^t)}{dt} \right] dt + \int_{t-1}^{t} \sum_j \omega_j^t \left[ d\frac{\ln(G_j^t)}{dt} \right] dt \tag{5.6}$$

Taking the exponents of both sides of Eq. (5.6), Eq. (5.4) can be expressed in the multiplicative form as

$$D_{GHG} = D_{tot} \cdot D_{soc} \cdot D_{tech} \tag{5.7}$$

where

$$D_{tot} = \frac{E^t}{E^{t-1}} = \frac{\sum_j E_j^t}{\sum_j E_j^{t-1}} \tag{5.8}$$

$$D_{soc} = \exp\left[\sum_j \omega_j^{*,t} \ln \frac{S_j^t}{S_j^{t-1}}\right] = \prod_j \exp\left(\omega_j^{*,t} \ln \frac{S_j^t}{S_j^{t-1}}\right) = \prod_j D_{soc,j} \tag{5.9}$$

$$D_{tech} = \exp\left[\sum_j \omega_j^{*,t} \ln \frac{G_j^t}{G_j^{t-1}}\right] = \prod_j \exp\left(\omega_j^{*,t} \ln \frac{G_j^t}{G_j^{t-1}}\right) = \prod_j D_{tech,j} \tag{5.10}$$

Eq. (5.8) is obtained with a simple ratio of $E_j$ without a complex operation; the structural factor of Eq. (5.9) denotes the energy use structure in Korean industries, implying a social effect. The emission coefficient factor of Eq. (5.10) shows the GHG emission intensity, which depends on the specific technologies relevant to energy use in sector *j*, implying a technological effect.

To fulfill the basic property of the weight functions, the applied weight $\omega_j^{*,t}$, as suggested by Ang and Choi[25] in Eqs. (5.8)-(5.10), is as follows:

$$\omega_j^{*,t} = \frac{L(\omega_j^t, \omega_j^{t-1})}{\sum_{k,v} L(\omega_{k,v}^t, \omega_{k,v}^{t-1})} \tag{5.11}$$

where $\omega_j^t = \frac{G_j^t}{G^t}$, $\omega_j^{t-1} = \frac{G_j^{t-1}}{G^{t-1}}$

$$L(\alpha, \beta) = \frac{\alpha - \beta}{\ln(\alpha) - \ln(\beta)}$$

Summation in the denominator on the right side of Eq. (5.11) is taken over all final energy types and sectors. Here, the residual is equal to unity.

### 5.2.2 Korea's energy and GHG emission data: hybrid IO tables from 1985 to 2005

Since decomposition using an established model requires the structure of sectoral energy use and an environment inventory, the energy data and GHG emission data associated with economic activities were estimated using the E-IO table in monetary unit (KRW) and energy unit (TOE). The basic concept of the energy hybrid IO analysis was introduced in an earlier study [26] and was improved later [27]. The details of Korea E-IO table are described in chapter 3. However the industry sectors were rearranged into a total of 90 sectors from 403 sector IO tables issued by the BOK, as shown in Table 5.3. The industry sectors were classified into three groups consisting of energy group, energy intensive group, and energy less-intensive group, and these contained 8 energy sectors, 31 energy intensive non-energy sectors, and 51 energy less-intensive non-energy sectors, respectively. The final two groups are rearranged according to the Euclidean distance from the origin of rectangular coordinates based on the final energy input ratio at each industry and final energy input to the economy input as a whole [30]. The suffix "-p" at the end of some sectors' names in non-energy group shows, although they have the same name, original sectors listed in the original 169×169 sector IO table are rearranged into two different group according to the distance.

**Table 5.3 Sector classification of intermediate industries in Korea**

| Group | | Code and sector name |
|---|---|---|
| Energy group | | 1-Coal, 2-Fuel, 3-Nfuel, 4-Gas, 5-Lelec, 6-Felec, 7-Nap, 8- Heat |
| Non-energy group | energy intensive group | 9-Crops-p, 10-Fishery products, 11-Metallic minerals, 12-Nonmetallic minerals, 13-Sugar and starches 14-Fiber yarn, 15-Fiber fabrics-p, 16-Wood and it's products-p, 17-Pulp and paper-p, 18-Organic basic chemical products, 19-Inorganic basic chemical products, 20-Synthetic resins, synthetic rubber-p, 21-Chemical fibers, 22-Fertilizers, agricultural chemicals-p, 23-Other chemical products, 24-Glass products, 25-Pottery and clay products, 26-Cement and concrete products, 27-Other nonmetallic mineral products, 28-Pig iron and crude steel, 29-Primary iron and steel products, 30-Nonferrous metal ingots and primary nonferrous metal products-p, 31-Fabricated metal products-p, 32-Machinery and equipment of general purpose-p, 33-Wholesale and retail trade, 34-Eating and drinking places, and hotels and other lodging places, 35-Transportation and warehousing-p, 36-Public administration and defense, 37-Gas and water supply, 38-Medical and health services, and social security-p, 39-Other services-p |
| | energy less-intensive group | 40-Crops-p, 41-Livestock breeding, 42-Forestry products, 43-Meat and dairy products, 44-Processed seafood products, 45-Polished grains, flour and milled cereals, 46-Bakery and confectionery products, noodles, 47-Seasonings and fats and oils, 48-Canned or cured fruits and vegetables and misc. food preparations, 49-Beverages, 50-Prepared livestock feeds, 51-Tobacco products, 52-Fiber yarn-p, 53-Wearing apparels and apparel accessories, 54-Other fabricated textile products, 55-Leather and fur products, 56-Wood and wooden products-p, 57-Pulp and paper-p, 58-Printing, publishing and reproduction of recorded media, 59-Synthetic resins and synthetic rubber-p, 60-Fertilizers and agricultural chemicals-p, 61-Drugs, cosmetics, and soap, 62-Plastic products, 63-Rubber products, 64-Nonferrous metal ingots and primary nonferrous metal products-p, 65-Fabricated metal products-p, 66-Machinery and equipment of general purpose-p, 67-Machinery and equipment of special purpose, 68-Electronic machinery, equipment and supplies, 69-Electronic components and accessories, 70-Radio, television and communications equipment, 71-Computer and office equipment, 72-Household electrical appliances, 73-Precision instruments, 74-Motor vehicles, 75-Ship building and repairing, 76-Other transportation equipment, 77-Furniture, 78-Other manufacturing products, 79-Building construction and repair, 80-Civil Engineering, 81-Transportation and warehousing-p, 82-Communications and broadcasting, 83-Finance and insurance, 84-Real estate agencies and rental, 85-Business services, 86-Educational and research services, 87-Medical and health services, and social security, 88-Culture and recreational services, 89-Other services, 90-Nonclassifiable activities |

In the E-IO tables, matrix $\mathbf{A}^*$ can be easily calculated, as follows:

$$\mathbf{A}^* = \mathbf{Z}^* \cdot \left(\hat{\mathbf{X}}^*\right)^{-1} = \begin{bmatrix} \frac{TOE}{TOE} & \frac{TOE}{KRW} \\ \frac{KRW}{TOE} & \frac{KRW}{KRW} \end{bmatrix} \tag{5.12}$$

Here, $\mathbf{Z}^*$ is a matrix with a dimension of 90×90. It is also a new transaction matrix because the eight energy sectors in a conventional IO table have to undergo a change in their rows, from representing a monetary price to representing an energy unit. Thus, this matrix is comprised of an original inter-sector transaction matrix **Z** in the non-energy sectors and an energy flow matrix **E** in the energy sectors. In addition, $\mathbf{X}^*$ is a 90×1 vector which designates the total output; it is mixed as well with the monetary energy units according to various sectors. The caret symbol (^) represents the fact that the vector has been transformed into a diagonal matrix.

The GHGs for this study include carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) as in chapters 3 and 4. The emission coefficients of these components are calculated by considering the average calorific values of the 14 energy types used in Korea. We adopted GWP (Global Warming Potential) values of 21 and 310 for $CH_4$ and $N_2O$, respectively, to calculate the $CO_2$-eq. emissions with respect to a 100-year time horizon, as per the recommendations of the UNFCCC.

### 5.2.3 Changes in energy intensities

The direct and total (embodied) energy intensities are calculated with Eqs. (5.13) and (5.14), respectively as described in chapter 3.

$$\mathbf{EI}_{\delta} = \hat{\mathbf{F}}^{*}(\hat{\mathbf{X}}^{*})^{-1}\mathbf{A}^{*} \qquad (5.13)$$

$$\mathbf{EI}_{\alpha} = \hat{\mathbf{F}}^{*}(\hat{\mathbf{X}}^{*})^{-1}(\mathbf{I}-\mathbf{A}^{*})^{-1} \qquad (5.14)$$

$\hat{\mathbf{F}}$ is a 90×90 diagonal matrix. It consists of the total energy consumption of the energy sectors with 0 for all non-energy sectors as the diagonal elements. Figures 5.2 and 5.3 show the difference of energy intensity between 1985 and 2005 ($EI_{2005}$ - $EI_{1985}$) in Korea.

A negative value indicates that the energy intensity in 2005 was improved over that in 1985. A positive value, in contrast, indicates a measure of deterioration. Numbers written in the X-axis of Figure 5.2 - 5.5 show the industries listed in Table 5.3.

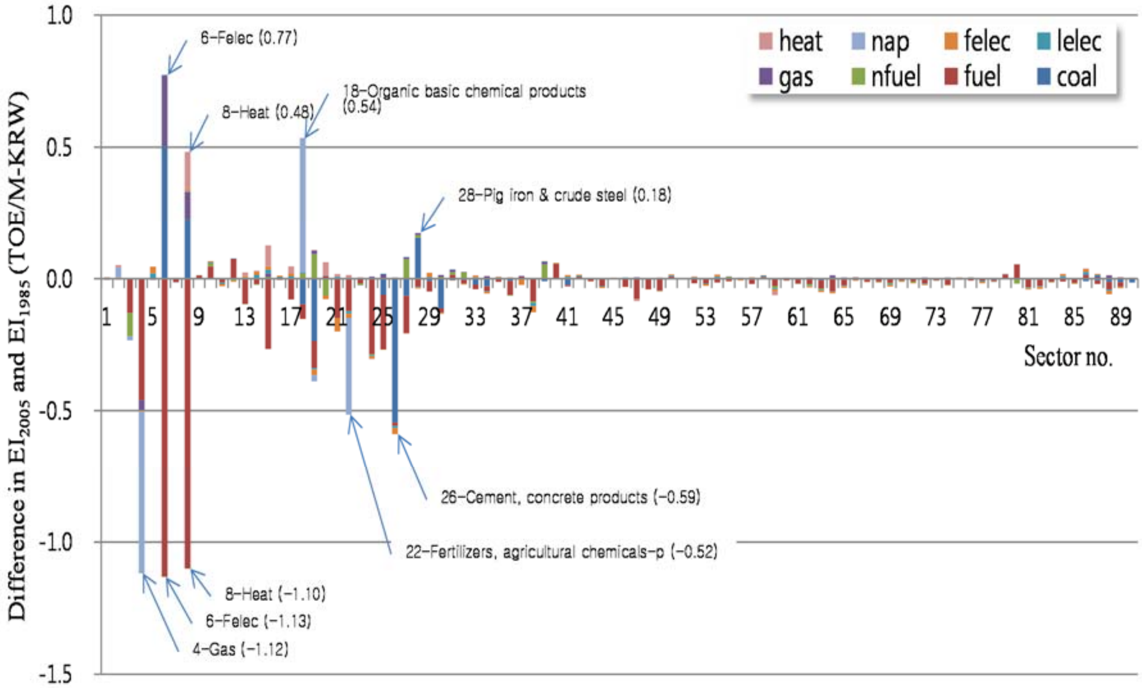



**Figure 5.2 Changes in direct energy intensities between 1985 and 2005.**

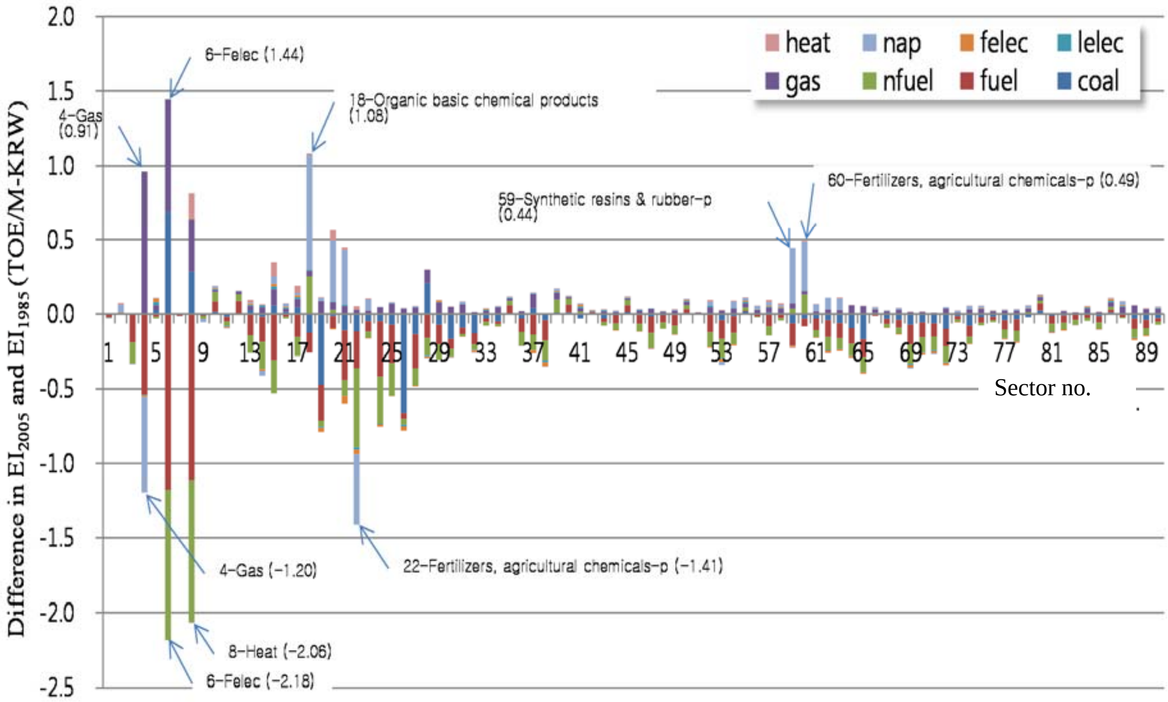



**Figure 5.3 Changes in embodied energy intensities between 1985 and 2005.**

The changes in the direct energy intensity can be summarized as follows (unit is TOE/M-KRW):

- Based on the changes in the intensity of the total sectors for each energy type, fuel energy-as indicated with the red bar-contributed to the largest decrease, with a total of -5.09. In contrast, gas energy contributed to the largest increase, with a total of 0.56.
- Regarding the individual sectors, a major decrease was observed in sectors #-4 (Gas, -1.12), #-6 (Felec, -1.13), #-8 (Heat, -1.10), #-22 (Fertilizers, agricultural chemicals-p, -0.52) and #-26 (Cement, concrete products, -0.59). In contrast, sectors #-6 (Felec, 0.77), #-8 (Heat, 0.48), #-18 (Organic basic chemical products, 0.54), and #-28 (Pig iron & crude steel, 0.18) demonstrated relatively significant increases.

Changes in the total (direct and induced) energy intensity, as shown in Figure 5.3, have the following characteristics (unit is TOE/M-KRW):

- Based on the changes in the intensity of the total sectors for each energy type, fuel energy showed the largest decrease of -9.10. Gas energy, on the other hand, showed the largest increase in its value, showing an increase of 4.69.
- In terms of individual sectors, sectors #-4 (Gas, -1.20), #-6 (Felec, -2.18), #-8 (Heat, -2.06), and #-22 (Fertilizers, agricultural chemicals-p, -1.41) showed a significant decrease. In contrast, sectors #-4 (Gas, 0.91), #-6 (Felec, 1.44), #-18 (Organic basic chemical products, 1.08), #-59 (Synthetic resins, synthetic rubber-p, 0.44), and #-60 (Fertilizers, agricultural chemicals-p, 0.49) showed a large increase in their values.

### 5.2.4 Changes in sectoral GHG emission intensities

Figures 5.4 and 5.5 indicate the range of GHG emission intensities, **GI**, from 1985 to 2005 by using Eqs. (5.15) and (5.16) as shown in chapter 3.

$$\mathbf{GI}_{\delta} = \hat{\mathbf{F}}(\hat{\mathbf{X}}^{*})^{-1}\mathbf{MA}^{*} \tag{5.15}$$

$$\mathbf{GI}_{\alpha} = \hat{\mathbf{F}}(\hat{\mathbf{X}}^{*})^{-1}\mathbf{M}(\mathbf{I}-\mathbf{A}^{*})^{-1} \tag{5.16}$$

M is a 90×90 dimensional symmetric matrix; it was modified to incorporate Korea's situation based on IPCC [31]. The factor M was modified according to the recommendations of the IPCC considering two points. The first considers the fraction of carbon stored and the fraction of carbon oxidized of each fuel to reflect the difference in the usage patterns of the eight energy sources. The second point considered that because the energy sources were combined into eight sectors, the emission factors were modified by the weighted average of the proportion of the included energy sources. The elements of the matrix represent coefficients of GHG emissions that occur when each industry uses fuel. Regarding the IPCC (1996) recommendation, the GHG emissions for $CO_2$, $CH_4$, and $N_2O$ were calculated. These, however, were simplified to CO2-equivalent emissions using the respective GWP values [31]. The unit of the matrix elements is the GHG emission of each gas under evaluation per unit use of energy (e.g., t-CO2-eq/TOE).

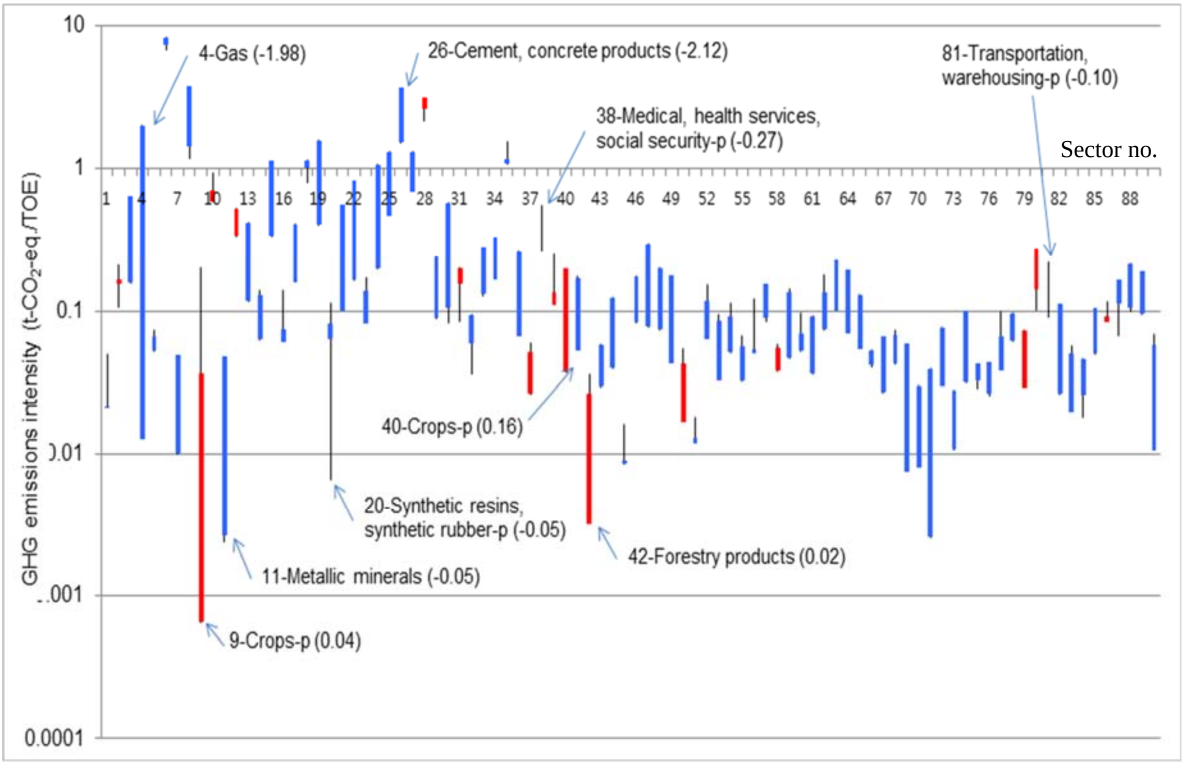



**Figure 5.4 Changes in direct GHG emission intensities during 1985-2005.**

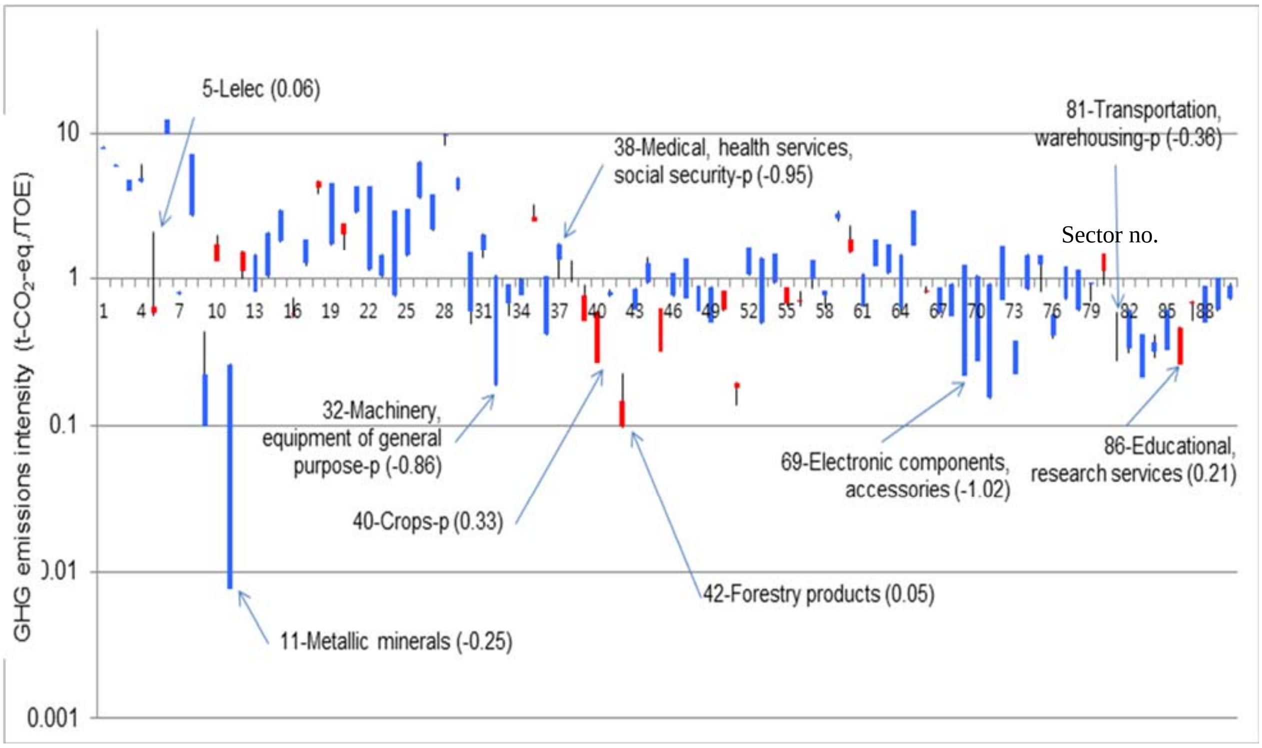



**Figure 5.5 Changes in embodied GHG emission intensities during 1985-2005.**

In Figures 5.4 and 5.5, the X-axis indicates 90 industrial sectors and the Y-axis denotes the GHG emissions per energy consumption (t-$CO_2$-eq./TOE) on a logarithmic scale. These figures are stock charts composed of blue and red bars; the blue bars indicate that the GHG emission intensity of a particular sector in 2005 decreased in comparison with that of 1985; the thick red bars imply the opposite case. In addition, the protruding black thin-line segment from the thick red or blue bars indicates a case in which the maximum or the minimum value of the changes during the corresponding period exceeds the horizon between the first year (1985) and the last year (2005).

In the direct emission matrix, a decrease in GHG emission was prominent in sectors #-4 (Gas), #-11 (Metallic minerals) and #-26 (Cement, concrete products). In contrast, it was found that GHG emissions increased in sectors #-9 (Crops-p), #-40 (Crops-p), and #-42 (Forestry products). In addition, although not shown prominently in the figures, sectors #-20 (Synthetic resins, synthetic rubber-p), #-38 (Medical, health services, social security-p), and #-81 (Transportation, warehousing-p) showed frequent increases and decreases during the period of analysis (Figure 5.4).

In the total emission matrix, a decrease in GHG emission was prominent in sectors #-11 (Metallic minerals), #-32 (Machinery, equipment of general purpose-p) and #-69 (Electronic components, accessories). In contrast, GHG emissions increased in sectors #-40 (Crops-p), #-42 (Forestry products), and #-86 (Educational, research services)(Figure 5.5).

## 5.3 Results and discussions

Dietzenbacher and Stage [32] pointed out that hybrid approach may induce arbitrary results that depend on the choice of units, rather than on changes in economic structure because of an economically meaningless sum of monetary and energy units during the calculations. However, in IDA which we adopted in this study, there is no place where this unit problem could happen. This is because energy and monetary values are not summed up together for the calculation.

### 5.3.1 Profile of the explanation of decomposition results

Korea, which is not obliged to reduce its GHG emissions, recognized the necessity of the establishment of climate change policy since about 1990s when the UNFCCC was founded at the Earth Summit in 1992 with the subsequent adoption of the Kyoto Protocol pertaining to industrialized countries in 1997. In this study, the decomposition analysis was performed for three periods: Phase I (1985-1990, 1990-1995), Phase II (1995-2000), and Phase III (2000-2005).

### 5.3.2 Decomposition results of the changes in GHG emissions

In Eqs. (5.9)-(5.10), $\mathrm{D_{soc}}$ and $\mathrm{D_{tech}}$ must have positive value. However, logarithmic index is easier to identify its change than the original exponential index as shown in eq. (5.9) or (5.10). Both indices are acceptable in the sense that there is a one-to-one correspondence between them. This study used the results from logarithmic index. Thus, the decomposition analysis for sector *j* has been transformed as Eqs. (5.11) and (5.12).

$$D'_{soc,j} = \omega_j^{*,t} \ln \frac{S_j^t}{S_j^{t-1}} = \ln D_{soc,j} \tag{5.11}$$

$$D'_{tech,j} = \omega_j^{*,t} \ln \frac{G_j^t}{G_j^{t-1}} = \ln D_{tech,j} \tag{5.12}$$

The rest of index was also converted to logarithmic one.

$$D'_{tot,j} = \ln D_{tot,j} \tag{5.13}$$

The decomposition results with respect to the three effects are depicted in Figures 5.6 and 5.7 using logarithmic indices. The figures associated with the analysis results were slightly modified in consideration of the energy market situation in Korea and considering the data treatment when the original IO table was composed by the BOK. One of the reasons for this is that Liquefied Natural Gas (LNG) and district heating were introduced in Korea in 1987 and 1992, respectively. As a result, in the analysis of the corresponding period, the effects of the market entry of these two fuels on the sector 4 (Gas) and sector 8 (Heat) were highly significant, overwhelming the other sectors (Figure 5.7). Another reason was related to a data-processing problem that arose due to the exclusion of energy sources according to changes in the data collection method. The BOK changed their data collection method such that no self-consumption of Naphtha appeared in the preparation of the IO table for 2005, which was published in 2008. Consequently, the effect of the market exit of sector-7 (Naphtha) during the corresponding period was exaggerated.

In this study, to specify the excessive incremental effects due to the entry of new energy sources and the exit of old sources, the letter ‘m’ in parentheses was appended in the right graphs in Figure 5.7. Here, the analyses were carried out under the assumption that the input values of the most recent period were continuously maintained.

Decomposition analysis of the changes in GHG emissions based on the E-IO tables for the years 1985 and 2005 revealed that the energy use effect ($D_{tot}$) had a positive impact while the technology change effect ($D_{tech}$) showed a negative impact. The social factor effect ($D_{soc}$) varied according to the sector (Figures 5.6 and 5.7).

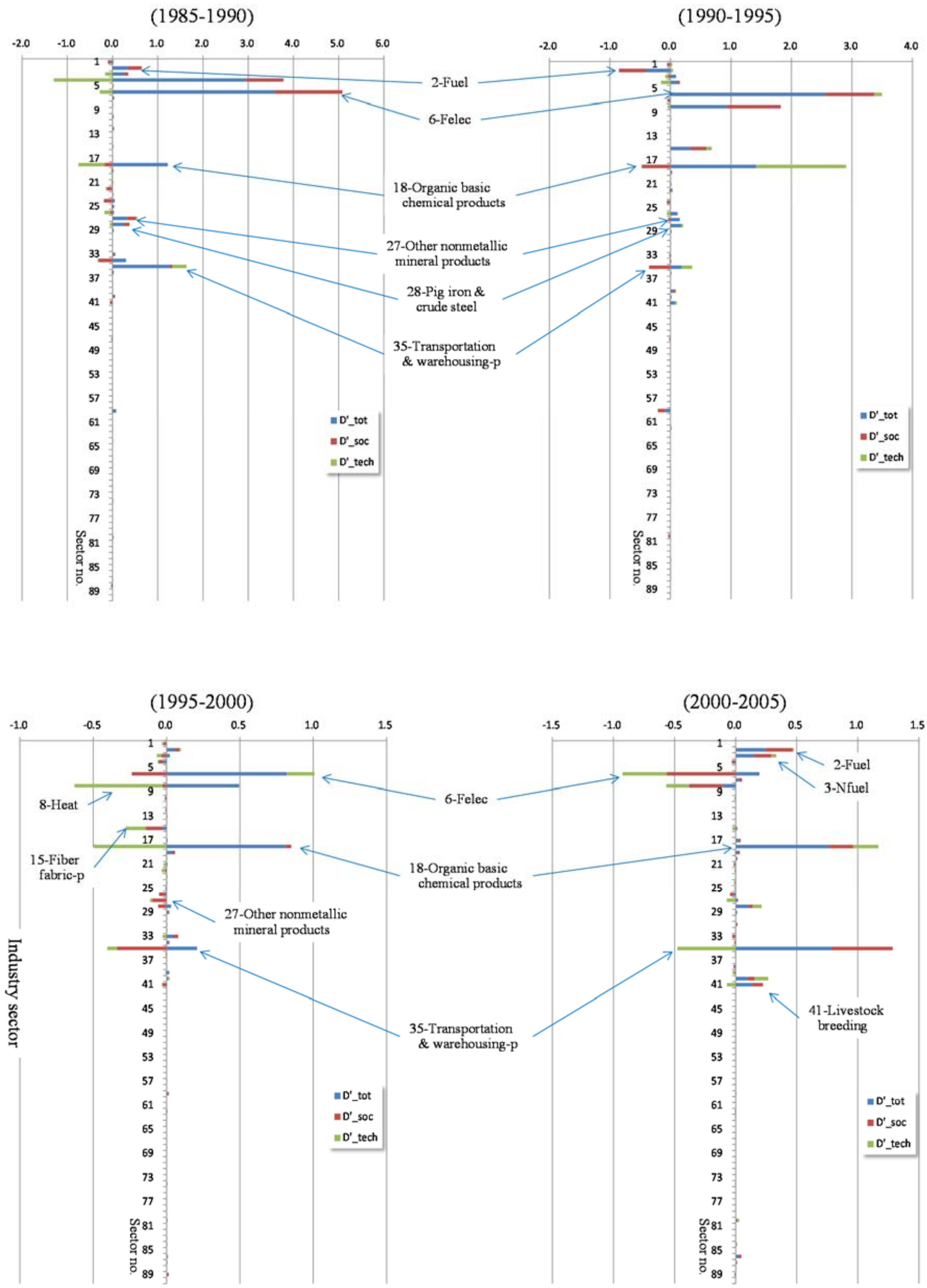



**Figure 5.6 Decomposition results of the direct GHG emissions for three effects.**

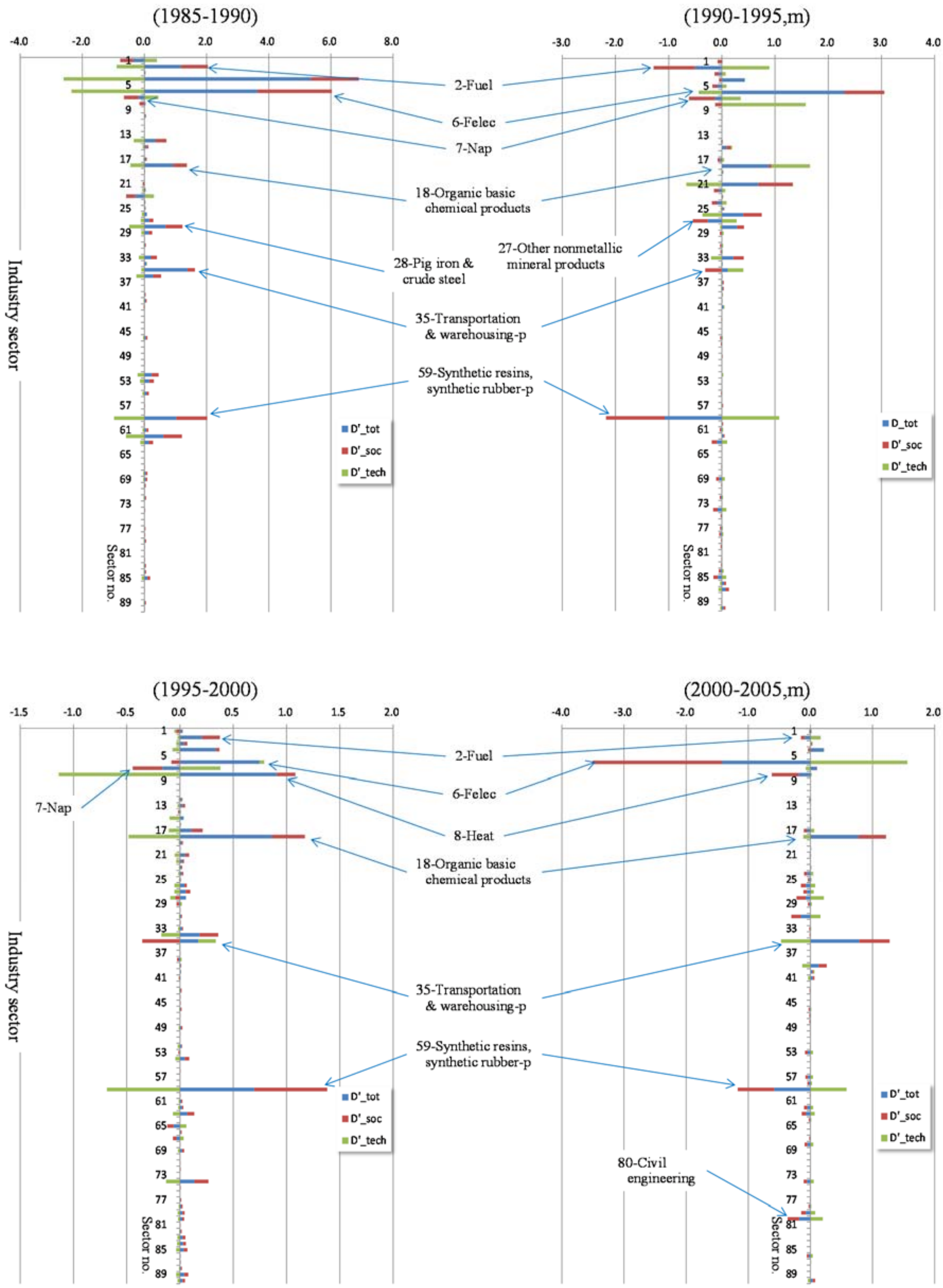



**Figure 5.7 Decomposition results of the embodied GHG emissions for three effects.**

Korea has considered climate change issues in its energy policy since the middle of the 1990s. An explanation of the three periods will be helpful for the reader to understand the situation in Korea. An increase in $D_{tot}$ was the greatest factor in the increase of the GHG emissions, whereas $D_{tech}$ had a growing negative effect from the "Phase II". However, as time passed, the magnitudes of the three decomposition effects have become smaller. This shows that changes in the GHG emissions according to energy use in the intermediate sectors of Korea have gradually stabilized. Moreover, it was demonstrated that this phenomenon has been more prominent in the energy sectors. In addition, the relative importance of $D_{tot}$, which has had a considerable impact on the "Phase I" , has tended to decrease gradually, whereas the relative levels of importance of $D_{soc}$ and $D_{tech}$ increased during the "Phase III" .

Hereafter, the results for each period are described separately.

***Phase I (1985-1995):*** $D_{tot}$ provided the largest contribution to the increase of GHG emissions, but it was found that the contribution of $D_{soc}$ was comparable in sectors #-2 (Fuel), #-4 (Gas), and #-8 (Heat). In sectors #-18 (Organic basic chemical products) and #-35 (Transportation & warehousing-p), a significant impact of $D_{tech}$ (upper side graphs in Figures 5.6 and 5.7) was evident. The $D_{tech}$ effect changed its contribution from negative to positive, while the $D_{tot}$ effect was found to follow the reverse path.

***Phase II (1995-2000):*** $D_{tot}$ had the greatest effect on the increase in GHG emissions as a whole and $D_{soc}$ followed, although it did in fact contribute to a negative impact in a few sectors. The impact of $D_{tech}$ increased so as to offset the impact of $D_{tot}$ in both the direct emission and total emission matrices of sectors #-8 (Heat), #-18 (Organic basic chemical products) and #-59 (Transportation & warehousing-p) (corresponding period in Figures 5.6 and 5.7).

***Phase III (2000-2005):*** $D_{tot}$ generally showed a positive impact due to the increase in GHG emissions. $D_{soc}$ and $D_{tech}$ showed negative as well as positive impacts across the various sectors. In particular, the $D_{tot}$ effect on sector 8 (Heat) turned negative from positive in the prior period due to the decrease in energy consumption in the direct emission matrix. In the total emission matrix, sector 8 (Heat), sector 59 (Transportation & warehousing-2p), and sector 80 (Civil Engineering) indicated negative indices because the negative values of $D_{tot}$ and $D_{soc}$ had surpassed the positive $D_{tech}$ (corresponding period in Figures 5.6 and 5.7).

### 5.3.3 Decomposition analysis of the aggregated data

According to Eqs. (5.8)-(5.10), Figure 5.8 shows the results of the decomposition analysis applied to the aggregated energy consumption data of Korea. The left and right sides of the figure represent the decomposition results of the direct GHG emission matrix and that of the total emission matrix, respectively. In terms of the direct GHG emission of Korea, during the first (85-90) and second terms (90-95), all effects increased. However, in the third (95-00) and fourth terms (00-05), the other effects except $D_{tech}$ tended to decrease gradually. $D_{tech}$ presented a small increase during the second (90-95) and third (95-00) terms. A slight change in the increase of $D_{tech}$ during these periods was attributed to the maintenance of the low prices of fossil fuels worldwide in an era before the efforts to address the climate change issues began in Korea.

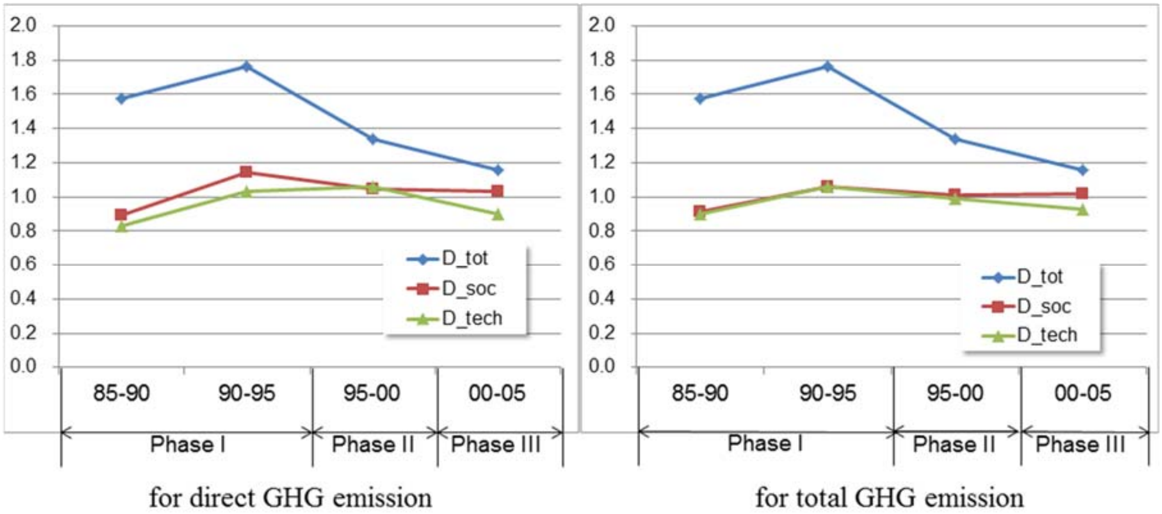



**Figure 5.8 Decomposition results for the aggregated changes in GHG emissions.**

On the other hand, all effects tended to decrease gradually after 1995 in an analysis of the total emissions. In addition, the contribution level of the three effects was found to have decreased as a whole. The largest contribution to the increase of GHG emissions (an effect having a value greater than 1 on the Y-axis) was $D_{tot}$; next was $D_{soc}$ (the $D_{soc}$ effect had almost no contribution to the changes in GHG emissions). In contrast, $D_{tech}$, which implies a GHG emission coefficient, contributed to a decrease in GHG emissions except during the second term (90-95) (an effect having a value smaller than 1 on the Y-axis).

## 5.4 Conclusion

The implementation of an aggregated GHG policy can diminish policy efficiency because the GHG emission characteristics are highly distinctive of each sector in an economy. Recently, therefore, a sectoral approach has been considered as required for the energy and environment policy. In this context, an IDA is also useful for understanding the characteristics of each sector and for preventing the illusion that either an increase (+) or a decrease (-) of GHG emissions is solely measured as a net value itself.

With respect to the energy and environment analysis of Korean economy, the following policy usefulness was obtained in the present work: By applying the IDA to the predetermined sectors obtained by the E-IO analysis instead of the national aggregate data, the homogeneity of the rearranged sectors under consideration was enhanced and a more realistic feature was made possible in the real world. In addition, through the analysis capability of the direct effect and the induced effect emphasized as an advantage of the IO analysis, both the direct and the induced GHG emissions can be measured.

Korea's energy and environment policy goals have the following priority. First, the aggregate demand saving is the top priority policy, because most of consumed energy relies on imports from foreign countries. Next, while undergoing two rounds of oil shocks in the 1970s, Korea's energy policy is concerned on the industry. As a part of the policy, the amounts of energy consumption in energy consuming industries are strictly managed. Finally, as importance of the international agreement on global warming, reducing GHG emissions in the energy sector was pursued. The policy resulted in the replacement of coal and oil with natural gas and nuclear energy emphasized as a low-carbon energy source.

The results of the IDA have well explained the performance of these national energy and environment policy. First, $D_{tot}$ was the biggest effect on the increase of GHG emissions in Korea. Total effect does not impact on the GHG emissions reduction because economic policy pursuing economic development through heavy and chemical industries overwhelmed national energy and environment policy. Thus, the reduction of energy consumption or GHG emissions by improving energy intensity was not achieved. Accordingly, the sectors with (+) value had a large number throughout analysis period. However, sectors having (-) value increased rapidly in non-energy groups and the number of the sectors with (-) value were more than double especially after the phase II in effect on $D_{soc}$. Number of sectors having (-) value were relatively larger than sectors having (+) but constant in energy intensive group, and number of sector having (-) was increased rapidly in energy less-intensive group. It shows that proportion of industry-specific energy use is rapidly diminishing in energy less-intensive group. In other words, it means national energy and GHG abatement policy influenced a lot in energy less-intensive group. Finally, similar temporal change of $D_{soc}$ was observed in $D_{tech}$. It means that the pattern of $D_{tech}$ was similar to that of $D_{soc}$ because the low-carbon energy, including nuclear and hydro, was introduced through electric power generation. The actual proportion of low-carbon energy has increased from 35.2% in 1985 to 41.7% in 2005.

This study is useful from the following viewpoints of national energy and environmental policy:

- As the relative importance of the energy sector is significant in the national low-carbon policy, it can take charge of the most basic role during the integration of policies and provide a quantitative foundation. Such a foundation is necessary for the establishment of an integrated policy in the form of useful information regarding any correlation among economic activities, energy consumption, and GHG emissions.
- As regards a long-term and future-oriented approach toward an energy policy, it can easily provide a basis in consistent, long-term and detailed data.
- It can provide a quantitative analysis foundation for a “Sectoral Approach”, the important issue that emerged during the post-Kyoto negotiations and that increased in importance with the adoption of the Bali Road Map in 2008.
- It is easy to minimize the time gap of economic data collection and policy planning through E-IO analysis which can generate useful information with sequential and consistent analysis, including economic activities, energy use, GHG emission and the verification of causes.
- The methodology and analytical techniques developed in this study can be easily applied to other problems if the relevant data is available.

In this study, changes in GHG emissions were decomposed into total energy consumption ($D_{tot}$), the sectoral structure of energy consumption ($D_{soc}$) and GHG emission according to energy use ($D_{tech}$) with the IDA method. Despite the advantages of this method, some limitations arose during the processes of the Divisia decomposition analysis.

- First, the three effects affecting GHG emissions can be measured quantitatively, but there are limits to directly explore causal factors related to the current status. It serves insufficient information for situational and experiential estimation and for interpreting effects of GHG emissions changes.
- Second, variations in the decomposition results showed unstable shift pattern unexpectedly. Usually quite stable changes of $D_{soc}$ or $D_{tech}$ can be expected in decomposition analysis. In this analysis, however, the amplitude of the variation was larger. Changes in these unstable trends can be explained in several ways. It implies that IDA may have a limitation in setting of the effects to be analyzed. Another finding gives inspiration on the effect selection and weighting measure as an average for the following researcher.
- Third, in a long-term energy analysis, the market entry of new energy sources and the exit of existing energy sources are common. In this situation, the use of the Divisia analysis and the LMDI index results in extraordinary values for specific sectors. In such cases, inconveniences in the observation of analysis results arise.

Nonetheless, we can conclude that IDA is a convenient decomposition tool for energy analyses and that it can provide useful pointers for national energy and environment policies when supplemented by other methods such as the econometric methods.

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# Chapter 6. Empirical Test of Index Decomposition Analysis

In this chapter, the acceptability was verified based on the validity of the analysis results counted from the whole procedure of the energy input-output analysis and decomposition analysis of two sectors: ‘organic basic chemical products’ and ‘cement and concrete products’. An empirical test was performed using changes in energy consumption, production, process improvements, and new facilities. Although the results showed unstable fluctuations of the Divisia index decomposition analysis, it was verified that the entire procedure can provide a useful decision-making basis in understanding each industry's energy consumption and GHG emissions.

## 6.1 Adequacy of the estimated energy data

The adequacy of the primary energy input calculated in this study from 1985 to 2000 has been verified through Table 4.2. The estimated energy consumptions from the E-IO table for 2005 are as follows (Table 6.1). KEEI in column (b) indicates Korea’s official energy data [1].

**Table 6.1 Comparison of the primary energy consumption**

(units: kTOE)

| Energy source | E-IO (a) | KEEI (b) | a/b (%) |
|---:|:---:|:---:|:---:|
| Coal | 56,045 | 54,788 | 102 |
| Crude petroleum | 123,395 | 101,526 | 122 |
| Natural gas | 31,775 | 30,355 | 105 |
| Water power generation | 450 | 1,297 | 35 |
| Thermal &self-power generation | 19,912 | 47,970 | 42 |
| Atomic power generation | 12,628 | 36,695 | 34 |

These estimations are acceptable as measures for Korea's energy and environmental policies because the sectoral price variation of the energy sources is small and the average national values for the energy sources were used.

## 6.2 Analysis of social and technical impacts on energy use and GHG emissions

### 6.2.1 Overall trends of plotting patterns from 1985 to 2005

Figure 4.7 shows the relationship between total energy and GHG emissions intensities for a 96-industry classification. Figure 6.1, in contrast, plots the direct energy intensities vs. GHG emission intensities for a 90-sector classification. The red lines and attached figures indicate the regression line passing through the origin and their slopes for three sectoral groups. The X-axis and Y-axis represent the energy consumption intensity and GHG emissions intensity, respectively.

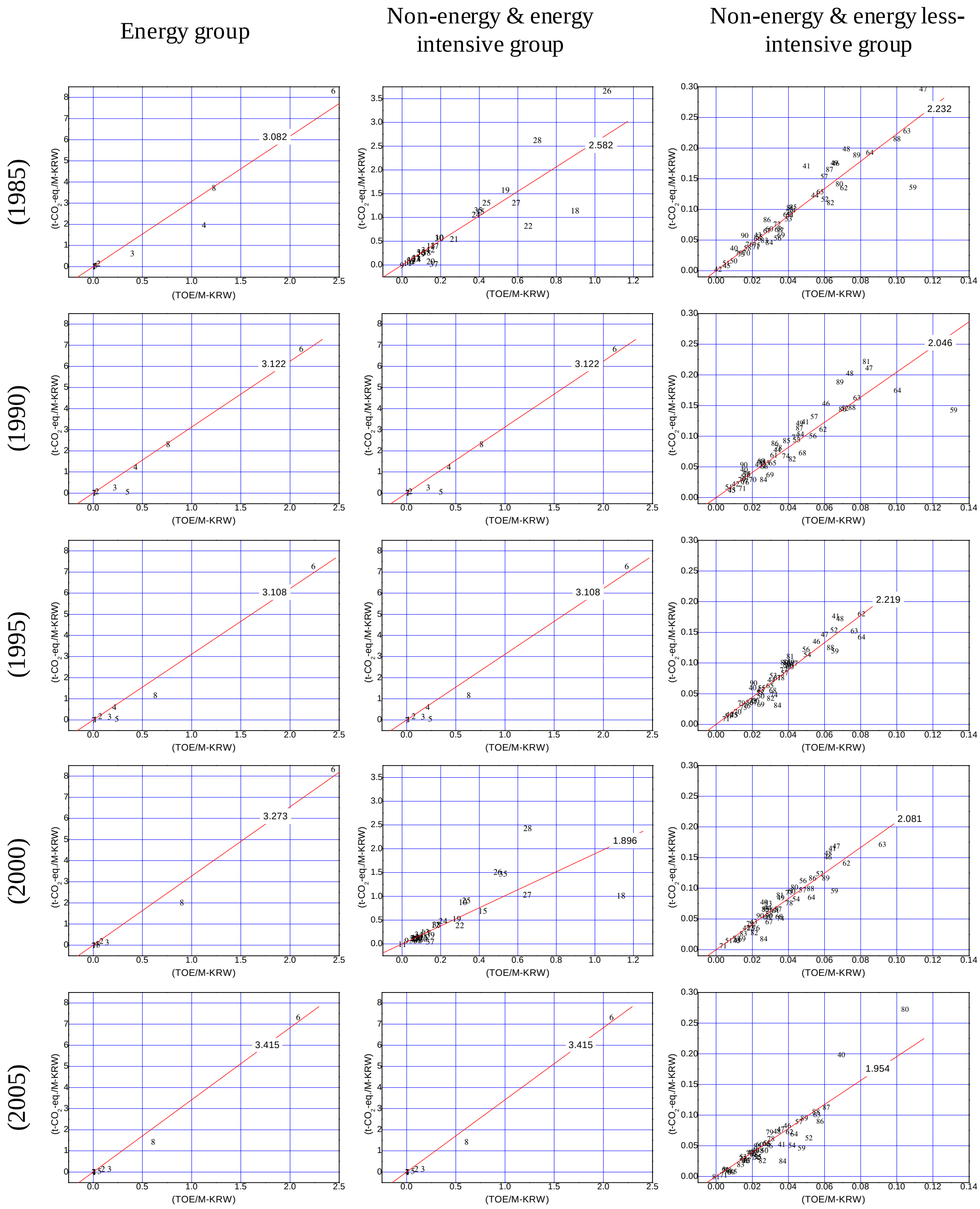



**Figure 6.1 Temporal distribution changes in direct intensities in each group.**

The changes in the slope of this line signify the rate of change in GHG emissions intensity with respect to a change in the energy intensity. Therefore, a decreasing slope over time means that the corresponding sector's GHG emissions intensity has improved. In contrast, an increasing slope implies that the GHG emission intensity has been degraded.

Slopes of direct intensities for the energy group (sector 1 - 8) over time increased, from 3.082 in 1985, to 3.415 in 2005. This indicates deterioration in the GHG emissions tendency. In contrast, the non-energy and energy intensive group (sector 9 - 39) and non-energy and energy less-intensive group (sector 40 - 90) had the slope of an improved pattern. In addition, the Euclidean distance from the origin to each sector has a message in the policy developer. The distance from the original point represents a worsening state of energy and/or GHG emissions intensities of the sector in question, whereas getting close to the original point represents an improving state.

### 6.2.2 Selection of distinct sector

In an effort to analyze the results of energy use and GHG emissions, as well as the implications of industrial policies, distinct sectors were selected from non-energy and energy intensive groups that have relatively high percentages of energy use (sector 9-39). The sectors have a relatively higher proportion of energy use and are analyzed in terms of socio- and technical- impacts on their energy use and GHG emissions.

The specific sectors are selected as follows based on the temporal distribution patterns of the sectors and IDA results, as shown in Figures 6.2 and 6.3:

- trending upward to the right: sector-18, organic basic chemical products including petrochemical basic products, petrochemical intermediate products, coal chemicals, and other basic organic chemicals, and;

- trending downward to the left: sector-26, cement & concrete products including cement, ready mixed concrete, concrete blocks, bricks, and other concrete products.

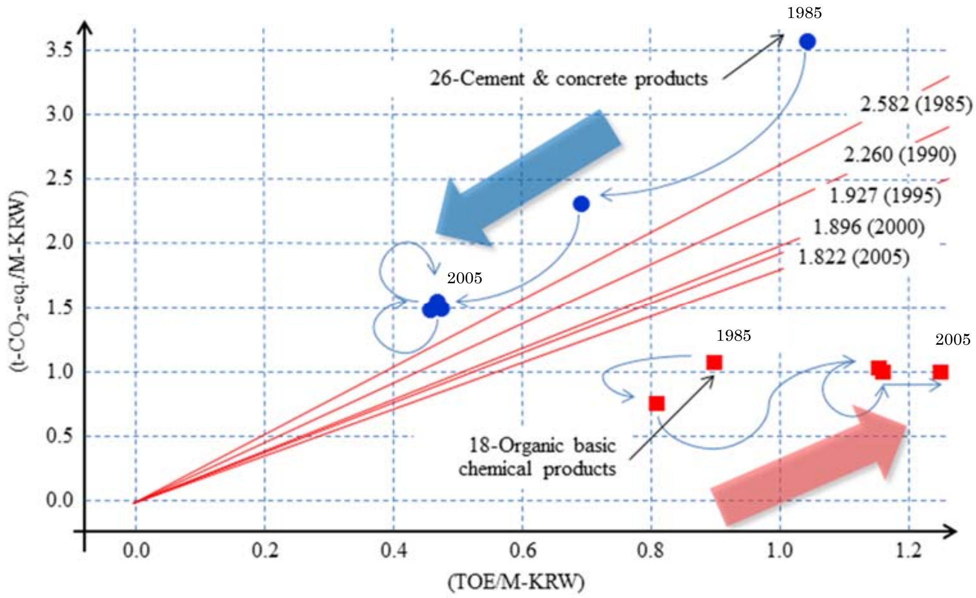
The red lines in Figure 6.2 have the same meaning as mentioned before. They show that the GHG emissions from the sectors in the non-energy and energy intensive groups are improving. Sector-18 shows an improvement by moving toward the origin from 1985 to 1990, and thereafter gradually moving away from the origin by 2005. In contrast, sector-26 has continuously shifted toward the origin since 1985.

The estimators generated from the E-IO analysis were compared with the actual data during the analysis period for validation of the E-IO analysis (Table 6.2).

Table 6.2 Comparison of energy consumption (kTOE) of 2 sectors

| | | 1985 | 1990 | 1995 | 2000 | 2005 |
|---|---|---|---|---|---|---|
| Sector-18 | E-IO(a) | 3,229,919 | 6,552,538 | 19,653,790 | 29,667,193 | 40,111,151 |
| | KEEI(b) | 5,088,000 | 9,839,000 | 22,838,000 | 35,641,000 | 42,488,000 |
| | a/b(%) | 63 | 67 | 86 | 83 | 94 |
| Sector-26 | E-IO(a) | 2,975,174 | 3,531,667 | 4,839,842 | 4,260,451 | 4,577,354 |
| | KEEI(b) | 1,926,847 | 3,055,314 | 3,868,469 | 3,946,645 | 3,492,593 |
| | a/b(%) | 154 | 116 | 125 | 108 | 131 |

Adequate KEEI (b) data of Sector-26 was not found. Thus, the data were partly extrapolated based on the reports of Korean energy consumption surveys [2]. It was created by a bottom-up process and was the results of a sample survey of a sector. Therefore, the value does not indicate the overall energy consumption of the sector. These estimates showed relatively acceptable results. The overall gap between the estimated value and the actual data is based on the difference in the aggregation of components. The reason for the estimation error in the two sectors is the difference in the aggregate sectors in general.




Remarks: Regression lines indicate relations for entire sectors. Blue circles and red squares are for two specific sectors in energy intensive group.

**Figure 6.2 Temporal changes in the relationship between energy and GHG emission intensities.**

$D_{soc}$ denotes the energy use structure in Korean industries. It can represent that how much an industry or sector has been activated compared to other sectors in the economy. $D_{tech}$

shows the GHG emission intensity, which depends on the specific technologies relevant to energy use in the corresponding sector. It will be able to estimate the relative level of process innovation and use of low-carbon energy technology.

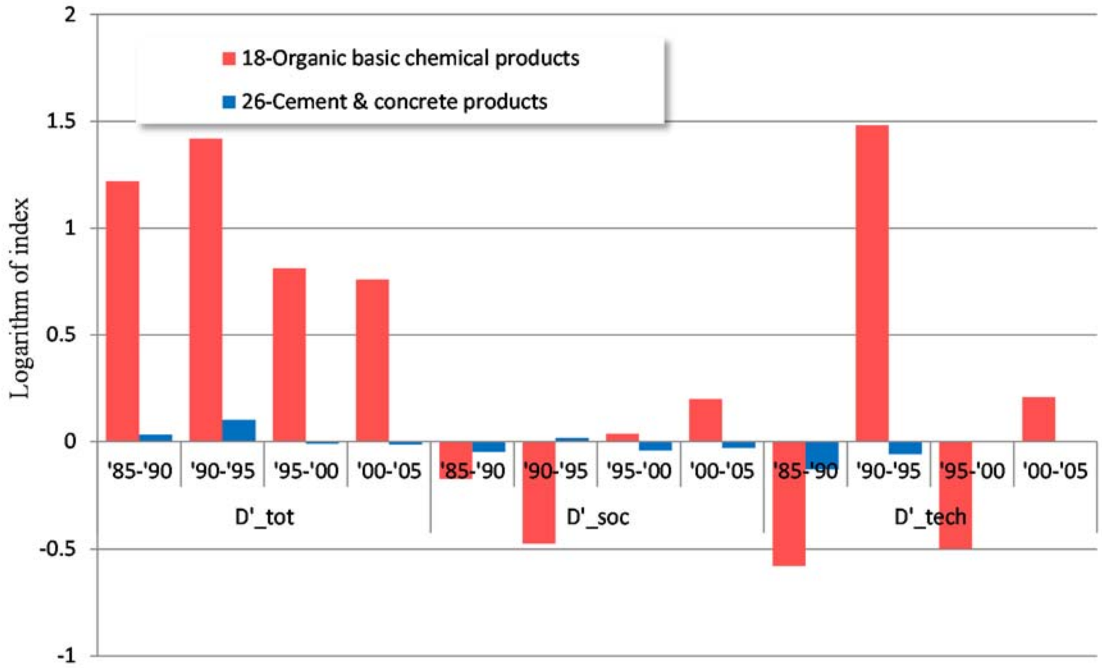



**Figure 6.3 IDA results for the two sectors in energy intensive group.**

Figure 6.3 demonstrates that even if the distribution pattern of a sector shows a continual improvement over time, the results of decomposition analysis can produce different values. For example, in terms of the overall pattern of sector-26 has been improved during 1990 and 1995, but in terms of the IDA the $D_{tot}$ and $D_{soc}$ effects have contributed to an increase (+), while $D_{tech}$ contributed to a decrease (-).

The IDA results shown in Figure 6.3 are difficult to analyze for statistical trends. This is too small a number of observations to obtain a statistical significance and stable estimation along the time series analysis. The reason for the IDA results will be analyzed empirically in the next section through an investigation of the circumstance changes of 2 specific industries.

## 6.3 Empirical analysis of two specific sectors

### 6.3.1 Comprehensive analysis of sector-18

Sector-18 (organic basic chemical products) is an energy-intensive industry in a highly competitive global economy. This industry uses the most energy to extract the intermediate goods such as ethylene, propylene and benzene from the raw materials such as naphtha. In addition, more energy is consumed in processing intermediate goods, the production of ammonia used as fertilizer, and the production of caustic soda for synthetic detergent. On average, the share of energy in total production costs is about 9%. For some petrochemicals, it rises up to 75%. Therefore, the chemical industry has already invested in energy efficiency improvement over many decades.

The petrochemical industry has a close relationship with cutting-edge new industries, such as the IT industry. High-tech industrial development needs the support of the petrochemical industry and requires the expanding role of the sector. The petrochemical industry is gradually expanding its scope through continuous research, and is developing high value-added intermediate goods through the high-performance engineering of plastics and fine chemicals.

GHG emissions from sector-18 have been increasing owing to the growth in demand for industrial gas, which is required for heavy electrical equipment and semiconductor production.

Because the proportion of GHG emissions from this sector is more than 6% of the national total emissions in South Korea, the national GHG reduction policy must include this sector [3]. The raw material of the petrochemical industry is naphtha, which has high carbon content. After oxygen combines with carbon, GHGs are emitted. Unlike other industries, the overall GHG emissions during manufacturing process of the petrochemical industry accounts for more than 10% of all GHG inventory in sector-18.

Under the circumstances of the South Korea statistical account, if the oil refinery industry is added to the petrochemical industry, the proportion of sector-18 will be more than 5% of the energy use in South Korea. The energy efficiency of Korean sector-18 was recorded as the world's highest as a part of the whole process. However, the cost proportion of naphtha is 60%, and that of energy is more than 10% of the whole cost in South Korea. Thus, the competitive factors in this industry will depend on the energy efficiency.

Over time, the distribution of sector-18 shows a trend upward and to the right (Figure 6.2). The deteriorating pattern of this sector can be explained in a real economy in terms of the social and technical aspects.

- Among the steep growth of the IT industry, the total energy consumption was increased. In the social aspect, sector-18's proportion of energy consumption to the national total is maintained at 1%. This implies that energy-saving efforts were not made.

- For the total effect, the annual average growth rate of the final energy consumption was 6.7% during the analysis period. In particular, the rates of Gas and Naphtha were 15.6% and 11.2%, respectively. Such high growth rates of the two sectors have influenced a positive direction in $D_{tot}$.

- For the social effect, because of an entry barrier, few companies were managing their business for domestic demand until 1995. Through an improvement in the process, companies have been working to improve their energy efficiency. The energy consumption per unit of production has been improved by 3% per year during this period. A large-scale petrochemical complex was built in 1991. The movement of raw materials and intermediate goods is reduced by integrating related industries, where the energy efficiency has been significantly improved as a result. The development of new technologies and processes has not been carried out since the currency crisis of 1997, and large-scale capital investment has been reduced. Therefore, in this industry, improvements in energy efficiency have stagnated.

Ethylene production capacity stood at 5.75 million tons in 2005, from 5.02 million tons in 1999. The trends of these changes in sector-18 affect the share of energy consumption. This is a pattern that matches the changing social effect.

- For the technical effect, 6 new companies entered the market owing to deregulations during the early 1990s. The new companies had a similar pattern of energy use, and their GHG emissions have increased rapidly. These efforts mean that the profile can lead to an increase in GHG emissions directly in the event of the entry of a new comer of this industry or a delayed improvement in energy efficiency. Changes in the structure of the energy consumption in this industry are needed. This means that a conversion effort is required to lower the carbon containing energy sources.

- In addition, the development of high value-added products in the industry is also an important factor because the common denominator of the energy intensity and GHG emissions intensity is the volume of the added value, which means that if a further reduction of energy use and/or GHG emissions is difficult, higher value-added products should be developed. As an example, while South Korea ranks fourth in the world in the scale of production of the total amount of universal resin in polymeric materials, the technology level in polymer materials for cutting-edge industries remained at 45% compared to the United States, and at 60% compared to Europe and Japan.

### 6.3.2 Comprehensive analysis of sector-26

Sector-26 (cement and concrete products) is considered to be one of the most important building materials around the world. It is mainly used for the production of concrete. Concrete is a mixture of inert mineral aggregates, e.g., sand, gravel, crushed stones, and cement. Cement consumption and production are closely related to construction, and therefore to general economic activities. Cement is one of the most highly produced materials in the world.

Three production steps are distinguished in the description of cement production:

- Preparing raw materials: mixing/homogenizing, grinding, and preheating (drying) produces the raw meal.

- Burning raw meal to form a cement clinker in a kiln: the components of the raw meal react at high temperatures (900 - 1500 °C) in the pre-calciner and in the rotary kiln, to give cement clinker.

- Finish grinding the clinker and mixing with additives: after cooling the clinker is ground together with additives.

Cement production is a highly energy-intensive sector. It is well known that the energy consumption of the cement industry is estimated to be about 2% of the global primary energy consumption, or almost 5% of the total global industrial energy consumption. Owing to the dominant use of carbon intensive fuels, e.g., coal, in clinker making, the cement industry is also a major emitter of GHG emissions. In addition to energy consumption, the clinker making process also emits GHGs from the calcining process. The cement industry contributes 5% of total global $CO_2$ emissions.

The major source of its $CO_2$ emissions is the chemical reaction during the production process. However, this study focuses on the $CO_2$ emissions associated with the energy use of the cement industry. The main energy sources in the cement manufacturing process are B-C oil, coal, electricity, and alternative energies (alternative fuel and raw materials). Among them, heavy oil and bituminous coal are used in direct heating (primarily kiln fuel), and electricity is used for a power supply for crushing and mixing. Other sources are used for the heating, lighting, etc., but the quantity is negligible.

The GHG emissions in cement manufacturing come directly from the combustion of fossil fuels and from calcining the limestone in the raw mix. An indirect and significantly smaller source of GHG emissions is from the consumption of electricity, assuming that the electricity is generated from fossil fuels. Roughly half of the emitted GHG originates from the fuel and half originates from the conversion of the raw material.

This sector changed production facilities from a wet to dry process to improve the energy efficiency. This process substitution can reduce the energy consumption by up to 50%. Energy costs account for 20–40% of the cement production cost. The energy consumption required to produce one ton of clinker is 5.9 – 6.7GJ for the wet process and only 2.9 – 4.6GJ for the dry process.

Over time, the distribution of sector-26 shows a trend upward and to the right (Figure 6.2). The deteriorating pattern of this sector can be explained in the real economy in terms of the social and technical aspects.

- For the total effect, the annual average growth rate of the final energy consumption was 6.7% during the analysis period. In particular, the rates of Nfuel and electricity were 17.6% and 9.9%, respectively. Such high growth rates of the two sectors have influenced a positive direction in $D_{tot}$.

- For the social effect, the process improvement influenced $D_{soc}$ to reduce the GHG emissions in general. However, $D_{soc}$ has increased during 1990–1995. The construction of 2 million housing units along the government’s expansion policy in 1988 led to a surge in cement production with a 10.4% annual average growth rate. Negative values showed that process improvements effect was discharged, and has been influenced from the decline in cement consumption since 1995. Cement production is reduced 4.7 million tons in 2005 from 5.5 million tons in 1995. This means an annual average growth rate of -1.5%.

- In contrast, for the technical aspect, process improvements have an influence on the energy efficiency and alternative energy. During 1985–1995, switching from coal to electricity affected the change in $D_{tech}$. Therefore, the process improvement was a negative factor during this period. During the economic downturn of sector-26 since 1995, a change of $D_{tech}$was rarely seen. This is because the energy alternation and process improvement were faced with limitations. Sweeping relaxation of the regulation on waste usage can be a breakthrough of the limitations of these improvements. Currently, the use of waste fuels is highly regulated in South Korea. Thus, the proportion of waste fuel in the cement sector has remained at 2.5% since the 1990s. This is significantly lower than the levels of Germany (38%), France (33%) and Japan (16%) [4]. Deregulation will lead to an increase in the utilization of waste fuel instead of coal, and it is expected to have additional reduction of GHG emissions from the cement sector.

## 6.4 Conclusion

This holistic approach is useful in an understanding of the industry's energy and GHG footprint.

The following efforts are required to improve the aforementioned two sectors:

- One is the reduction of energy consumption through energy conservation and an efficiency improvement of sector-18. Even if domestic petrochemical production companies produce the same product, there are large differences in the energy intensity of each company. The intensity of a company was 70% higher than that of the most efficient company in ethylene production, while another company showed a 150% higher intensity than the most efficient company during benzene production. Even if they have different operating conditions, it is evident that the process improvement for energy reduction is urgent. NCC (Naphtha Cracking Center) was evaluated to be the most energy consuming process. Therefore, the most effective process for the reduction of GHG emissions would be the NCC process.

- The other is that high-value added products should be sought. This exploitation should cover the efforts to convert low-price raw materials into high-value added products, as well as to create new higher value-added products.

A temporal plot of the relationship between energy and GHG emission intensities makes it easier to determine improvement opportunities where a large effect can be expected with less effort. As shown in Figure 6.2, a huge improvement in the cement industry occurred between 1985 and 1995. After that, it is difficult to find significant improvements through 2005. This means that technological innovation is needed to overcome the limits of gradual improvement in the cement industry from now on. Emissions of GHG can be reduced by the following efforts:

- improvement of the energy efficiency of the process;

- shift to a more energy efficient process (e.g., from a (semi) wet to (semi) dry process);

- replacement of high carbon fuels by low carbon fuels;

- application of the low clinker cements (increasing the ratio of additives to cement), that is, blended cements;

- application of alternative cements (mineral polymers);

- removal of GHG from the flue gases.

In an industry-specific analysis like this, the limitation of an IDA analysis should be recognized. In an IDA analysis, a slight change in data can excessively influence the result of a decomposition analysis, resulting in an unstable tendency. Therefore, it is necessary to study the ways to stabilize this unstable tendency, such as the selection of weighted values.

These results can then be the basis of an atlas map to support a sectoral policy in South Korea. For example, energy savings in a sector having a greater $D_{soc}$ have to be emphasized, while a sector having a greater $D_{tech}$ shall be encouraged to transition into a clean process using less carbon containing energy. National targets for energy and GHG reductions can be achieved effectively and efficiently using a sectoral approach. Therefore, it is necessary to introduce this method into a national policy as soon as possible.

## References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# Chapter 7. Conclusion

Because Korea is not an Annex I country in the Kyoto Protocol, it does not have GHG reduction obligations. Nevertheless, Korea wishes to participate in the worldwide efforts to mitigate GHG emissions because its trade volume ranks 9th in the world with a high dependence on foreign goods. Korea's proportion of imports and GHG emissions comprise more than 25% and 80% of the energy sector, respectively. Therefore, in order to minimize the contraction of economic activities while maximizing the reduction of GHG emissions, effective policy-making is necessary in the energy sector.

This study established a model that quantitatively examines the relationship between the economic activity, energy use, and GHG emissions with analyzing the time series changes of the decomposed factors of GHG emissions. The analysis model produced hybrid unit E-IO tables from 1985 to 2005 with 90×90 sectors. The sectors present in the tables, including the previously 96×96 sectored E-IO tables from 1985 to 2000, were aligned using decomposition and combination for similar sectors in terms of energy use based on the benchmark IO table of 2005. The 2005 benchmark table contains 403 categories announced by the BOK. Then, the decomposition of time series change factors was performed using the index decomposition analysis (IDA) method. The achievements along the E-IO analysis path were prepared as results and were discussed in each chapter.

The following were accomplished in this study.

- Previous studies have been conducted based on the energy consumption survey conducted by KEEI every three years. Therefore, it is inevitable that the industry classification standards and survey depth are not consistent with the monetary IO reported by the BOK. Thus, studies were not able to follow as much detail as the BOK classified. Unlike previous studies using 20,000 samples, this study only used data from the BOK and can obtain results that are as detailed as the original BOK classifications.
- The established E-IO model analyzed the characteristics of each energy source as used in each sector of the Korean economy, as well as the emissions characteristics of three GHGs ($CO_2$, $CH_4$, and $N_2O$). The compatibility of the estimated emissions was verified in a follow up comparison with those in the national communication report prepared for UNFCCC.
- The presented requirements of the energy conservation condition and Hawkins-Simon condition were reviewed during the E-IO model development process. In addition, the compatibility of Dietzenbacher and Stage’s statement that “a hybrid approach may induce arbitrary results that depend on the chosen units, rather than on changes in the economic structure” was verified as part of the IDA process.
- Finally, the structural analysis of specific sectors for empirical analyses of industries was attempted.

The E-IO analysis used in this study has the following additional advantages.

- The method suggested in this study can analyze the energy use and GHG emission characteristics for each sector, as can be achieved in the conventional IO analysis. Moreover, the relationship analyses of the emission and intensity of each GHG species and the source-wise energy use for each industry are possible. Relationship analyses, such as the induced effect and linkage effect, between industries are also possible. The implementation of the E-IO analysis has an important function in policy effectiveness such as the GHG emissions quota system, which was effective in Korea from 2012.

- A metric model that describes climate change must include not only the direct emissions of pollution sources but also the induced indirect emissions. An assessment that incorporates the indirect emissions should be considered carefully during discussions for a new climate change regime, such as in the post-Kyoto Protocol era, that encourages the participation of developing countries, because it is difficult to expect a real worldwide or nationwide decrease in pollutant emissions if countries or industries simply transfer emissions from one country or industry to another. Moreover, not only does a national climate change countermeasure decrease pollutant emissions, but it also directly affects the sustainable growth of an economy. Because the enforcing of environmental policies has a profound effect on economic progress, a metric analysis of the relationship between the economy, energy, and environment is essential.
- The analysis results are useful for establishing a national energy-GHG policy on a sectorial basis considering the characteristics of each industry, which is recommended rather than an aggregated policy that would be subjected to the nation as a whole. That is, this signifies the possibility of policy planning that reflects the total energy use and/or GHG emission effect, including the induced effects rather than only the direct effects. In addition, depending on whether the priority of the policy goals is energy consumption reduction or GHG emission reduction, reliable quantitative data can be provided to establish an appropriate industry-specific policy basis.
- It can provide a tool such as a geological atlas, which enables the exploration of an organic relationship between the economy, energy, and environment. Based on the E-IO table's recorded economic activities, there is a great advantage in analyzing the relationship between the economy and energy. This is also expected to provide reliable results if it is supplemented with the results obtained from international organizations such as the Intergovernmental Panel on Climate Change (IPCC).

In order to improve the accuracy of the E-IO analysis model used in this study, the following requirements should be satisfied.

- The national statistics system must be unified. In order to produce highly reliable E-IO tables through the collection and verification of national energy statistics, the GHG emissions statistics and economic statistics must be consistent and the differences between the sector classification standards and data accounting standards should be harmonized.
- An E-IO table with much higher sectorial resolution must be developed, such as the BOK's basic IO table [27] with a classification system using 403 sectors. More detailed sector classification is required in order to establish a more sophisticated and useful energy-environment policy using the analysis results.
- Energy sources must be classified in more detail, particularly according to the final energy use pattern. In this study, the energy sources were grouped into 14 types through verification with the energy balance sheet listed in KEEI [1], but a more detailed sector classification is required in order to practically support Korea's energy policy. For example, in order to implement a more effective analysis of climate change from the transportation sector, fuels such as gasoline, diesel, kerosene, bunkers, LPG, and LNG should be ungrouped and each should be set as an independent sector.

- In this study, a single weighted average price was used for each energy source when composing the E-IO tables; however, in reality, the same energy source is priced differently from sector to sector. For example, electricity tariffs vary across consumers and a differential pricing system is being implemented to foster specific industries.

This study can lead to the following future works.

- The energy and GHG emissions analysis in this study can be applied to various hybrid industry-related analyses according to the changes in the subject of policy establishment characteristics. For example, it allows to the additional assessment of global and/or regional environmental factors, such as the acidification potential and ozone layer depletion potential, while minimizing the additional work required in order to analyze the effects of environmental pollution on international trade.
- The effective achievement of a common global goal could be accomplished through a cross-national comparative analysis. In particular, when promoting efficiency lessons gained from the experiences of developed nations in energy-environment policies as best practice, it can be expected that sharing the efficient policy can lead to low energy use or GHG emissions reduction without inhibiting the economic growth in developing nations.
- Furthermore, the relocation or transfer effect analysis of the cross-national energy consumption or GHG emissions is possible through a multi-sector economy linkage analysis. This can provide meaningful information for the establishment of global energy and GHG policies.
- Finally, the expansion of the time span to predict future values through the application of conventional inter-industry analysis methods such as MEM or RAS is necessary. This allows visual simulations of the effects that can be expected with the implementation of policies, which can provide motivation for decision makers to become more aware of the importance of implementing the policy in focus.

The valuable results of the energy input-output analyses proposed in this paper suggest that the proposed model will be a useful analytical tool for the establishment of national energy and GHG policies.

# Appendices

Appendix 1. Sector Classifications

Appendix 2. Sectoral Energy Intensity

Appendix 3. Sectoral $CO_2$ Emission Intensity by Energy Use

Appendix 4. Sectoral $CH_4$ Emission Intensity by Energy Use

Appendix 5. Sectoral $N_2O$ Emission Intensity by Energy Use

Appendix 6. Sectoral GHG Emission Intensity by Energy Use

Appendix 7. Decomposition Results of the Direct GHG Emissions for Three Effects

Appendix 8. Decomposition Results of the Embodied GHG Emissions for Three Effects

# Appendix 1. Sector Classifications

## ✧ Classification method according to energy input

- Final energy input ratio of sector *i*

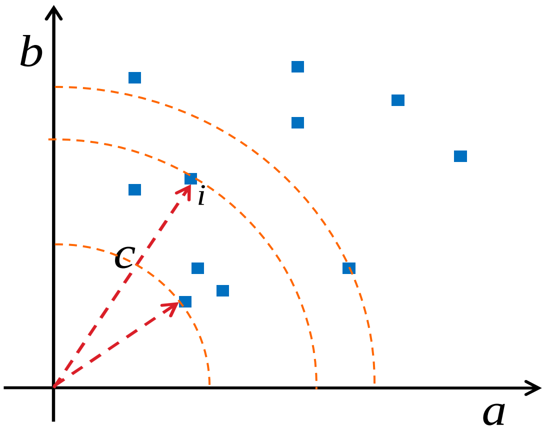
$$a_i = \frac{\text{Final energy input for sector } i}{\text{Total input for sector } i}$$

- Proportion of final energy input of sector *i*

$$b_i = \frac{\text{Final energy input for sector } i}{\text{Total energy input to entire economy}}$$

- Distance of Sector *i*

$$c_i = \sqrt{a_i^2 + b_i^2}$$




※ In this study, less energy intensive group was composed of the sectors of the bottom 30% of the cumulative distance distribution

## ✧ Relationship between various classification

| no. | E-IO (96) | no. | E-IO (90) | no. | M-IO (404) |
|---|---|---|---|---|---|
| 1 | Coal | 1 | Coal | 0031 | Anthracite |
| | | | | 0032 | Bituminous coal |
| 2 | Crude petroleum | 2 | Fuel | 0033 | Crude petroleum |
| 3 | Natural gas | 4 | Gas | 0034 | Natural gas |
| 4 | Coal products | 1 | Coal | 0137 | Coal briquettes |
| | | | | 0138 | Coke and other coal products |
| 5 | Naphtha | 7 | Nap | 0139 | Naphtha |
| 6 | Gasoline | 2 | Fuel | 0140 | Gasoline |
| 7 | Fuel Oil | 2 | Fuel | 0141 | Jet oil |
| | | | | 0142 | Kerosene |
| | | | | 0143 | Light oil |
| | | | | 0144 | Heavy oil |
| | | | | 0145 | Liquefied petroleum gas |
| 8 | Misc. Petroleum refinery products | 3 | Nfuel | 0146 | Lubricants |
| | | | | 0147 | Misc. Petroleum refinery products |

| | | | | | |
|---|---|---|---|---|---|
| 9 | Water power generation | 5 | Lelec | 0305 | Water power generation |
| 10 | Thermal & self-power generation | 6 | Felec | 0306 | Thermal power generation |
| | | | | 0308 | Self-Power generation |
| 11 | Atomic power generation | 5 | Lelec | 0307 | Atomic power generation |
| 12 | Town Gas | 4 | Gas | 0309 | Manufactured gas supply |
| 13 | Heat | 8 | Heat | 0310 | Steam and hot water supply |
| 14 | woods | | | 0026 | Misc. Forestry products |
| 15 | Crops-p | 9 | Crops-p | 0002 | Barley |
| | | | | 0003 | Wheat |
| | | | | 0004 | Miscellaneous cereals |
| 16 | Fishery products | 10 | Fishery products | 0027 | Marine fishing |
| | | | | 0028 | Fresh water fishing |
| | | | | 0029 | Marine culture |
| | | | | 0030 | Fresh water culture |
| 17 | Metallic minerals | 11 | Metallic minerals | 0035 | Iron ores |
| | | | | 0036 | Copper ores |
| | | | | 0037 | Lead and zinc ores |
| | | | | 0038 | Misc. Nonferrous metal ores |
| 18 | Nonmetallic minerals | 12 | Nonmetallic minerals | 0039 | Sand and gravel |
| | | | | 0040 | Crushed and broken stone |
| | | | | 0041 | Other bulk stones |
| | | | | 0042 | Limestone |
| | | | | 0043 | Materials for ceramics |
| | | | | 0044 | Crude salt |
| | | | | 0045 | Misc. Nonmetallic minerals |
| 19 | Sugar and starches | 13 | Sugar and starches | 0060 | Raw sugar |
| | | | | 0061 | Refined sugar |
| | | | | 0062 | Starches |
| | | | | 0063 | Glucose, glucose syrup and maltose |
| 20 | Fiber yarn | 14 | Fiber yarn | 0087 | Silk yarn |
| | | | | 0088 | Woolen yarn |
| | | | | 0089 | Cotton yarn |
| | | | | 0090 | Hempen yarn |
| | | | | 0091 | Regenerated fiber yarn |
| | | | | 0092 | Synthetic fiber yarn |
| | | | | 0093 | Thread and other fiber yarns |
| 21 | Fiber fabrics-p | 15 | Fiber fabrics-p | 0101 | Knitted fabrics |
| | | | | 0102 | Fiber bleaching and dyeing |
| 22 | Wood and wooden products-p | 16 | Wood and wooden products-p | 0118 | Lumber |
| | | | | 0119 | Plywood |

| | | | | | |
|---|---|---|---|---|---|
| | | | | 0120 | Reconstituted and densified wood |
| 23 | Pulp and paper-p | 17 | Pulp and paper-p | 0124 | Pulp |
| | | | | 0125 | Newsprint |
| | | | | 0126 | Printing paper |
| | | | | 0127 | Other raw paper and paperboard |
| 24 | Organic basic chemical products | 18 | Organic basic chemical products | 0148 | Petrochemical basic products |
| | | | | 0149 | Petrochemical intermediate products |
| | | | | 0150 | Coal chemicals |
| | | | | 0151 | Other basic organic chemicals |
| 25 | Inorganic basic chemical products | 19 | Inorganic basic chemical products | 0152 | Industrial gases |
| | | | | 0153 | Basic inorganic chemicals |
| 26 | Synthetic resins and synthetic rubber-p | 20 | Synthetic resins and synthetic rubber-p | 0155 | Synthetic rubber |
| 27 | Chemical fibers | 21 | Chemical fibers | 0156 | Regenerated cellulose fibers |
| | | | | 0157 | Synthetic fibers |
| 28 | Fertilizers and agricultural chemicals-p | 22 | Fertilizers and agricultural chemicals-p | 0158 | Nitrogen compounds |
| | | | | 0159 | Fertilizers |
| 29 | Other chemical products | 23 | Other chemical products | 0164 | Dyes, pigments, and tanning materials |
| | | | | 0165 | Paints, varnishes, and allied products |
| | | | | 0166 | Printing ink |
| | | | | 0167 | Adhesives, gelatin and sealants |
| | | | | 0168 | Explosives and fireworks products |
| | | | | 0169 | Recording media for electronic equipments |
| | | | | 0170 | Photographic chemical products |
| | | | | 0171 | Misc. Chemical products |
| 30 | Glass products | 24 | Glass products | 0178 | Sheet glass and primary glass products |
| | | | | 0179 | Industrial glass products |
| | | | | 0180 | Household glass products and others |
| 31 | Pottery and clay products | 25 | Pottery and clay products | 0181 | Industrial pottery products |
| | | | | 0182 | Pottery, china and earthenware for home use |
| | | | | 0183 | Clay refractories |
| | | | | 0184 | Clay products for construction |
| 32 | Cement and concrete products | 26 | Cement and concrete products | 0185 | Cement |
| | | | | 0186 | Ready mixed concrete |
| | | | | 0187 | Concrete blocks, bricks, and other concrete products |

| | | | | | |
|---|---|---|---|---|---|
| 33 | Other nonmetallic mineral products | 27 | Other nonmetallic mineral products | 0188 | Lime, gypsum, and plaster products |
| | | | | 0189 | Cut stone & stone products |
| | | | | 0190 | Asbestos and mineral wool products |
| | | | | 0191 | Abrasives |
| | | | | 0192 | Asphalts |
| | | | | 0193 | Misc. Nonmetallic minerals products |
| 34 | Pig iron and crude steel | 28 | Pig iron and crude steel | 0194 | Pig iron |
| | | | | 0195 | Ferroalloys |
| | | | | 0196 | Steel ingots and semifinished products |
| 35 | Primary iron and steel products | 29 | Primary iron and steel products | 0197 | Steel rods and bars |
| | | | | 0198 | Section steel |
| | | | | 0199 | Rails and wires |
| | | | | 0200 | Hot rolled steel plates and sheets |
| | | | | 0201 | Steel pipe and tubes, except foundry iron pipe and tubes |
| | | | | 0202 | Cold rolled steel sheet, strip, and bars |
| | | | | 0203 | Iron foundries and foundry iron pipe and tubes |
| | | | | 0204 | Forgings |
| | | | | 0205 | Coated steel plates |
| | | | | 0206 | Misc. Primary iron and steel products |
| 36 | Nonferrous metal ingots and primary nonferrous metal products-p | 30 | Nonferrous metal ingots and primary nonferrous metal products-p | 0207 | Copper ingots |
| | | | | 0208 | Aluminum ingots |
| | | | | 0209 | Lead and zinc ingots |
| | | | | 0210 | Gold and silver ingots |
| | | | | 0211 | Other nonferrous metal ingots |
| 37 | Fabricated metal products-p | 31 | Fabricated metal products-p | 0219 | Handtools |
| | | | | 0220 | Bolts, nuts, screws, rivets, and washers |
| | | | | 0221 | Fabricated wire products |
| | | | | 0222 | Fastening metal products |
| | | | | 0223 | Treatment and coating of metals |
| | | | | 0224 | Household metallic utensils |
| | | | | 0225 | Misc. Fabricated metal products |
| 38 | Machinery and equipment of general purpose-p | 32 | Machinery and equipment of general purpose-p | 0227 | Valves |
| | | | | 0228 | Bearings, gears, gearing and driving elements |

| | | | | | |
|---|---|---|---|---|---|
| 39 | Wholesale and retail trade | 33 | Wholesale and retail trade | 0329 | Wholesale trade |
| | | | | 0330 | Retail trade |
| 40 | Eating and drinking places, and hotels and other lodging places | 34 | Eating and drinking places, and hotels and other lodging places | 0331 | Eating and drinking places |
| | | | | 0332 | Hotels and other lodging places |
| 41 | Transportation and warehousing-p | 35 | Transportation and warehousing-p | 0333 | Railroad passenger transportation |
| | | | | 0334 | Railroad freight transportation |
| | | | | 0335 | Road passenger transportation |
| | | | | 0336 | Road freight transportation |
| | | | | 0337 | Coastal and inland water transportation |
| | | | | 0338 | Deep sea transportation |
| | | | | 0339 | Air transportation |
| | | | | 0340 | Services incidental to road transportation |
| | | | | 0341 | Services incidental to water transportation |
| | | | | 0342 | Airports, flying, fields and airport terminal services |
| | | | | 0343 | Cargo loading or unloading operations |
| | | | | 0344 | Warehousing and storage |
| 42 | Public administration and defense | 36 | Public administration and defense | 0372 | Public government |
| | | | | 0373 | Local government |
| 43 | Gas and water supply | 37 | Gas and water supply | 0311 | Water supply |
| 44 | Medical and health services, and social security-p | 38 | Medical and health services, and social security-p | 0386 | Sanitary services(public) |
| | | | | 0387 | Sanitary services (commercial) |
| 45 | Other services-p | 39 | Other services-p | 0396 | Motor repair services |
| | | | | 0397 | Other personal repair services |
| | | | | 0398 | Laundry and cleaning services |
| | | | | 0399 | Barber and beauty shops |
| | | | | 0400 | Domestic services |
| | | | | 0401 | Other personal services |
| 46 | Crops-p | 40 | Crops-p | 0001 | Unmilled rice |
| | | | | 0005 | Vegetables |
| | | | | 0006 | Fruits |
| | | | | 0007 | Pulses |
| | | | | 0008 | Potatoes |
| | | | | 0009 | Oleaginous crops |

| | | | | | |
|---|---|---|---|---|---|
| | | | | 0010 | Cultivated medicinal herbs |
| | | | | 0011 | Other edible crops |
| | | | | 0012 | Cotton and hemp |
| | | | | 0013 | Leaf tobacco |
| | | | | 0014 | Ornamental floriculture |
| | | | | 0015 | Natural rubber |
| | | | | 0016 | Seeds and seedlings |
| | | | | 0017 | Other Inedible crops |
| 47 | Livestock breeding | 41 | Livestock breeding | 0018 | Dairy farming |
| | | | | 0019 | Beef cattle |
| | | | | 0020 | Swine |
| | | | | 0021 | Poultry and eggs |
| | | | | 0022 | Other livestock breeding |
| 48 | Forestry products | 42 | Forestry products | 0023 | Forest planting and conservation |
| | | | | 0024 | Raw timber |
| | | | | 0025 | Edible forestry products |
| 49 | Meat and dairy products | 43 | Meat and dairy products | 0046 | Slaughtering and meat processing |
| | | | | 0047 | Poultry slaughtering and processing |
| | | | | 0048 | Prepared meat products |
| | | | | 0049 | Milk |
| | | | | 0050 | Milk products |
| | | | | 0051 | Ice cream |
| 50 | Processed seafood products | 44 | Processed seafood products | 0052 | Fish fillets and fish cake products |
| | | | | 0053 | Canned seafood |
| | | | | 0054 | Frozen fish and seafood |
| | | | | 0055 | Salted, dried and smoked seafood |
| | | | | 0056 | Misc. Processed seafood |
| 51 | Polished grains, flour and milled cereals | 45 | Polished grains, flour and milled cereals | 0057 | Polished rice |
| | | | | 0058 | Polished barley |
| | | | | 0059 | Flour and cereal preparations |
| 52 | Bakery and confectionery products, noodles | 46 | Bakery and confectionery products, noodles | 0064 | Bakery products |
| | | | | 0065 | Confectionery products |
| | | | | 0066 | Noodles |
| 53 | Seasonings and fats and oils | 47 | Seasonings and fats and oils | 0067 | Refined salt |
| | | | | 0068 | Fermented seasonings |
| | | | | 0069 | Other seasonings |
| | | | | 0070 | Soy sauce ad bean paste |

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|---|---|---|---|---|---|
| | | | | 0071 | Animal and marine fats and oils |
| | | | | 0072 | Vegetable fats and oils, and processed edible refined oil |
| 54 | Canned or cured fruits and vegetables and misc. food preparations | 48 | Canned or cured fruits and vegetables and misc. food preparations | 0073 | Canned or cured fruits and vegetables |
| | | | | 0074 | Coffee and tea |
| | | | | 0075 | Ginseng products |
| | | | | 0076 | Malt and yeast |
| | | | | 0077 | Bean curd |
| | | | | 0078 | Miscellaneous foodstuffs |
| 55 | Beverages | 49 | Beverages | 0079 | Ethyl alcohol for beverages |
| | | | | 0080 | Distilled spirits (soju) |
| | | | | 0081 | Beer |
| | | | | 0082 | Other liquors |
| | | | | 0083 | Soft drinks |
| | | | | 0084 | Spring water and manufactured ice |
| 56 | Prepared livestock feeds | 50 | Prepared livestock feeds | 0085 | Prepared livestock feeds |
| 57 | Tobacco products | 51 | Tobacco products | 0086 | Tobacco products |
| 58 | Fiber yarn-p | 52 | Fiber yarn-p | 0094 | Silk fabrics |
| | | | | 0095 | Woolen fabrics |
| | | | | 0096 | Cotton fabrics |
| | | | | 0097 | Hempen fabrics |
| | | | | 0098 | Regenerated fiber fabrics |
| | | | | 0099 | Synthetic fiber fabrics |
| | | | | 0100 | Other fiber fabrics |
| 59 | Wearing apparels and apparel accessories | 53 | Wearing apparels and apparel accessories | 0103 | Knitted wearing apparels |
| | | | | 0104 | Knitted clothing accessories |
| | | | | 0105 | Textile wearing apparels |
| | | | | 0106 | Other clothing accessories |
| | | | | 0107 | Leather wearing apparels |
| | | | | 0108 | Fur wearing apparels |
| 60 | Other fabricated textile products | 54 | Other fabricated textile products | 0109 | Textile products |
| | | | | 0110 | Misc. Textile products |
| | | | | 0111 | Cordage, rope, and fishing nets |
| 61 | Leather and fur products | 55 | Leather and fur products | 0112 | Leather |
| | | | | 0113 | Fur |
| | | | | 0114 | Luggage and handbags |
| | | | | 0115 | Leather footwear |
| | | | | 0116 | Textile footwear and other shoes |

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|---|---|---|---|---|---|
| | | | | 0117 | Other leather products |
| 62 | Wood and wooden products-p | 56 | Wood and wooden products-p | 0121 | Wooden products for construction |
| | | | | 0122 | Wooden containers |
| | | | | 0123 | Other wooden products |
| 63 | Pulp and paper-p | 57 | Pulp and paper-p | 0128 | Corrugated paper and solid fiber boxes |
| | | | | 0129 | Paper containers |
| | | | | 0130 | Stationery paper and office paper |
| | | | | 0131 | Sanitary paper products |
| | | | | 0132 | Other paper products |
| 64 | Printing, publishing and reproduction of recorded media | 58 | Printing, publishing and reproduction of recorded media | 0133 | Newspapers |
| | | | | 0134 | Publishing |
| | | | | 0135 | Printing |
| | | | | 0136 | Publishing and reproduction of recorded media |
| 65 | Synthetic resins and synthetic rubber-p | 59 | Synthetic resins and synthetic rubber-p | 0154 | Synthetic resins |
| 66 | Fertilizers and agricultural chemicals-p | 60 | Fertilizers and agricultural chemicals-p | 0160 | Pesticides and other agricultural chemicals |
| 67 | Drugs, cosmetics, and soap | 61 | Drugs, cosmetics, and soap | | |
| | | | | 0161 | Medicaments |
| | | | | 0162 | Cosmetics and dentifrices |
| | | | | 0163 | Soap and detergents |
| 68 | Plastic products | 62 | Plastic products | 0172 | Primary plastic products |
| | | | | 0173 | Industrial plastic products |
| | | | | 0174 | Household articles of plastic material |
| 69 | Rubber products | 63 | Rubber products | 0175 | Tires and tubes |
| | | | | 0176 | Industrial rubber products |
| | | | | 0177 | Misc. Rubber products |
| 70 | Nonferrous metal ingots and primary nonferrous metal products-p | 64 | Nonferrous metal ingots and primary nonferrous metal products-p | 0212 | Primary copper products |
| | | | | 0213 | Primary aluminum products |
| | | | | 0214 | Other nonferrous metal casting and forgings, and primary nonferrous metals |
| 71 | Fabricated metal products-p | 65 | Fabricated metal products-p | 0215 | Metal products for construction |
| | | | | 0216 | Metal products for structure |
| | | | | 0217 | Metal tanks and reservoirs for equipment |

| | | | | | |
|---|---|---|---|---|---|
| | | | | 0218 | Metal cans, barrels, and drums |
| 72 | Machinery and equipment of general purpose-p | 66 | Machinery and equipment of general purpose-p | 0226 | Internal combustion engines and turbines |
| | | | | 0229 | Conveyors and conveying equipment |
| | | | | 0230 | Air-conditioning equipment and industrial refrigeration equipment |
| | | | | 0231 | Boiler |
| | | | | 0232 | Heating apparatus and cooking appliances |
| | | | | 0233 | Pumps and compressors |
| | | | | 0234 | Filtering or purifying machinery for liquid and gases |
| | | | | 0235 | Misc. Machinery and equipment of general purpose |
| 73 | Machinery and equipment of special purpose | 67 | Machinery and equipment of special purpose | 0236 | Metal cutting type machine tools |
| | | | | 0237 | Metal forming machine tools |
| | | | | 0238 | Agricultural implements and machinery |
| | | | | 0239 | Construction and mining machinery |
| | | | | 0240 | Food processing machinery |
| | | | | 0241 | Textile machinery |
| | | | | 0242 | Metal molds and industrial patterns |
| | | | | 0243 | Printing machinery |
| | | | | 0244 | Machinery for manufacturing semiconductors |
| | | | | 0245 | Misc. Machinery and equipment of special purpose |
| 74 | Electronic machinery, equipment, and supplies | 68 | Electronic machinery, equipment, and supplies | 0246 | Motors and generators |
| | | | | 0247 | Electric transformers |
| | | | | 0248 | Capacitors and rectifiers |
| | | | | 0249 | Electric transmission and distribution equipment |
| | | | | 0250 | Insulated wires and cables |
| | | | | 0251 | Batteries |
| | | | | 0252 | Electric lamps and electric lighting fixtures |
| | | | | 0253 | Misc. Electric equipment and supplies |
| 75 | Electronic components and accessories | 69 | Electronic components and accessories | 0254 | Electron tubes |
| | | | | 0255 | Flat digital display |
| | | | | 0256 | Semiconductor devices |
| | | | | 0257 | Integrated circuits |

| | | | | | |
|---|---|---|---|---|---|
| | | | | 0258 | Electric resistors and storage batteries |
| | | | | 0259 | Electric coils, transformers and other inductors |
| | | | | 0260 | Printed circuit boards |
| | | | | 0261 | Misc. Electronic components |
| 76 | Radio, television and communications equipment | 70 | Radio, television and communications equipment | 0262 | Television receiving sets |
| | | | | 0263 | Video cassette recorders and players |
| | | | | 0264 | Electric household audio equipment |
| | | | | 0265 | Other audio and visual equipment |
| | | | | 0266 | Wire telephone and telegraph equipment |
| | | | | 0267 | Radio and television broadcasting and wireless communications equipment |
| 77 | Computer and office equipment | 71 | Computer and office equipment | 0268 | Computer and peripheral equipment |
| | | | | 0269 | Office machines and devices |
| 78 | Household electrical appliances | 72 | Household electrical appliances | 0270 | Household refrigerators and freezers |
| | | | | 0271 | Household laundry equipment |
| | | | | 0272 | Electric household fans |
| | | | | 0273 | Household electric cooking and heating equipment |
| | | | | 0274 | Other household electrical appliances |
| 79 | Precision instruments | 73 | Precision instruments | 0275 | Medical instruments and supplies |
| | | | | 0276 | Industrial automatic regulators |
| | | | | 0277 | Measuring and analytical instruments |
| | | | | 0278 | Cinematograph cameras and projectors |
| | | | | 0279 | Other photographic and optical instruments |
| | | | | 0280 | Watches and clocks |
| 80 | Motor vehicles | 74 | Motor vehicles | 0281 | Passenger automobiles |
| | | | | 0282 | Buses and vans |
| | | | | 0283 | Trucks |
| | | | | 0284 | Motor vehicles with special equipment |
| | | | | 0285 | Motor vehicle engines |
| | | | | 0286 | Motor vehicle chassis, bodies and parts |
| | | | | 0287 | Trailers and containers |
| 81 | Ship building and repairing | 75 | Ship building and repairing | 0288 | Steel ships |
| | | | | 0289 | Other ships |
| | | | | 0290 | Ship repairing and ship parts |

| | | | | | |
|---|---|---|---|---|---|
| 82 | Other transportation equipment | 76 | Other transportation equipment | 0291 | Railroad vehicles and parts |
| | | | | 0292 | Aircraft and parts |
| | | | | 0293 | Motorcycles and parts |
| | | | | 0294 | Bicycles and parts and misc. transportation equipment |
| 83 | Furniture | 77 | Furniture | 0295 | Wood furniture |
| | | | | 0296 | Metal furniture |
| | | | | 0297 | Other furniture |
| 84 | Other manufacturing products | 78 | Other manufacturing products | 0298 | Toys and games |
| | | | | 0299 | Sporting and athletic goods |
| | | | | 0300 | Musical instruments |
| | | | | 0301 | Pens, pencils, and other artists' materials |
| | | | | 0302 | Jewelry and plated ware |
| | | | | 0303 | Models and decorations |
| | | | | 0304 | Misc. Manufacturing products |
| 85 | Building construction and repair | 79 | Building construction and repair | 0312 | Steel concrete residential building construction |
| | | | | 0313 | Wooden and other residential building construction |
| | | | | 0314 | Steel concrete nonresidential building construction |
| | | | | 0315 | Wooden and other nonresidential building construction |
| | | | | 0316 | Building repairs |
| 86 | Civil Engineering | 80 | Civil Engineering | 0317 | Road construction |
| | | | | 0318 | Railroad construction |
| | | | | 0319 | Subway construction |
| | | | | 0320 | Breakwater, pier, and harbor construction |
| | | | | 0321 | Airport construction |
| | | | | 0322 | Dam, levee, and flood control project construction |
| | | | | 0323 | Water main line and drainage project construction |
| | | | | 0324 | Land clearing and reclamation, and irrigation project construction |
| | | | | 0325 | Land leveling and athletic field construction |
| | | | | 0326 | Electric power plant construction |
| | | | | 0327 | Communications line construction |
| | | | | 0328 | Misc. Construction |
| 87 | Transportation and warehousing-p | 81 | Transportation and warehousing-p | 0345 | Other services incidental to transportation |

| | | | | | |
|---|---|---|---|---|---|
| 88 | Communications and broadcasting | 82 | Communications and broadcasting | 0346 | Postal services |
| | | | | 0347 | Telephone |
| | | | | 0348 | High-speed network services |
| | | | | 0349 | Value added communication |
| | | | | 0350 | Terrestrial broadcasting |
| | | | | 0351 | Cable broadcasting |
| 89 | Finance and insurance | 83 | Finance and insurance | 0352 | Central bank and banking institutions |
| | | | | 0353 | Non-bank depository institutions |
| | | | | 0354 | Other financial brokerage institutions |
| | | | | 0355 | Life insurance |
| | | | | 0356 | Casualty insurance |
| | | | | 0357 | Services auxiliary to finance and insurance |
| 90 | Real estate agencies and rental | 84 | Real estate agencies and rental | 0358 | Owner-occupied dwellings (imputed rent) |
| | | | | 0359 | Real estate rental |
| | | | | 0360 | Real estate agents and managers |
| 91 | Business services | 85 | Business services | 0361 | Legal and accounting services |
| | | | | 0362 | Architectural engineering services |
| | | | | 0363 | Other engineering services |
| | | | | 0364 | Computer softwares development and supply |
| | | | | 0365 | Computer programming, data processing, and other computer related services |
| | | | | 0366 | Renting of machinery and goods |
| | | | | 0367 | Advertising services |
| | | | | 0368 | Information provision services |
| | | | | 0369 | Cleaning and disinfection services |
| | | | | 0370 | Agriculture and fishing service |
| | | | | 0371 | Misc. Business services |
| 92 | Educational and research services | 86 | Educational and research services | 0374 | School education (public) |
| | | | | 0375 | School education (private, non-profit) |
| | | | | 0376 | School education (commercial) |
| | | | | 0377 | Research institutes(public) |
| | | | | 0378 | Research institutes (private, non-profit) |
| | | | | 0379 | Research institutes (commercial) |
| | | | | 0380 | Research and experiment in enterprise |
| 93 | Medical and health services, and social security | 87 | Medical and health services, and social security | 0381 | Medical and health services(public) |

| | | | | | |
|---|---|---|---|---|---|
| | | | | 0382 | Medical and health services (private, non-profit) |
| | | | | 0383 | Medical and health services (commercial) |
| | | | | 0384 | Social welfare services (public) |
| | | | | 0385 | Social welfare services (Private, non-profit) |
| 94 | Culture and recreational services | 88 | Culture and recreational services | 0388 | Culture services (public) |
| | | | | 0389 | Culture services (other) |
| | | | | 0390 | Motion picture production and distribution |
| | | | | 0391 | Theatrical producers, bands, and entertainers |
| | | | | 0392 | Sports organizations and sports facility operation |
| | | | | 0393 | Misc. amusement and recreation services |
| 95 | Other services | 89 | Other services | 0394 | Business associations and professional membership organizations |
| | | | | 0395 | Religious, political, labor, and other social organizations |
| 96 | Unclassified activities | 90 | Unclassified activities | 0402 | Office supplies |
| | | | | 0403 | Business consumption expenditures |
| | | | | 0404 | Unclassified activities |

# Appendix 2. Sectoral Energy Intensity

(unit: TOE/million Korean Won in 2000)

| | | sector | Energy intensity (direct) | | | | | Energy intensity (total) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1985 | 1990 | 1995 | 2000 | 2005 | 1985 | 1990 | 1995 | 2000 | 2005 |
| energy | 1 | coal | 0.0103 | 0.0162 | 0.0218 | 0.0112 | 0.0114 | 2.0456 | 2.0487 | 2.0420 | 2.0210 | 2.0182 |
| | 2 | fuel | 0.0544 | 0.0409 | 0.0735 | 0.0837 | 0.1020 | 2.0610 | 2.0494 | 2.0867 | 2.1088 | 2.1341 |
| | 3 | nfuel | 0.3994 | 0.2211 | 0.1693 | 0.1430 | 0.1668 | 2.5676 | 2.2869 | 2.2219 | 2.1908 | 2.2330 |
| | 4 | gas | 1.1276 | 0.4310 | 0.2174 | 0.0360 | 0.0092 | 2.2517 | 2.4820 | 2.2398 | 2.0445 | 2.0145 |
| | 5 | lelec | 0.0248 | 0.3507 | 0.2422 | 0.0537 | 0.0669 | 2.2006 | 3.0330 | 2.6673 | 2.2380 | 2.2785 |
| | 6 | felec | 2.4418 | 2.1166 | 2.2400 | 2.4401 | 2.0846 | 4.6902 | 4.3663 | 4.6711 | 4.5707 | 3.9503 |
| | 7 | nap | 0.0172 | 0.0114 | 0.0065 | 0.0054 | 0.0068 | 1.0193 | 1.0141 | 1.0085 | 1.0073 | 1.0106 |
| | 8 | heat | 1.2285 | 0.7635 | 0.6347 | 0.9027 | 0.6105 | 3.3529 | 2.2418 | 2.2481 | 2.7665 | 2.1034 |
| non energy and energy intensive | 9 | Crops-p | 0.0004 | 0.0505 | 0.0668 | 0.0245 | 0.0125 | 0.0922 | 0.1624 | 0.1514 | 0.0661 | 0.0374 |
| | 10 | Fishery products | 0.1935 | 0.3019 | 0.3245 | 0.3154 | 0.2591 | 0.4373 | 0.6041 | 0.7012 | 0.7024 | 0.6275 |
| | 11 | Metallic minerals | 0.0289 | 0.0077 | 0.0052 | 0.0014 | 0.0010 | 0.0978 | 0.0248 | 0.0133 | 0.0040 | 0.0027 |
| | 12 | Nonmetallic minerals | 0.1484 | 0.1943 | 0.1850 | 0.1737 | 0.2128 | 0.4124 | 0.4241 | 0.4464 | 0.4044 | 0.5634 |
| | 13 | Sugar, starches | 0.1489 | 0.1512 | 0.1115 | 0.1197 | 0.0765 | 0.5031 | 0.4732 | 0.3913 | 0.4428 | 0.3380 |
| | 14 | Fiber yarn | 0.0759 | 0.0749 | 0.0641 | 0.0734 | 0.0834 | 0.8440 | 0.8448 | 0.4980 | 0.6023 | 0.4975 |
| | 15 | Fiber fabrics-p | 0.4059 | 0.3003 | 0.4190 | 0.4185 | 0.2658 | 1.0409 | 0.7265 | 1.0924 | 1.2491 | 0.8589 |
| | 16 | Wood, wooden products-p | 0.0401 | 0.0422 | 0.0496 | 0.0702 | 0.0479 | 0.2191 | 0.2175 | 0.2383 | 0.3056 | 0.2596 |
| | 17 | Pulp, paper-p | 0.1682 | 0.1427 | 0.1196 | 0.1283 | 0.1365 | 0.6651 | 0.4776 | 0.4791 | 0.5519 | 0.5728 |
| | 18 | Organic basic chemical products | 0.8973 | 0.8074 | 1.1499 | 1.1367 | 1.2788 | 2.0281 | 1.9720 | 2.5107 | 2.6067 | 2.8540 |
| | 19 | Inorganic basic chemical products | 0.5360 | 0.3490 | 0.2558 | 0.2838 | 0.2567 | 1.4418 | 0.9773 | 0.8265 | 0.8437 | 0.7660 |
| | 20 | Synthetic resins, synthetic rubber-p | 0.1485 | 0.0449 | 0.0817 | 0.1112 | 0.1333 | 0.9800 | 0.8076 | 1.0270 | 1.1935 | 1.4412 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | Chemical fibers | 0.2703 | 0.1982 | 0.1280 | 0.1128 | 0.0877 | 1.7773 | 1.6767 | 1.8205 | 1.7588 | 1.6255 |
| 22 | Fertilizers, agricultural chemicals-p | 0.6546 | 0.5510 | 0.4649 | 0.2996 | 0.1543 | 1.9034 | 1.5271 | 1.1669 | 0.9161 | 0.5456 |
| 23 | Other chemical products | 0.0710 | 0.0859 | 0.0669 | 0.0725 | 0.0511 | 0.6089 | 0.6366 | 0.6177 | 0.6389 | 0.5490 |
| 24 | Glass products | 0.3827 | 0.4017 | 0.2410 | 0.2125 | 0.0861 | 1.0087 | 0.9242 | 0.6744 | 0.6250 | 0.3038 |
| 25 | Pottery, clay products | 0.4377 | 0.3971 | 0.3723 | 0.3342 | 0.1867 | 1.0075 | 0.8506 | 0.9111 | 0.8421 | 0.5391 |
| 26 | Cement, concrete products | 1.0640 | 0.6887 | 0.4891 | 0.4963 | 0.4786 | 1.9131 | 1.2632 | 1.2099 | 1.1720 | 1.1742 |
| 27 | Other nonmetallic mineral products | 0.5916 | 0.6835 | 0.6814 | 0.6488 | 0.4668 | 1.4884 | 1.4480 | 1.3019 | 1.2497 | 1.0596 |
| 28 | Pig iron & crude steel | 0.7027 | 0.5989 | 0.6379 | 0.6511 | 0.8383 | 2.6526 | 2.3317 | 2.7253 | 2.4806 | 2.6540 |
| 29 | Primary iron, steel products | 0.0977 | 0.0854 | 0.0754 | 0.0810 | 0.0727 | 1.4398 | 1.2105 | 1.3425 | 1.2785 | 1.2301 |
| 30 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.1927 | 0.1162 | 0.0800 | 0.0586 | 0.0734 | 0.4911 | 0.3043 | 0.2387 | 0.2005 | 0.2469 |
| 31 | Fabricated metal products-p | 0.0737 | 0.0539 | 0.0845 | 0.0892 | 0.1025 | 0.6518 | 0.5286 | 0.5667 | 0.5038 | 0.5822 |
| 32 | Machinery, equipment of general purpose-p | 0.0459 | 0.0304 | 0.0562 | 0.0808 | 0.0499 | 0.3420 | 0.2775 | 0.3207 | 0.3619 | 0.0976 |
| 33 | Wholesale, retail trade | 0.0989 | 0.1010 | 0.0993 | 0.0652 | 0.0708 | 0.3071 | 0.2860 | 0.2966 | 0.2162 | 0.2669 |
| 34 | Eating, drinking places, hotels, other lodging places | 0.1212 | 0.1177 | 0.0822 | 0.0865 | 0.0745 | 0.3316 | 0.3522 | 0.3241 | 0.3100 | 0.3012 |
| 35 | Transportation & warehousing-p | 0.3952 | 0.4881 | 0.5471 | 0.5244 | 0.3912 | 0.8358 | 0.9172 | 1.0970 | 1.1110 | 0.9542 |
| 36 | Public administration, defense | 0.0975 | 0.0868 | 0.0741 | 0.0596 | 0.0369 | 0.3566 | 0.3070 | 0.2733 | 0.2107 | 0.1621 |
| 37 | Gas, water supply | 0.1645 | 0.1357 | 0.1423 | 0.1454 | 0.1512 | 0.7209 | 0.4885 | 0.6013 | 0.5762 | 0.6033 |
| 38 | Medical, health services, social security-p | 0.1270 | 0.2376 | 0.1898 | 0.1790 | 0.0000 | 0.3498 | 0.5067 | 0.4596 | 0.4726 | 0.0000 |
| 39 | Other services-p | 0.0468 | 0.0764 | 0.1670 | 0.1467 | 0.1046 | 0.1810 | 0.2336 | 0.4242 | 0.3978 | 0.3522 |
| 40 | Crops-p | 0.0099 | 0.0155 | 0.0202 | 0.0265 | 0.0693 | 0.1027 | 0.1237 | 0.1445 | 0.1582 | 0.2269 |
| 41 | Livestock breeding | 0.0501 | 0.0494 | 0.0662 | 0.0644 | 0.0363 | 0.2615 | 0.3114 | 0.2829 | 0.3005 | 0.3035 |
| 42 | Forestry products | 0.0011 | 0.0108 | 0.0076 | 0.0168 | 0.0164 | 0.0401 | 0.0520 | 0.0583 | 0.0915 | 0.0609 |
| 43 | Meat, dairy products | 0.0231 | 0.0236 | 0.0246 | 0.0207 | 0.0151 | 0.2927 | 0.2936 | 0.3003 | 0.2632 | 0.2476 |
| 44 | Processed seafood products | 0.0547 | 0.0338 | 0.0305 | 0.0288 | 0.0193 | 0.4379 | 0.4854 | 0.4813 | 0.4097 | 0.3480 |

non energy and energy less intensive

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 45 | Polished grains, flour, milled cereals | 0.0059 | 0.0086 | 0.0098 | 0.0116 | 0.0095 | 0.1247 | 0.1589 | 0.1793 | 0.1826 | 0.2437 |
| 46 | Bakery, confectionery products, noodles | 0.0661 | 0.0608 | 0.0555 | 0.0620 | 0.0394 | 0.3916 | 0.3482 | 0.3060 | 0.3410 | 0.3093 |
| 47 | Seasonings, fats and oils | 0.1146 | 0.0846 | 0.0601 | 0.0665 | 0.0357 | 0.4997 | 0.3755 | 0.3163 | 0.3385 | 0.2992 |
| 48 | Canned or cured fruits, vegetables, misc. food preparations | 0.0721 | 0.0740 | 0.0686 | 0.0621 | 0.0337 | 0.3144 | 0.2742 | 0.2771 | 0.2657 | 0.2353 |
| 49 | Beverages | 0.0654 | 0.0463 | 0.0413 | 0.0357 | 0.0219 | 0.3048 | 0.2400 | 0.2540 | 0.2318 | 0.1996 |
| 50 | Prepared livestock feeds | 0.0097 | 0.0157 | 0.0247 | 0.0291 | 0.0268 | 0.2310 | 0.2465 | 0.2395 | 0.2382 | 0.3322 |
| 51 | Tobacco products | 0.0056 | 0.0070 | 0.0068 | 0.0070 | 0.0052 | 0.0682 | 0.0703 | 0.0556 | 0.0626 | 0.0797 |
| 52 | Fiber yarn-p | 0.0602 | 0.0713 | 0.0652 | 0.0573 | 0.0513 | 0.6389 | 0.6161 | 0.6921 | 0.6172 | 0.5086 |
| 53 | Wearing apparels, apparel accessories | 0.0400 | 0.0446 | 0.0316 | 0.0289 | 0.0149 | 0.5311 | 0.5055 | 0.3798 | 0.3807 | 0.2186 |
| 54 | Other fabricated textile products | 0.0407 | 0.0467 | 0.0505 | 0.0443 | 0.0419 | 0.5751 | 0.5386 | 0.5193 | 0.5909 | 0.4539 |
| 55 | Leather, fur products | 0.0238 | 0.0254 | 0.0252 | 0.0277 | 0.0229 | 0.2604 | 0.2785 | 0.2679 | 0.3151 | 0.3722 |
| 56 | Wood, wooden products-p | 0.0340 | 0.0535 | 0.0497 | 0.0481 | 0.0293 | 0.2648 | 0.2624 | 0.3006 | 0.3211 | 0.3004 |
| 57 | Pulp, paper-p | 0.0598 | 0.0543 | 0.0379 | 0.0478 | 0.0458 | 0.4793 | 0.3916 | 0.3400 | 0.4460 | 0.4315 |
| 58 | Printing, publishing, reproduction of recorded media | 0.0174 | 0.0168 | 0.0243 | 0.0294 | 0.0282 | 0.2977 | 0.2476 | 0.2601 | 0.3298 | 0.3251 |
| 59 | Synthetic resins, synthetic rubber-p | 0.1089 | 0.1315 | 0.0658 | 0.0655 | 0.0473 | 1.2853 | 1.2567 | 1.4705 | 1.5586 | 1.4990 |
| 60 | Fertilizers, agricultural chemicals-p | 0.0294 | 0.0250 | 0.0409 | 0.0418 | 0.0241 | 0.6511 | 0.7683 | 1.0466 | 1.2172 | 1.0599 |
| 61 | Drugs, cosmetics, soap | 0.0392 | 0.0320 | 0.0338 | 0.0331 | 0.0208 | 0.4049 | 0.3486 | 0.4176 | 0.3889 | 0.3108 |
| 62 | Plastic products | 0.0707 | 0.0592 | 0.0805 | 0.0722 | 0.0406 | 0.7813 | 0.6693 | 0.8003 | 0.8482 | 0.6291 |
| 63 | Rubber products | 0.1056 | 0.0780 | 0.0765 | 0.0920 | 0.0558 | 0.6673 | 0.5011 | 0.5211 | 0.5622 | 0.5309 |
| 64 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.0851 | 0.1003 | 0.0805 | 0.0528 | 0.0432 | 0.4959 | 0.3769 | 0.3326 | 0.2464 | 0.2617 |
| 65 | Fabricated metal products-p | 0.0576 | 0.0313 | 0.0298 | 0.0320 | 0.0278 | 0.9043 | 0.5718 | 0.6044 | 0.6183 | 0.5620 |
| 66 | Machinery, equipment of general purpose-p | 0.0230 | 0.0265 | 0.0218 | 0.0281 | 0.0210 | 0.2628 | 0.3102 | 0.2707 | 0.3046 | 0.2956 |
| 67 | Machinery, equipment of special purpose | 0.0281 | 0.0157 | 0.0205 | 0.0293 | 0.0173 | 0.2784 | 0.2012 | 0.2229 | 0.2639 | 0.2075 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 68 | Electronic machinery, equipment, supplies | 0.0345 | 0.0478 | 0.0314 | 0.0349 | 0.0241 | 0.3269 | 0.3330 | 0.2773 | 0.2622 | 0.2302 |
| 69 | Electronic components, accessories | 0.0359 | 0.0298 | 0.0247 | 0.0143 | 0.0083 | 0.4449 | 0.3986 | 0.3061 | 0.1623 | 0.0957 |
| 70 | Radio, television, communications equipment | 0.0167 | 0.0202 | 0.0119 | 0.0109 | 0.0062 | 0.3764 | 0.3510 | 0.2476 | 0.1634 | 0.1168 |
| 71 | Computer, office equipment | 0.0221 | 0.0145 | 0.0055 | 0.0039 | 0.0042 | 0.3275 | 0.3573 | 0.2249 | 0.1379 | 0.0667 |
| 72 | Household electrical appliances | 0.0337 | 0.0257 | 0.0203 | 0.0187 | 0.0147 | 0.5941 | 0.4875 | 0.3559 | 0.2967 | 0.2986 |
| 73 | Precision instruments | 0.0138 | 0.0087 | 0.0101 | 0.0114 | 0.0065 | 0.1328 | 0.1106 | 0.1035 | 0.1117 | 0.0967 |
| 74 | Motor vehicles | 0.0419 | 0.0386 | 0.0320 | 0.0356 | 0.0216 | 0.4791 | 0.4547 | 0.3840 | 0.4100 | 0.3319 |
| 76 | Other transportation equipment | 0.0184 | 0.0161 | 0.0170 | 0.0221 | 0.0165 | 0.1906 | 0.1554 | 0.1456 | 0.1890 | 0.1597 |
| 77 | Furniture | 0.0354 | 0.0439 | 0.0374 | 0.0404 | 0.0187 | 0.4389 | 0.3661 | 0.3626 | 0.3492 | 0.2961 |
| 78 | Other manufacturing products | 0.0406 | 0.0345 | 0.0358 | 0.0404 | 0.0303 | 0.4305 | 0.3462 | 0.3041 | 0.3308 | 0.2706 |
| 79 | Building construction, repair | 0.0126 | 0.0143 | 0.0140 | 0.0188 | 0.0296 | 0.3010 | 0.2488 | 0.3040 | 0.3380 | 0.3363 |
| 80 | Civil Engineering | 0.0682 | 0.0699 | 0.0377 | 0.0433 | 0.1046 | 0.3928 | 0.3382 | 0.3713 | 0.4001 | 0.5231 |
| 81 | Transportation, warehousing-p | 0.0410 | 0.0832 | 0.0410 | 0.0354 | 0.0000 | 0.1273 | 0.2140 | 0.1175 | 0.1010 | 0.0000 |
| 82 | Communications, broadcasting | 0.0632 | 0.0422 | 0.0301 | 0.0212 | 0.0256 | 0.2295 | 0.1572 | 0.1340 | 0.1269 | 0.1402 |
| 83 | Finance, insurance | 0.0268 | 0.0276 | 0.0186 | 0.0151 | 0.0136 | 0.1511 | 0.1390 | 0.1117 | 0.0885 | 0.0863 |
| 84 | Real estate agencies, rental | 0.0294 | 0.0262 | 0.0340 | 0.0263 | 0.0369 | 0.1321 | 0.1303 | 0.1663 | 0.1181 | 0.1379 |
| 85 | Business services | 0.0426 | 0.0390 | 0.0392 | 0.0272 | 0.0228 | 0.2199 | 0.1942 | 0.1725 | 0.1273 | 0.1286 |
| 86 | Educational, research services | 0.0281 | 0.0326 | 0.0406 | 0.0534 | 0.0575 | 0.0849 | 0.0977 | 0.1355 | 0.1669 | 0.1938 |
| 87 | Medical, health services, social security | 0.0628 | 0.0461 | 0.0432 | 0.0343 | 0.0610 | 0.2371 | 0.1967 | 0.2144 | 0.2324 | 0.2943 |
| 88 | Culture, recreational services | 0.1001 | 0.0752 | 0.0632 | 0.0523 | 0.0553 | 0.3217 | 0.2524 | 0.2654 | 0.2085 | 0.2046 |
| 89 | Other services | 0.0778 | 0.0685 | 0.0390 | 0.0607 | 0.0488 | 0.3515 | 0.3303 | 0.2607 | 0.2827 | 0.2433 |
| 90 | Unclassified activities | 0.0158 | 0.0154 | 0.0208 | 0.0243 | 0.0053 | 0.3128 | 0.3398 | 0.3489 | 0.3523 | 0.2916 |

# Appendix 3. Sectoral $CO_2$ Emission Intensity by Energy Use

(unit: t-$CO_2$/million Korean Won in 2000)

| | | sector | $CO_2$ emission intensity (direct) | | | | | $CO_2$ emission intensity (total) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1985 | 1990 | 1995 | 2000 | 2005 | 1985 | 1990 | 1995 | 2000 | 2005 |
| energy | 1 | coal | 0.0214 | 0.0281 | 0.0491 | 0.0221 | 0.0209 | 7.9520 | 7.9176 | 7.8935 | 7.8300 | 7.8218 |
| | 2 | fuel | 0.1557 | 0.1062 | 0.2001 | 0.2113 | 0.1653 | 6.0735 | 5.9949 | 6.0815 | 6.0742 | 5.9883 |
| | 3 | nfuel | 0.6345 | 0.2712 | 0.1806 | 0.1587 | 0.1559 | 4.7231 | 4.1510 | 4.0347 | 4.0070 | 4.0080 |
| | 4 | gas | 1.9817 | 1.2584 | 0.6355 | 0.0902 | 0.0127 | 4.9475 | 6.1149 | 5.3905 | 4.7426 | 4.6580 |
| | 5 | lelec | 0.0661 | 0.0711 | 0.0731 | 0.0526 | 0.0521 | 0.5842 | 2.0766 | 1.2862 | 0.5636 | 0.6415 |
| | 6 | felec | 8.2925 | 6.8268 | 7.2572 | 8.3133 | 7.3201 | 12.0753 | 10.3437 | 11.4095 | 11.6669 | 9.7371 |
| | 7 | nap | 0.0485 | 0.0296 | 0.0164 | 0.0126 | 0.0099 | 0.8066 | 0.7885 | 0.7739 | 0.7693 | 0.7702 |
| | 8 | heat | 3.7350 | 2.3268 | 1.1728 | 2.0152 | 1.4379 | 7.1196 | 3.7570 | 2.7887 | 4.3368 | 2.7024 |
| non energy and energy intensive | 9 | Crops-p | 0.0006 | 0.1525 | 0.1997 | 0.0723 | 0.0359 | 0.2169 | 0.4268 | 0.4264 | 0.1809 | 0.0981 |
| | 10 | Fishery products | 0.5902 | 0.8875 | 0.9311 | 0.8858 | 0.7073 | 1.3131 | 1.7616 | 2.0116 | 1.9835 | 1.7315 |
| | 11 | Metallic minerals | 0.0477 | 0.0088 | 0.0114 | 0.0024 | 0.0026 | 0.2599 | 0.0577 | 0.0347 | 0.0100 | 0.0076 |
| | 12 | Nonmetallic minerals | 0.3363 | 0.3719 | 0.4412 | 0.4072 | 0.5266 | 1.1310 | 1.0086 | 1.1995 | 1.0894 | 1.5364 |
| | 13 | Sugar, starches | 0.4138 | 0.4218 | 0.2926 | 0.2529 | 0.1165 | 1.4563 | 1.3396 | 1.0831 | 1.1433 | 0.8140 |
| | 14 | Fiber yarn | 0.1283 | 0.1391 | 0.1235 | 0.1206 | 0.0626 | 2.0890 | 1.9118 | 1.1045 | 1.2944 | 1.0332 |
| | 15 | Fiber fabrics-p | 1.1302 | 0.8030 | 0.9134 | 0.7033 | 0.3346 | 2.9751 | 1.9712 | 2.6547 | 2.8162 | 1.8081 |
| | 16 | Wood, wooden products-p | 0.0739 | 0.0853 | 0.1049 | 0.1407 | 0.0608 | 0.5694 | 0.5396 | 0.5892 | 0.7398 | 0.5821 |
| | 17 | Pulp, paper-p | 0.4069 | 0.3379 | 0.2465 | 0.2361 | 0.1590 | 1.8466 | 1.2430 | 1.2235 | 1.3880 | 1.2695 |
| | 18 | Organic basic chemical products | 1.1376 | 0.7931 | 1.0447 | 1.0166 | 0.9971 | 4.2204 | 3.8830 | 4.3363 | 4.6735 | 4.6739 |
| | 19 | Inorganic basic chemical products | 1.5778 | 1.0004 | 0.6206 | 0.5293 | 0.3997 | 4.4969 | 2.9000 | 2.2661 | 2.0937 | 1.7215 |
| | 20 | Synthetic resins, synthetic rubber-p | 0.0799 | 0.0059 | 0.1062 | 0.1121 | 0.0620 | 2.0343 | 1.5975 | 1.8857 | 2.2755 | 2.3892 |
| | 21 | Chemical fibers | 0.5534 | 0.3500 | 0.2067 | 0.1384 | 0.1000 | 4.2646 | 3.6562 | 3.4157 | 3.3510 | 2.8597 |
| | 22 | Fertilizers, agricultural chemicals-p | 0.8222 | 0.6431 | 0.5383 | 0.3921 | 0.1636 | 4.2771 | 3.2394 | 2.3528 | 2.0023 | 1.1498 |
| | 23 | Other chemical products | 0.1385 | 0.1701 | 0.1218 | 0.1268 | 0.0811 | 1.4506 | 1.3985 | 1.2577 | 1.3042 | 1.0315 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 24 | Glass products | 1.0682 | 1.0669 | 0.6108 | 0.4930 | 0.1981 | 2.9389 | 2.5403 | 1.8260 | 1.6421 | 0.7663 |
| | 25 | Pottery, clay products | 1.3159 | 1.1357 | 1.0548 | 0.9133 | 0.4692 | 3.0197 | 2.4077 | 2.5827 | 2.3608 | 1.4297 |
| | 26 | Cement, concrete products | 3.6443 | 2.2918 | 1.5190 | 1.5122 | 1.5367 | 6.3167 | 3.9737 | 3.6589 | 3.5316 | 3.5966 |
| | 27 | Other nonmetallic mineral products | 1.3098 | 1.1240 | 1.0737 | 1.0314 | 0.6851 | 3.7916 | 2.9983 | 2.6390 | 2.5823 | 2.1506 |
| | 28 | Pig iron & crude steel | 2.6203 | 2.1580 | 2.3671 | 2.4231 | 3.1118 | 9.5700 | 8.1471 | 9.7779 | 8.9469 | 9.5604 |
| | 29 | Primary iron, steel products | 0.2400 | 0.1928 | 0.1392 | 0.1121 | 0.0883 | 4.9461 | 3.9979 | 4.5379 | 4.2581 | 4.0505 |
| | 30 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.5714 | 0.3237 | 0.1830 | 0.0828 | 0.1044 | 1.5196 | 0.8788 | 0.6545 | 0.4974 | 0.5955 |
| | 31 | Fabricated metal products-p | 0.1538 | 0.0845 | 0.1541 | 0.1615 | 0.2013 | 2.0169 | 1.5487 | 1.6293 | 1.3993 | 1.5778 |
| | 32 | Machinery, equipment of general purpose-p | 0.0942 | 0.0362 | 0.0592 | 0.0817 | 0.0588 | 1.0481 | 0.7948 | 0.8515 | 0.8981 | 0.1889 |
| | 33 | Wholesale, retail trade | 0.2782 | 0.2635 | 0.2496 | 0.1282 | 0.1302 | 0.9133 | 0.7973 | 0.8107 | 0.5545 | 0.6802 |
| | 34 | Eating, drinking places, hotels, other lodging places | 0.3261 | 0.3248 | 0.1953 | 0.2034 | 0.1659 | 0.9766 | 0.9894 | 0.8613 | 0.8157 | 0.7719 |
| | 35 | Transportation & warehousing-p | 1.1563 | 1.3619 | 1.5488 | 1.4708 | 1.0754 | 2.4646 | 2.6029 | 3.1531 | 3.1775 | 2.6852 |
| | 36 | Public administration, defense | 0.2625 | 0.2258 | 0.1705 | 0.1262 | 0.0665 | 1.0353 | 0.8496 | 0.7321 | 0.5455 | 0.4113 |
| | 37 | Gas, water supply | 0.0261 | 0.0265 | 0.0528 | 0.0596 | 0.0507 | 1.7447 | 1.0079 | 1.3816 | 1.3342 | 1.3445 |
| | 38 | Medical, health services, social security-p | 0.2667 | 0.5508 | 0.4688 | 0.4126 | 0.0000 | 0.9471 | 1.3271 | 1.2477 | 1.2541 | 0.0000 |
| | 39 | Other services-p | 0.1100 | 0.1612 | 0.2493 | 0.1939 | 0.1324 | 0.5111 | 0.5940 | 0.9112 | 0.8421 | 0.7605 |
| non energy and energy less intensive | 40 | Crops-p | 0.0350 | 0.0451 | 0.0591 | 0.0765 | 0.1960 | 0.2592 | 0.3023 | 0.3445 | 0.3859 | 0.5872 |
| | 41 | Livestock breeding | 0.1630 | 0.1223 | 0.1761 | 0.1643 | 0.0514 | 0.7806 | 0.8246 | 0.7625 | 0.7957 | 0.7465 |
| | 42 | Forestry products | 0.0032 | 0.0228 | 0.0166 | 0.0356 | 0.0264 | 0.0962 | 0.1237 | 0.1333 | 0.2196 | 0.1454 |
| | 43 | Meat, dairy products | 0.0581 | 0.0546 | 0.0569 | 0.0458 | 0.0294 | 0.8501 | 0.7781 | 0.8025 | 0.6899 | 0.6173 |
| | 44 | Processed seafood products | 0.1232 | 0.0782 | 0.0724 | 0.0689 | 0.0397 | 1.2684 | 1.3825 | 1.3545 | 1.1329 | 0.9334 |
| | 45 | Polished grains, flour, milled cereals | 0.0089 | 0.0130 | 0.0161 | 0.0153 | 0.0085 | 0.3188 | 0.3936 | 0.4397 | 0.4505 | 0.6262 |
| | 46 | Bakery, confectionery products, noodles | 0.1754 | 0.1532 | 0.1355 | 0.1508 | 0.0827 | 1.0915 | 0.9187 | 0.7906 | 0.8692 | 0.7641 |
| | 47 | Seasonings, fats and oils | 0.2961 | 0.2107 | 0.1467 | 0.1689 | 0.0773 | 1.3704 | 0.9816 | 0.8119 | 0.8694 | 0.7298 |
| | 48 | Canned or cured fruits, vegetables, misc. food preparations | 0.1986 | 0.2025 | 0.1724 | 0.1574 | 0.0737 | 0.8935 | 0.7488 | 0.7402 | 0.7010 | 0.6006 |
| | 49 | Beverages | 0.1759 | 0.1213 | 0.1018 | 0.0846 | 0.0430 | 0.8751 | 0.6499 | 0.6806 | 0.6043 | 0.4987 |
| | 50 | Prepared livestock feeds | 0.0167 | 0.0349 | 0.0463 | 0.0548 | 0.0423 | 0.6164 | 0.6351 | 0.6163 | 0.6058 | 0.8258 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | Tobacco products | 0.0131 | 0.0181 | 0.0144 | 0.0150 | 0.0118 | 0.1820 | 0.1802 | 0.1385 | 0.1554 | 0.1964 |
| 52 | Fiber yarn-p | 0.1166 | 0.1454 | 0.1539 | 0.1237 | 0.0635 | 1.6281 | 1.4676 | 1.5480 | 1.3444 | 1.0617 |
| 53 | Wearing apparels, apparel accessories | 0.0848 | 0.0947 | 0.0798 | 0.0759 | 0.0328 | 1.3873 | 1.2292 | 0.9132 | 0.8910 | 0.4944 |
| 54 | Other fabricated textile products | 0.0911 | 0.1035 | 0.1139 | 0.0828 | 0.0510 | 1.4696 | 1.2735 | 1.1571 | 1.2739 | 0.9380 |
| 55 | Leather, fur products | 0.0560 | 0.0579 | 0.0601 | 0.0666 | 0.0320 | 0.6833 | 0.6777 | 0.6465 | 0.7440 | 0.8599 |
| 56 | Wood, wooden products-p | 0.0540 | 0.1007 | 0.1224 | 0.1128 | 0.0506 | 0.7082 | 0.6568 | 0.7738 | 0.8124 | 0.7104 |
| 57 | Pulp, paper-p | 0.1534 | 0.1322 | 0.0844 | 0.0980 | 0.0899 | 1.3300 | 1.0159 | 0.8512 | 1.0947 | 1.0007 |
| 58 | Printing, publishing, reproduction of recorded media | 0.0377 | 0.0379 | 0.0522 | 0.0583 | 0.0548 | 0.8228 | 0.6414 | 0.6608 | 0.8207 | 0.7646 |
| 59 | Synthetic resins, synthetic rubber-p | 0.1351 | 0.1421 | 0.1200 | 0.0958 | 0.0465 | 2.8227 | 2.4982 | 2.7058 | 2.9382 | 2.5692 |
| 60 | Fertilizers, agricultural chemicals-p | 0.0687 | 0.0606 | 0.0938 | 0.0956 | 0.0524 | 1.5057 | 1.6382 | 1.9731 | 2.3399 | 1.8683 |
| 61 | Drugs, cosmetics, soap | 0.0917 | 0.0699 | 0.0763 | 0.0645 | 0.0361 | 1.0765 | 0.8543 | 0.9413 | 0.8711 | 0.6451 |
| 62 | Plastic products | 0.1351 | 0.1116 | 0.1801 | 0.1407 | 0.0735 | 1.8437 | 1.4524 | 1.6728 | 1.7600 | 1.2125 |
| 63 | Rubber products | 0.2278 | 0.1624 | 0.1526 | 0.1713 | 0.1006 | 1.7221 | 1.1959 | 1.1676 | 1.2484 | 1.0919 |
| 64 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.1932 | 0.1742 | 0.1426 | 0.0852 | 0.0692 | 1.4519 | 0.9514 | 0.8473 | 0.6033 | 0.6285 |
| 65 | Fabricated metal products-p | 0.1291 | 0.0563 | 0.0635 | 0.0656 | 0.0538 | 2.9164 | 1.7512 | 1.9071 | 1.9082 | 1.6862 |
| 66 | Machinery, equipment of general purpose-p | 0.0528 | 0.0513 | 0.0399 | 0.0534 | 0.0413 | 0.8158 | 0.8879 | 0.7883 | 0.8571 | 0.8221 |
| 67 | Machinery, equipment of special purpose | 0.0660 | 0.0266 | 0.0356 | 0.0456 | 0.0272 | 0.8639 | 0.5855 | 0.6450 | 0.7381 | 0.5779 |
| 68 | Electronic machinery, equipment, supplies | 0.0679 | 0.0731 | 0.0555 | 0.0544 | 0.0425 | 0.9261 | 0.8352 | 0.7083 | 0.6427 | 0.5568 |
| 69 | Electronic components, accessories | 0.0586 | 0.0377 | 0.0333 | 0.0178 | 0.0075 | 1.2359 | 1.0114 | 0.7589 | 0.3848 | 0.2160 |
| 70 | Radio, television, communications equipment | 0.0296 | 0.0296 | 0.0212 | 0.0159 | 0.0080 | 1.0493 | 0.8894 | 0.6314 | 0.3973 | 0.2739 |
| 71 | Computer, office equipment | 0.0392 | 0.0153 | 0.0098 | 0.0066 | 0.0026 | 0.9108 | 0.9170 | 0.5677 | 0.3328 | 0.1541 |
| 72 | Household electrical appliances | 0.0764 | 0.0532 | 0.0385 | 0.0357 | 0.0298 | 1.6837 | 1.2725 | 0.9488 | 0.7710 | 0.7167 |
| 73 | Precision instruments | 0.0276 | 0.0130 | 0.0159 | 0.0190 | 0.0107 | 0.3722 | 0.2850 | 0.2641 | 0.2773 | 0.2237 |
| 74 | Motor vehicles | 0.0990 | 0.0682 | 0.0485 | 0.0509 | 0.0314 | 1.4566 | 1.2574 | 1.0303 | 1.0586 | 0.8445 |
| 75 | Ship building, repairing | 0.0423 | 0.0387 | 0.0284 | 0.0353 | 0.0324 | 1.4375 | 1.1831 | 0.8812 | 0.8236 | 1.2295 |
| 76 | Other transportation equipment | 0.0435 | 0.0255 | 0.0309 | 0.0358 | 0.0261 | 0.5663 | 0.4166 | 0.3889 | 0.4852 | 0.4066 |
| 77 | Furniture | 0.0663 | 0.0990 | 0.0891 | 0.0933 | 0.0383 | 1.2100 | 0.9597 | 0.9390 | 0.9031 | 0.7268 |
| 78 | Other manufacturing products | 0.0955 | 0.0818 | 0.0766 | 0.0765 | 0.0616 | 1.1411 | 0.8527 | 0.7351 | 0.7762 | 0.6102 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 79 | Building construction, repair | 0.0290 | 0.0301 | 0.0351 | 0.0429 | 0.0726 | 0.9334 | 0.7076 | 0.8795 | 0.9387 | 0.9231 |
| 80 | Civil Engineering | 0.1418 | 0.1438 | 0.1013 | 0.1017 | 0.2726 | 1.1279 | 0.9078 | 1.0742 | 1.1328 | 1.4721 |
| 81 | Transportation, warehousing-p | 0.1030 | 0.2119 | 0.1059 | 0.0890 | 0.0000 | 0.3593 | 0.5822 | 0.3226 | 0.2726 | 0.0000 |
| 82 | Communications, broadcasting | 0.1107 | 0.0632 | 0.0426 | 0.0279 | 0.0261 | 0.6169 | 0.3830 | 0.3364 | 0.3149 | 0.3327 |
| 83 | Finance, insurance | 0.0497 | 0.0565 | 0.0365 | 0.0264 | 0.0196 | 0.4157 | 0.3644 | 0.2938 | 0.2259 | 0.2122 |
| 84 | Real estate agencies, rental | 0.0461 | 0.0302 | 0.0317 | 0.0182 | 0.0258 | 0.3636 | 0.3233 | 0.4143 | 0.2857 | 0.3191 |
| 85 | Business services | 0.1035 | 0.0926 | 0.1020 | 0.0662 | 0.0500 | 0.6105 | 0.5133 | 0.4643 | 0.3335 | 0.3234 |
| 86 | Educational, research services | 0.0831 | 0.0882 | 0.0970 | 0.1165 | 0.0903 | 0.2577 | 0.2740 | 0.3617 | 0.4355 | 0.4662 |
| 87 | Medical, health services, social security | 0.1649 | 0.1135 | 0.0997 | 0.0661 | 0.1131 | 0.6711 | 0.5121 | 0.5376 | 0.5573 | 0.6923 |
| 88 | Culture, recreational services | 0.2146 | 0.1463 | 0.1254 | 0.0997 | 0.1056 | 0.8842 | 0.6383 | 0.6733 | 0.5238 | 0.4982 |
| 89 | Other services | 0.1881 | 0.1881 | 0.0976 | 0.1161 | 0.0945 | 1.0086 | 0.9306 | 0.7060 | 0.7154 | 0.6086 |
| 90 | Unclassified activities | 0.0578 | 0.0533 | 0.0679 | 0.0553 | 0.0105 | 0.8988 | 0.9268 | 0.9297 | 0.9001 | 0.7201 |

# Appendix 4. Sectoral $CH_4$ Emission Intensity by Energy Use

(unit: kg-$CH_4$/million Korean Won in 2000)

| sector | | | $CH_4$ emission intensity (direct) | | | | | $CH_4$ emission intensity (total) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1985 | 1990 | 1995 | 2000 | 2005 | 1985 | 1990 | 1995 | 2000 | 2005 |
| energy | 1 | coal | 0.0007 | 0.0012 | 0.0015 | 0.0011 | 0.0007 | 0.0880 | 0.0881 | 0.0873 | 0.0858 | 0.0850 |
| | 2 | fuel | 0.0066 | 0.0057 | 0.0089 | 0.0096 | 0.0129 | 0.2583 | 0.2577 | 0.2614 | 0.2633 | 0.2676 |
| | 3 | nfuel | 0.0500 | 0.0277 | 0.0211 | 0.0177 | 0.0208 | 0.3212 | 0.2867 | 0.2785 | 0.2744 | 0.2797 |
| | 4 | gas | 0.1369 | 0.0496 | 0.0264 | 0.0038 | 0.0005 | 0.1927 | 0.1390 | 0.1125 | 0.0882 | 0.0846 |
| | 5 | lelec | 0.0028 | 0.0034 | 0.0032 | 0.0025 | 0.0024 | 0.0192 | 0.0624 | 0.0380 | 0.0183 | 0.0182 |
| | 6 | felec | 0.2069 | 0.1685 | 0.1628 | 0.1366 | 0.0973 | 0.3570 | 0.2890 | 0.2942 | 0.2208 | 0.1438 |
| | 7 | nap | 0.0021 | 0.0015 | 0.0007 | 0.0006 | 0.0009 | 0.1278 | 0.1273 | 0.1264 | 0.1263 | 0.1268 |
| | 8 | heat | 0.1534 | 0.0873 | 0.2976 | 0.1051 | 0.0609 | 0.9415 | 0.5393 | 1.5196 | 0.4176 | 0.3228 |
| non energy and energy intensive | 9 | Crops-p | 0.0002 | 0.0211 | 0.0278 | 0.0102 | 0.0052 | 0.1617 | 0.1342 | 0.1023 | 0.0585 | 0.0364 |
| | 10 | Fishery products | 0.0398 | 0.0626 | 0.0673 | 0.0652 | 0.0523 | 0.0868 | 0.1209 | 0.1414 | 0.1397 | 0.1208 |
| | 11 | Metallic minerals | 0.0017 | 0.0004 | 0.0003 | 0.0001 | 0.0001 | 0.0135 | 0.0034 | 0.0015 | 0.0006 | 0.0003 |
| | 12 | Nonmetallic minerals | 0.0108 | 0.0146 | 0.0129 | 0.0119 | 0.0155 | 0.0483 | 0.0450 | 0.0488 | 0.0482 | 0.0626 |
| | 13 | Sugar, starches | 0.0114 | 0.0117 | 0.0082 | 0.0108 | 0.0070 | 0.0509 | 0.0471 | 0.0423 | 0.0623 | 0.0521 |
| | 14 | Fiber yarn | 0.0039 | 0.0042 | 0.0054 | 0.0045 | 0.0032 | 0.1054 | 0.0943 | 0.0637 | 0.0788 | 0.0751 |
| | 15 | Fiber fabrics-p | 0.0312 | 0.0231 | 0.1135 | 0.0605 | 0.0344 | 0.1077 | 0.0752 | 0.2252 | 0.1956 | 0.1407 |
| | 16 | Wood, wooden products-p | 0.0023 | 0.0026 | 0.0031 | 0.0042 | 0.0021 | 0.0274 | 0.0235 | 0.0266 | 0.0389 | 0.0368 |
| | 17 | Pulp, paper-p | 0.0116 | 0.0106 | 0.0075 | 0.0087 | 0.0126 | 0.0756 | 0.0518 | 0.0581 | 0.0822 | 0.0962 |
| | 18 | Organic basic chemical products | 0.1211 | 0.0804 | 0.1124 | 0.1061 | 0.1114 | 0.2549 | 0.2035 | 0.2674 | 0.2764 | 0.2773 |
| | 19 | Inorganic basic chemical products | 0.1356 | 0.0852 | 0.0507 | 0.0439 | 0.0377 | 0.3415 | 0.2242 | 0.1657 | 0.1629 | 0.1410 |
| | 20 | Synthetic resins, synthetic rubber-p | 0.0246 | 0.0137 | 0.0334 | 0.0145 | 0.0242 | 0.1306 | 0.0967 | 0.1486 | 0.1517 | 0.1718 |
| | 21 | Chemical fibers | 0.0155 | 0.0101 | 0.0214 | 0.0087 | 0.0060 | 0.2205 | 0.1877 | 0.2194 | 0.2081 | 0.1795 |
| | 22 | Fertilizers, agricultural chemicals-p | 0.0526 | 0.0443 | 0.0461 | 0.0256 | 0.0147 | 0.2128 | 0.1538 | 0.1331 | 0.1141 | 0.0710 |
| | 23 | Other chemical products | 0.0070 | 0.0102 | 0.0063 | 0.0070 | 0.0062 | 0.0844 | 0.0779 | 0.0740 | 0.0790 | 0.0653 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 24 | Glass products | 0.0320 | 0.0334 | 0.0180 | 0.0152 | 0.0076 | 0.1101 | 0.0950 | 0.0743 | 0.0789 | 0.0409 |
| | 25 | Pottery, clay products | 0.0585 | 0.0377 | 0.0370 | 0.0347 | 0.0191 | 0.1305 | 0.0904 | 0.1063 | 0.1112 | 0.0758 |
| | 26 | Cement, concrete products | 0.3824 | 0.2323 | 0.1441 | 0.1419 | 0.1536 | 0.5647 | 0.3411 | 0.2827 | 0.2845 | 0.2891 |
| | 27 | Other nonmetallic mineral products | 0.0937 | 0.0873 | 0.0882 | 0.0786 | 0.0624 | 0.2174 | 0.1851 | 0.1676 | 0.1611 | 0.1420 |
| | 28 | Pig iron & crude steel | 0.2589 | 0.2096 | 0.2363 | 0.2442 | 0.3239 | 0.9216 | 0.7803 | 0.9860 | 0.9178 | 1.0034 |
| | 29 | Primary iron, steel products | 0.0110 | 0.0090 | 0.0054 | 0.0042 | 0.0045 | 0.4326 | 0.3513 | 0.4240 | 0.4083 | 0.3991 |
| | 30 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.0544 | 0.0277 | 0.0140 | 0.0047 | 0.0083 | 0.1204 | 0.0670 | 0.0456 | 0.0358 | 0.0505 |
| | 31 | Fabricated metal products-p | 0.0064 | 0.0041 | 0.0055 | 0.0061 | 0.0082 | 0.1453 | 0.1180 | 0.1190 | 0.1038 | 0.1171 |
| | 32 | Machinery, equipment of general purpose-p | 0.0042 | 0.0018 | 0.0041 | 0.0057 | 0.0038 | 0.0732 | 0.0601 | 0.0657 | 0.0706 | 0.0125 |
| | 33 | Wholesale, retail trade | 0.0359 | 0.0371 | 0.0357 | 0.0239 | 0.0204 | 0.1210 | 0.1110 | 0.1133 | 0.0835 | 0.0957 |
| | 34 | Eating, drinking places, hotels, other lodging places | 0.0402 | 0.0414 | 0.0259 | 0.0280 | 0.0227 | 0.1263 | 0.1317 | 0.1197 | 0.1129 | 0.1064 |
| | 35 | Transportation & warehousing-p | 0.1852 | 0.2295 | 0.2575 | 0.2472 | 0.1834 | 0.3862 | 0.4271 | 0.5155 | 0.5184 | 0.4443 |
| | 36 | Public administration, defense | 0.0366 | 0.0336 | 0.0254 | 0.0186 | 0.0101 | 0.1426 | 0.1218 | 0.1043 | 0.0766 | 0.0573 |
| | 37 | Gas, water supply | 0.0039 | 0.0041 | 0.0069 | 0.0079 | 0.0072 | 0.2245 | 0.1299 | 0.1733 | 0.1659 | 0.1618 |
| | 38 | Medical, health services, social security-p | 0.0386 | 0.0816 | 0.0669 | 0.0599 | 0.0000 | 0.1308 | 0.1900 | 0.1759 | 0.1758 | 0.0000 |
| | 39 | Other services-p | 0.0138 | 0.0272 | 0.0653 | 0.0538 | 0.0365 | 0.0683 | 0.0889 | 0.1689 | 0.1507 | 0.1284 |
| non energy and energy less intensive | 40 | Crops-p | 0.0972 | 0.0441 | 0.0462 | 0.0548 | 0.1182 | 0.2867 | 0.2312 | 0.2610 | 0.3281 | 0.4564 |
| | 41 | Livestock breeding | 0.3498 | 0.0437 | 0.0412 | 0.0418 | 0.0477 | 1.1415 | 0.5177 | 0.4145 | 0.5463 | 0.7875 |
| | 42 | Forestry products | 0.0002 | 0.0017 | 0.0013 | 0.0026 | 0.0019 | 0.0769 | 0.0730 | 0.0810 | 0.1718 | 0.1536 |
| | 43 | Meat, dairy products | 0.0018 | 0.0016 | 0.0017 | 0.0014 | 0.0010 | 0.0468 | 0.0348 | 0.0350 | 0.0333 | 0.0346 |
| | 44 | Processed seafood products | 0.0038 | 0.0022 | 0.0021 | 0.0020 | 0.0012 | 0.0468 | 0.0483 | 0.0472 | 0.0424 | 0.0385 |
| | 45 | Polished grains, flour, milled cereals | 0.0003 | 0.0004 | 0.0005 | 0.0005 | 0.0003 | 0.0173 | 0.0185 | 0.0217 | 0.0244 | 0.0322 |
| | 46 | Bakery, confectionery products, noodles | 0.0050 | 0.0046 | 0.0043 | 0.0047 | 0.0027 | 0.0464 | 0.0389 | 0.0346 | 0.0414 | 0.0393 |
| | 47 | Seasonings, fats and oils | 0.0136 | 0.0094 | 0.0043 | 0.0053 | 0.0032 | 0.0623 | 0.0440 | 0.0360 | 0.0414 | 0.0394 |
| | 48 | Canned or cured fruits, vegetables, misc. food preparations | 0.0058 | 0.0057 | 0.0049 | 0.0047 | 0.0022 | 0.0389 | 0.0305 | 0.0317 | 0.0329 | 0.0309 |
| | 49 | Beverages | 0.0053 | 0.0039 | 0.0029 | 0.0032 | 0.0023 | 0.0365 | 0.0296 | 0.0329 | 0.0330 | 0.0293 |
| | 50 | Prepared livestock feeds | 0.0005 | 0.0012 | 0.0020 | 0.0020 | 0.0014 | 0.0301 | 0.0280 | 0.0278 | 0.0307 | 0.0418 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | Tobacco products | 0.0004 | 0.0006 | 0.0004 | 0.0005 | 0.0004 | 0.0090 | 0.0085 | 0.0067 | 0.0083 | 0.0105 |
| 52 | Fiber yarn-p | 0.0034 | 0.0043 | 0.0052 | 0.0040 | 0.0022 | 0.0782 | 0.0680 | 0.0950 | 0.0784 | 0.0738 |
| 53 | Wearing apparels, apparel accessories | 0.0030 | 0.0029 | 0.0029 | 0.0025 | 0.0012 | 0.0664 | 0.0562 | 0.0509 | 0.0472 | 0.0308 |
| 54 | Other fabricated textile products | 0.0029 | 0.0034 | 0.0034 | 0.0027 | 0.0020 | 0.0716 | 0.0599 | 0.0640 | 0.0738 | 0.0611 |
| 55 | Leather, fur products | 0.0019 | 0.0019 | 0.0018 | 0.0020 | 0.0018 | 0.0346 | 0.0320 | 0.0322 | 0.0392 | 0.0516 |
| 56 | Wood, wooden products-p | 0.0022 | 0.0033 | 0.0036 | 0.0034 | 0.0016 | 0.0348 | 0.0296 | 0.0329 | 0.0395 | 0.0418 |
| 57 | Pulp, paper-p | 0.0053 | 0.0040 | 0.0030 | 0.0033 | 0.0029 | 0.0566 | 0.0433 | 0.0405 | 0.0608 | 0.0619 |
| 58 | Printing, publishing, reproduction of recorded media | 0.0016 | 0.0013 | 0.0016 | 0.0020 | 0.0021 | 0.0381 | 0.0288 | 0.0307 | 0.0450 | 0.0468 |
| 59 | Synthetic resins, synthetic rubber-p | 0.0240 | 0.0179 | 0.0044 | 0.0050 | 0.0052 | 0.1747 | 0.1397 | 0.1614 | 0.1776 | 0.1582 |
| 60 | Fertilizers, agricultural chemicals-p | 0.0024 | 0.0024 | 0.0043 | 0.0032 | 0.0017 | 0.0836 | 0.0843 | 0.1152 | 0.1335 | 0.1078 |
| 61 | Drugs, cosmetics, soap | 0.0030 | 0.0024 | 0.0024 | 0.0021 | 0.0016 | 0.0524 | 0.0407 | 0.0476 | 0.0473 | 0.0372 |
| 62 | Plastic products | 0.0044 | 0.0050 | 0.0078 | 0.0053 | 0.0027 | 0.1013 | 0.0780 | 0.0935 | 0.1035 | 0.0729 |
| 63 | Rubber products | 0.0091 | 0.0056 | 0.0052 | 0.0064 | 0.0039 | 0.0955 | 0.0640 | 0.0679 | 0.0729 | 0.0676 |
| 64 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.0061 | 0.0071 | 0.0059 | 0.0036 | 0.0038 | 0.0901 | 0.0564 | 0.0492 | 0.0386 | 0.0468 |
| 65 | Fabricated metal products-p | 0.0047 | 0.0019 | 0.0021 | 0.0024 | 0.0023 | 0.2247 | 0.1379 | 0.1593 | 0.1647 | 0.1472 |
| 66 | Machinery, equipment of general purpose-p | 0.0022 | 0.0019 | 0.0016 | 0.0022 | 0.0019 | 0.0577 | 0.0616 | 0.0588 | 0.0649 | 0.0641 |
| 67 | Machinery, equipment of special purpose | 0.0031 | 0.0011 | 0.0013 | 0.0018 | 0.0011 | 0.0610 | 0.0424 | 0.0477 | 0.0571 | 0.0457 |
| 68 | Electronic machinery, equipment, supplies | 0.0028 | 0.0035 | 0.0024 | 0.0025 | 0.0021 | 0.0565 | 0.0497 | 0.0430 | 0.0426 | 0.0388 |
| 69 | Electronic components, accessories | 0.0021 | 0.0018 | 0.0014 | 0.0008 | 0.0006 | 0.0655 | 0.0536 | 0.0424 | 0.0243 | 0.0154 |
| 70 | Radio, television, communications equipment | 0.0010 | 0.0014 | 0.0010 | 0.0007 | 0.0004 | 0.0569 | 0.0471 | 0.0344 | 0.0245 | 0.0185 |
| 71 | Computer, office equipment | 0.0017 | 0.0006 | 0.0003 | 0.0003 | 0.0001 | 0.0516 | 0.0512 | 0.0305 | 0.0200 | 0.0106 |
| 72 | Household electrical appliances | 0.0023 | 0.0024 | 0.0014 | 0.0014 | 0.0017 | 0.1038 | 0.0767 | 0.0598 | 0.0525 | 0.0504 |
| 73 | Precision instruments | 0.0016 | 0.0005 | 0.0006 | 0.0007 | 0.0005 | 0.0214 | 0.0156 | 0.0148 | 0.0168 | 0.0148 |
| 74 | Motor vehicles | 0.0041 | 0.0032 | 0.0021 | 0.0024 | 0.0015 | 0.0972 | 0.0860 | 0.0717 | 0.0762 | 0.0632 |
| 75 | Ship building, repairing | 0.0013 | 0.0014 | 0.0009 | 0.0012 | 0.0012 | 0.1071 | 0.0877 | 0.0661 | 0.0637 | 0.1021 |
| 76 | Other transportation equipment | 0.0017 | 0.0011 | 0.0013 | 0.0016 | 0.0012 | 0.0363 | 0.0274 | 0.0252 | 0.0328 | 0.0289 |
| 77 | Furniture | 0.0028 | 0.0029 | 0.0026 | 0.0028 | 0.0013 | 0.0702 | 0.0504 | 0.0495 | 0.0543 | 0.0471 |
| 78 | Other manufacturing products | 0.0043 | 0.0040 | 0.0034 | 0.0037 | 0.0020 | 0.0599 | 0.0446 | 0.0411 | 0.0470 | 0.0370 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 79 | Building construction, repair | 0.0011 | 0.0012 | 0.0010 | 0.0016 | 0.0024 | 0.0680 | 0.0479 | 0.0614 | 0.0672 | 0.0661 |
| 80 | Civil Engineering | 0.0062 | 0.0060 | 0.0031 | 0.0035 | 0.0087 | 0.0726 | 0.0562 | 0.0712 | 0.0800 | 0.0923 |
| 81 | Transportation, warehousing-p | 0.0149 | 0.0322 | 0.0156 | 0.0136 | 0.0000 | 0.0502 | 0.0850 | 0.0463 | 0.0394 | 0.0000 |
| 82 | Communications, broadcasting | 0.0152 | 0.0091 | 0.0062 | 0.0045 | 0.0040 | 0.0831 | 0.0535 | 0.0467 | 0.0443 | 0.0450 |
| 83 | Finance, insurance | 0.0070 | 0.0082 | 0.0051 | 0.0052 | 0.0031 | 0.0568 | 0.0512 | 0.0410 | 0.0336 | 0.0293 |
| 84 | Real estate agencies, rental | 0.0063 | 0.0040 | 0.0039 | 0.0025 | 0.0033 | 0.0479 | 0.0433 | 0.0536 | 0.0369 | 0.0391 |
| 85 | Business services | 0.0146 | 0.0130 | 0.0147 | 0.0099 | 0.0074 | 0.0862 | 0.0742 | 0.0675 | 0.0483 | 0.0469 |
| 86 | Educational, research services | 0.0101 | 0.0114 | 0.0139 | 0.0169 | 0.0169 | 0.0334 | 0.0371 | 0.0514 | 0.0604 | 0.0679 |
| 87 | Medical, health services, social security | 0.0218 | 0.0155 | 0.0149 | 0.0103 | 0.0160 | 0.0937 | 0.0750 | 0.0834 | 0.0867 | 0.1033 |
| 88 | Culture, recreational services | 0.0279 | 0.0199 | 0.0172 | 0.0139 | 0.0136 | 0.1182 | 0.0876 | 0.0956 | 0.0722 | 0.0647 |
| 89 | Other services | 0.0242 | 0.0235 | 0.0138 | 0.0326 | 0.0173 | 0.1354 | 0.1261 | 0.1016 | 0.1218 | 0.0900 |
| 90 | Unclassified activities | 0.0066 | 0.0064 | 0.0085 | 0.0099 | 0.0022 | 0.1256 | 0.1326 | 0.1387 | 0.1347 | 0.1078 |

# Appendix 5. Sectoral $N_2O$ Emission Intensity by Energy Use

(unit: kg-$N_2O$ /million Korean Won in 2000)

| sector | | | $N_2O$ emission intensity (direct) | | | | | $N_2O$ emission intensity (total) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1985 | 1990 | 1995 | 2000 | 2005 | 1985 | 1990 | 1995 | 2000 | 2005 |
| energy | 1 | coal | 0.0002 | 0.0004 | 0.0007 | 0.0003 | 0.0003 | 0.1184 | 0.1184 | 0.1183 | 0.1177 | 0.1176 |
| | 2 | fuel | 0.0013 | 0.0011 | 0.0018 | 0.0019 | 0.0025 | 0.0517 | 0.0515 | 0.0523 | 0.0528 | 0.0535 |
| | 3 | nfuel | 0.0100 | 0.0056 | 0.0042 | 0.0036 | 0.0041 | 0.0646 | 0.0575 | 0.0558 | 0.0550 | 0.0560 |
| | 4 | gas | 0.0272 | 0.0097 | 0.0053 | 0.0007 | 0.0001 | 0.0345 | 0.0193 | 0.0142 | 0.0093 | 0.0086 |
| | 5 | lelec | 0.0006 | 0.0008 | 0.0007 | 0.0005 | 0.0005 | 0.0065 | 0.0221 | 0.0138 | 0.0065 | 0.0075 |
| | 6 | felec | 0.1008 | 0.0813 | 0.0879 | 0.1141 | 0.1030 | 0.1348 | 0.1082 | 0.1235 | 0.1469 | 0.1236 |
| | 7 | nap | 0.0004 | 0.0003 | 0.0001 | 0.0001 | 0.0002 | 0.0256 | 0.0255 | 0.0253 | 0.0253 | 0.0254 |
| | 8 | heat | 0.0307 | 0.0216 | 0.0476 | 0.0333 | 0.0214 | 0.1451 | 0.0854 | 0.2218 | 0.0927 | 0.0643 |
| non energy and energy intensive | 9 | Crops-p | 0.0000 | 0.0013 | 0.0017 | 0.0006 | 0.0003 | 0.0026 | 0.0042 | 0.0039 | 0.0017 | 0.0010 |
| | 10 | Fishery products | 0.0048 | 0.0075 | 0.0081 | 0.0078 | 0.0063 | 0.0104 | 0.0144 | 0.0169 | 0.0166 | 0.0142 |
| | 11 | Metallic minerals | 0.0004 | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0027 | 0.0006 | 0.0003 | 0.0001 | 0.0001 |
| | 12 | Nonmetallic minerals | 0.0030 | 0.0043 | 0.0038 | 0.0035 | 0.0046 | 0.0111 | 0.0107 | 0.0112 | 0.0105 | 0.0144 |
| | 13 | Sugar, starches | 0.0034 | 0.0035 | 0.0025 | 0.0026 | 0.0014 | 0.0131 | 0.0120 | 0.0100 | 0.0122 | 0.0090 |
| | 14 | Fiber yarn | 0.0011 | 0.0012 | 0.0013 | 0.0011 | 0.0007 | 0.0234 | 0.0215 | 0.0137 | 0.0162 | 0.0129 |
| | 15 | Fiber fabrics-p | 0.0093 | 0.0068 | 0.0191 | 0.0109 | 0.0055 | 0.0273 | 0.0185 | 0.0410 | 0.0355 | 0.0222 |
| | 16 | Wood, wooden products-p | 0.0006 | 0.0008 | 0.0009 | 0.0012 | 0.0005 | 0.0061 | 0.0055 | 0.0061 | 0.0081 | 0.0067 |
| | 17 | Pulp, paper-p | 0.0034 | 0.0030 | 0.0022 | 0.0022 | 0.0023 | 0.0177 | 0.0120 | 0.0121 | 0.0152 | 0.0154 |
| | 18 | Organic basic chemical products | 0.0266 | 0.0210 | 0.0302 | 0.0290 | 0.0318 | 0.0587 | 0.0522 | 0.0678 | 0.0696 | 0.0730 |
| | 19 | Inorganic basic chemical products | 0.0211 | 0.0134 | 0.0081 | 0.0077 | 0.0066 | 0.0564 | 0.0367 | 0.0276 | 0.0272 | 0.0227 |
| | 20 | Synthetic resins, synthetic rubber-p | 0.0044 | 0.0015 | 0.0049 | 0.0024 | 0.0036 | 0.0286 | 0.0219 | 0.0317 | 0.0327 | 0.0377 |
| | 21 | Chemical fibers | 0.0046 | 0.0030 | 0.0038 | 0.0018 | 0.0012 | 0.0498 | 0.0434 | 0.0506 | 0.0474 | 0.0418 |
| | 22 | Fertilizers, agricultural chemicals-p | 0.0155 | 0.0132 | 0.0122 | 0.0070 | 0.0036 | 0.0518 | 0.0396 | 0.0318 | 0.0247 | 0.0144 |
| | 23 | Other chemical products | 0.0018 | 0.0023 | 0.0016 | 0.0017 | 0.0013 | 0.0182 | 0.0177 | 0.0170 | 0.0175 | 0.0145 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 24 | Glass products | 0.0091 | 0.0096 | 0.0053 | 0.0043 | 0.0016 | 0.0271 | 0.0237 | 0.0172 | 0.0163 | 0.0072 |
| | 25 | Pottery, clay products | 0.0128 | 0.0100 | 0.0095 | 0.0085 | 0.0041 | 0.0293 | 0.0222 | 0.0246 | 0.0236 | 0.0136 |
| | 26 | Cement, concrete products | 0.0548 | 0.0340 | 0.0218 | 0.0216 | 0.0227 | 0.0867 | 0.0533 | 0.0461 | 0.0457 | 0.0462 |
| | 27 | Other nonmetallic mineral products | 0.0189 | 0.0199 | 0.0199 | 0.0183 | 0.0135 | 0.0460 | 0.0417 | 0.0375 | 0.0358 | 0.0299 |
| | 28 | Pig iron & crude steel | 0.0369 | 0.0301 | 0.0336 | 0.0346 | 0.0455 | 0.1350 | 0.1140 | 0.1416 | 0.1309 | 0.1405 |
| | 29 | Primary iron, steel products | 0.0024 | 0.0019 | 0.0013 | 0.0011 | 0.0009 | 0.0662 | 0.0532 | 0.0627 | 0.0596 | 0.0565 |
| | 30 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.0080 | 0.0043 | 0.0023 | 0.0010 | 0.0012 | 0.0194 | 0.0109 | 0.0075 | 0.0058 | 0.0068 |
| | 31 | Fabricated metal products-p | 0.0015 | 0.0010 | 0.0015 | 0.0017 | 0.0019 | 0.0246 | 0.0194 | 0.0198 | 0.0172 | 0.0185 |
| | 32 | Machinery, equipment of general purpose-p | 0.0010 | 0.0005 | 0.0012 | 0.0016 | 0.0010 | 0.0126 | 0.0099 | 0.0112 | 0.0121 | 0.0023 |
| | 33 | Wholesale, retail trade | 0.0029 | 0.0028 | 0.0022 | 0.0012 | 0.0012 | 0.0096 | 0.0083 | 0.0075 | 0.0056 | 0.0068 |
| | 34 | Eating, drinking places, hotels, other lodging places | 0.0034 | 0.0031 | 0.0015 | 0.0016 | 0.0013 | 0.0105 | 0.0095 | 0.0077 | 0.0075 | 0.0072 |
| | 35 | Transportation & warehousing-p | 0.0138 | 0.0171 | 0.0192 | 0.0184 | 0.0136 | 0.0290 | 0.0318 | 0.0381 | 0.0385 | 0.0324 |
| | 36 | Public administration, defense | 0.0025 | 0.0022 | 0.0015 | 0.0011 | 0.0006 | 0.0105 | 0.0086 | 0.0072 | 0.0054 | 0.0043 |
| | 37 | Gas, water supply | 0.0003 | 0.0003 | 0.0004 | 0.0004 | 0.0004 | 0.0196 | 0.0109 | 0.0147 | 0.0159 | 0.0163 |
| | 38 | Medical, health services, social security-p | 0.0023 | 0.0049 | 0.0040 | 0.0036 | 0.0000 | 0.0093 | 0.0124 | 0.0116 | 0.0123 | 0.0000 |
| | 39 | Other services-p | 0.0012 | 0.0018 | 0.0039 | 0.0032 | 0.0020 | 0.0056 | 0.0065 | 0.0110 | 0.0105 | 0.0089 |
| non energy and energy less intensive | 40 | Crops-p | 0.0005 | 0.0005 | 0.0007 | 0.0009 | 0.0021 | 0.0034 | 0.0037 | 0.0045 | 0.0049 | 0.0069 |
| | 41 | Livestock breeding | 0.0024 | 0.0015 | 0.0019 | 0.0019 | 0.0016 | 0.0101 | 0.0093 | 0.0085 | 0.0093 | 0.0103 |
| | 42 | Forestry products | 0.0000 | 0.0002 | 0.0002 | 0.0003 | 0.0002 | 0.0011 | 0.0013 | 0.0015 | 0.0024 | 0.0016 |
| | 43 | Meat, dairy products | 0.0005 | 0.0005 | 0.0005 | 0.0004 | 0.0003 | 0.0093 | 0.0078 | 0.0079 | 0.0071 | 0.0065 |
| | 44 | Processed seafood products | 0.0011 | 0.0007 | 0.0006 | 0.0006 | 0.0003 | 0.0116 | 0.0125 | 0.0123 | 0.0106 | 0.0089 |
| | 45 | Polished grains, flour, milled cereals | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0037 | 0.0042 | 0.0049 | 0.0051 | 0.0067 |
| | 46 | Bakery, confectionery products, noodles | 0.0015 | 0.0013 | 0.0012 | 0.0014 | 0.0008 | 0.0108 | 0.0089 | 0.0079 | 0.0090 | 0.0079 |
| | 47 | Seasonings, fats and oils | 0.0031 | 0.0021 | 0.0012 | 0.0014 | 0.0006 | 0.0142 | 0.0100 | 0.0082 | 0.0089 | 0.0074 |
| | 48 | Canned or cured fruits, vegetables, misc. food preparations | 0.0017 | 0.0017 | 0.0015 | 0.0014 | 0.0006 | 0.0089 | 0.0072 | 0.0072 | 0.0071 | 0.0062 |
| | 49 | Beverages | 0.0015 | 0.0011 | 0.0009 | 0.0008 | 0.0004 | 0.0084 | 0.0065 | 0.0069 | 0.0065 | 0.0053 |
| | 50 | Prepared livestock feeds | 0.0001 | 0.0003 | 0.0005 | 0.0005 | 0.0004 | 0.0066 | 0.0065 | 0.0063 | 0.0063 | 0.0085 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | Tobacco products | 0.0001 | 0.0002 | 0.0001 | 0.0001 | 0.0001 | 0.0020 | 0.0019 | 0.0015 | 0.0017 | 0.0021 |
| 52 | Fiber yarn-p | 0.0010 | 0.0013 | 0.0014 | 0.0011 | 0.0006 | 0.0175 | 0.0155 | 0.0202 | 0.0166 | 0.0131 |
| 53 | Wearing apparels, apparel accessories | 0.0008 | 0.0008 | 0.0008 | 0.0007 | 0.0003 | 0.0147 | 0.0128 | 0.0109 | 0.0101 | 0.0055 |
| 54 | Other fabricated textile products | 0.0008 | 0.0010 | 0.0010 | 0.0008 | 0.0004 | 0.0159 | 0.0137 | 0.0142 | 0.0158 | 0.0116 |
| 55 | Leather, fur products | 0.0005 | 0.0005 | 0.0005 | 0.0006 | 0.0005 | 0.0075 | 0.0073 | 0.0072 | 0.0085 | 0.0098 |
| 56 | Wood, wooden products-p | 0.0005 | 0.0009 | 0.0011 | 0.0010 | 0.0005 | 0.0074 | 0.0066 | 0.0077 | 0.0085 | 0.0078 |
| 57 | Pulp, paper-p | 0.0014 | 0.0012 | 0.0008 | 0.0009 | 0.0008 | 0.0130 | 0.0100 | 0.0088 | 0.0121 | 0.0112 |
| 58 | Printing, publishing, reproduction of recorded media | 0.0004 | 0.0003 | 0.0005 | 0.0005 | 0.0005 | 0.0084 | 0.0065 | 0.0066 | 0.0088 | 0.0083 |
| 59 | Synthetic resins, synthetic rubber-p | 0.0036 | 0.0033 | 0.0012 | 0.0011 | 0.0009 | 0.0379 | 0.0334 | 0.0395 | 0.0419 | 0.0386 |
| 60 | Fertilizers, agricultural chemicals-p | 0.0006 | 0.0006 | 0.0011 | 0.0009 | 0.0005 | 0.0189 | 0.0206 | 0.0283 | 0.0325 | 0.0272 |
| 61 | Drugs, cosmetics, soap | 0.0008 | 0.0007 | 0.0007 | 0.0006 | 0.0004 | 0.0116 | 0.0093 | 0.0111 | 0.0104 | 0.0080 |
| 62 | Plastic products | 0.0013 | 0.0012 | 0.0019 | 0.0014 | 0.0006 | 0.0223 | 0.0178 | 0.0216 | 0.0229 | 0.0161 |
| 63 | Rubber products | 0.0024 | 0.0016 | 0.0015 | 0.0019 | 0.0011 | 0.0199 | 0.0138 | 0.0146 | 0.0154 | 0.0141 |
| 64 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.0017 | 0.0021 | 0.0015 | 0.0009 | 0.0006 | 0.0165 | 0.0109 | 0.0090 | 0.0067 | 0.0065 |
| 65 | Fabricated metal products-p | 0.0012 | 0.0005 | 0.0006 | 0.0006 | 0.0004 | 0.0367 | 0.0221 | 0.0247 | 0.0251 | 0.0216 |
| 66 | Machinery, equipment of general purpose-p | 0.0005 | 0.0005 | 0.0004 | 0.0006 | 0.0004 | 0.0099 | 0.0107 | 0.0098 | 0.0108 | 0.0101 |
| 67 | Machinery, equipment of special purpose | 0.0007 | 0.0003 | 0.0004 | 0.0005 | 0.0003 | 0.0104 | 0.0072 | 0.0080 | 0.0094 | 0.0071 |
| 68 | Electronic machinery, equipment, supplies | 0.0007 | 0.0010 | 0.0006 | 0.0007 | 0.0004 | 0.0107 | 0.0098 | 0.0082 | 0.0078 | 0.0064 |
| 69 | Electronic components, accessories | 0.0006 | 0.0005 | 0.0003 | 0.0002 | 0.0001 | 0.0134 | 0.0111 | 0.0083 | 0.0045 | 0.0025 |
| 70 | Radio, television, communications equipment | 0.0003 | 0.0004 | 0.0002 | 0.0002 | 0.0001 | 0.0115 | 0.0098 | 0.0069 | 0.0046 | 0.0031 |
| 71 | Computer, office equipment | 0.0004 | 0.0002 | 0.0001 | 0.0001 | 0.0000 | 0.0102 | 0.0102 | 0.0061 | 0.0038 | 0.0018 |
| 72 | Household electrical appliances | 0.0007 | 0.0006 | 0.0003 | 0.0003 | 0.0002 | 0.0196 | 0.0148 | 0.0110 | 0.0092 | 0.0084 |
| 73 | Precision instruments | 0.0003 | 0.0001 | 0.0002 | 0.0002 | 0.0001 | 0.0042 | 0.0031 | 0.0029 | 0.0032 | 0.0026 |
| 74 | Motor vehicles | 0.0010 | 0.0008 | 0.0006 | 0.0007 | 0.0004 | 0.0172 | 0.0152 | 0.0126 | 0.0133 | 0.0103 |
| 75 | Ship building, repairing | 0.0004 | 0.0004 | 0.0003 | 0.0004 | 0.0003 | 0.0178 | 0.0146 | 0.0110 | 0.0105 | 0.0157 |
| 76 | Other transportation equipment | 0.0004 | 0.0003 | 0.0004 | 0.0005 | 0.0003 | 0.0066 | 0.0050 | 0.0046 | 0.0059 | 0.0048 |
| 77 | Furniture | 0.0006 | 0.0009 | 0.0008 | 0.0008 | 0.0003 | 0.0138 | 0.0104 | 0.0103 | 0.0104 | 0.0084 |
| 78 | Other manufacturing products | 0.0010 | 0.0009 | 0.0008 | 0.0008 | 0.0005 | 0.0126 | 0.0095 | 0.0085 | 0.0093 | 0.0071 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 79 | Building construction, repair | 0.0003 | 0.0003 | 0.0003 | 0.0004 | 0.0006 | 0.0115 | 0.0085 | 0.0106 | 0.0116 | 0.0110 |
| 80 | Civil Engineering | 0.0017 | 0.0017 | 0.0009 | 0.0010 | 0.0025 | 0.0134 | 0.0108 | 0.0127 | 0.0139 | 0.0167 |
| 81 | Transportation, warehousing-p | 0.0009 | 0.0322 | 0.0156 | 0.0008 | 0.0000 | 0.0034 | 0.0055 | 0.0030 | 0.0026 | 0.0000 |
| 82 | Communications, broadcasting | 0.0010 | 0.0006 | 0.0004 | 0.0003 | 0.0002 | 0.0063 | 0.0039 | 0.0033 | 0.0033 | 0.0035 |
| 83 | Finance, insurance | 0.0004 | 0.0005 | 0.0003 | 0.0002 | 0.0002 | 0.0041 | 0.0034 | 0.0027 | 0.0023 | 0.0022 |
| 84 | Real estate agencies, rental | 0.0004 | 0.0002 | 0.0002 | 0.0001 | 0.0002 | 0.0039 | 0.0033 | 0.0042 | 0.0032 | 0.0034 |
| 85 | Business services | 0.0010 | 0.0008 | 0.0009 | 0.0006 | 0.0004 | 0.0062 | 0.0050 | 0.0044 | 0.0033 | 0.0032 |
| 86 | Educational, research services | 0.0009 | 0.0009 | 0.0008 | 0.0010 | 0.0008 | 0.0029 | 0.0029 | 0.0034 | 0.0042 | 0.0048 |
| 87 | Medical, health services, social security | 0.0016 | 0.0010 | 0.0008 | 0.0005 | 0.0009 | 0.0069 | 0.0050 | 0.0052 | 0.0059 | 0.0070 |
| 88 | Culture, recreational services | 0.0021 | 0.0013 | 0.0010 | 0.0008 | 0.0007 | 0.0091 | 0.0062 | 0.0064 | 0.0052 | 0.0044 |
| 89 | Other services | 0.0019 | 0.0020 | 0.0008 | 0.0012 | 0.0008 | 0.0106 | 0.0096 | 0.0066 | 0.0073 | 0.0059 |
| 90 | Unclassified activities | 0.0009 | 0.0008 | 0.0009 | 0.0007 | 0.0001 | 0.0097 | 0.0096 | 0.0092 | 0.0090 | 0.0073 |

# Appendix 6. Sectoral GHG Emission Intensity by Energy Use

(unit: t-$CO_2$-eq./million Korean Won in 2000)

| sector | | | $CO_2$-eq. emission intensity (direct) | | | | | $CO_2$-eq. emission intensity (total) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1985 | 1990 | 1995 | 2000 | 2005 | 1985 | 1990 | 1995 | 2000 | 2005 |
| energy | 1 | coal | 0.0215 | 0.0283 | 0.0494 | 0.0223 | 0.0210 | 7.9906 | 7.9562 | 7.9320 | 7.8683 | 7.8601 |
| | 2 | fuel | 0.1563 | 0.1066 | 0.2008 | 0.2121 | 0.1663 | 6.0949 | 6.0163 | 6.1032 | 6.0961 | 6.0105 |
| | 3 | nfuel | 0.6386 | 0.2735 | 0.1824 | 0.1602 | 0.1576 | 4.7498 | 4.1748 | 4.0578 | 4.0299 | 4.0313 |
| | 4 | gas | 1.9930 | 1.2625 | 0.6377 | 0.0905 | 0.0127 | 4.9623 | 6.1238 | 5.3973 | 4.7474 | 4.6625 |
| | 5 | lelec | 0.0664 | 0.0714 | 0.0733 | 0.0528 | 0.0523 | 0.5867 | 2.0847 | 1.2913 | 0.5659 | 0.6442 |
| | 6 | felec | 8.3281 | 6.8555 | 7.2879 | 8.3515 | 7.3541 | 12.1246 | 10.3833 | 11.4540 | | 9.7784 |
| | 7 | nap | 0.0487 | 0.0297 | 0.0165 | 0.0126 | 0.0100 | 0.8172 | 0.7991 | 0.7844 | 0.7798 | 0.7807 |
| | 8 | heat | 3.7477 | 2.3353 | 1.1938 | 2.0277 | 1.4458 | 7.1844 | 3.7949 | 2.8894 | 4.3743 | 2.7291 |
| non energy and energy intensive | 9 | Crops-p | 0.0006 | 0.1533 | 0.2008 | 0.0727 | 0.0361 | 0.2211 | 0.4309 | 0.4298 | 0.1827 | 0.0991 |
| | 10 | Fishery products | 0.5926 | 0.8911 | 0.9350 | 0.8896 | 0.7104 | 1.3181 | 1.7686 | 2.0198 | 1.9916 | 1.7385 |
| | 11 | Metallic minerals | 0.0479 | 0.0088 | 0.0115 | 0.0024 | 0.0026 | 0.2610 | 0.0580 | 0.0348 | 0.0100 | 0.0076 |
| | 12 | Nonmetallic minerals | 0.3375 | 0.3736 | 0.4427 | 0.4085 | 0.5283 | 1.1355 | 1.0128 | 1.2041 | 1.0937 | 1.5422 |
| | 13 | Sugar, starches | 0.4151 | 0.4231 | 0.2935 | 0.2539 | 0.1171 | 1.4615 | 1.3443 | 1.0870 | 1.1484 | 0.8179 |
| | 14 | Fiber yarn | 0.1287 | 0.1396 | 0.1240 | 0.1211 | 0.0629 | 2.0985 | 1.9205 | 1.1101 | 1.3011 | 1.0388 |
| | 15 | Fiber fabrics-p | 1.1337 | 0.8056 | 0.9217 | 0.7079 | 0.3371 | 2.9858 | 1.9786 | 2.6721 | 2.8313 | 1.8179 |
| | 16 | Wood, wooden products-p | 0.0741 | 0.0856 | 0.1052 | 0.1412 | 0.0611 | 0.5718 | 0.5418 | 0.5916 | 0.7432 | 0.5849 |
| | 17 | Pulp, paper-p | 0.4081 | 0.3391 | 0.2473 | 0.2370 | 0.1600 | 1.8537 | 1.2479 | 1.2284 | 1.3944 | 1.2762 |
| | 18 | Organic basic chemical products | 1.1484 | 0.8013 | 1.0565 | 1.0279 | 1.0093 | 4.2440 | 3.9034 | 4.3629 | 4.7009 | 4.7024 |
| | 19 | Inorganic basic chemical products | 1.5872 | 1.0063 | 0.6242 | 0.5326 | 0.4025 | 4.5215 | 2.9160 | 2.2782 | 2.1055 | 1.7315 |
| | 20 | Synthetic resins, synthetic rubber-p | 0.0818 | 0.0066 | 0.1085 | 0.1132 | 0.0636 | 2.0459 | 1.6063 | 1.8987 | 2.2889 | 2.4045 |
| | 21 | Chemical fibers | 0.5551 | 0.3511 | 0.2083 | 0.1391 | 0.1004 | 4.2847 | 3.6736 | 3.4360 | 3.3700 | 2.8765 |
| | 22 | Fertilizers, agricultural chemicals-p | 0.8282 | 0.6481 | 0.5430 | 0.3948 | 0.1650 | 4.2976 | 3.2549 | 2.3655 | 2.0123 | 1.1558 |
| | 23 | Other chemical products | 0.1392 | 0.1710 | 0.1225 | 0.1274 | 0.0817 | 1.4580 | 1.4056 | 1.2645 | 1.3113 | 1.0373 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 24 | Glass products | 1.0716 | 1.0705 | 0.6128 | 0.4947 | 0.1987 | 2.9496 | 2.5497 | 1.8329 | 1.6488 | 0.7694 |
| | 25 | Pottery, clay products | 1.3211 | 1.1396 | 1.0585 | 0.9167 | 0.4709 | 3.0315 | 2.4165 | 2.5926 | 2.3704 | 1.4355 |
| | 26 | Cement, concrete products | 3.6693 | 2.3072 | 1.5287 | 1.5219 | 1.5470 | 6.3555 | 3.9974 | 3.6792 | 3.5517 | 3.6170 |
| | 27 | Other nonmetallic mineral products | 1.3176 | 1.1320 | 1.0817 | 1.0388 | 0.6906 | 3.8104 | 3.0151 | 2.6541 | 2.5968 | 2.1628 |
| | 28 | Pig iron & crude steel | 2.6371 | 2.1717 | 2.3825 | 2.4390 | 3.1327 | 9.6312 | 8.1988 | 9.8425 | 9.0068 | 9.6250 |
| | 29 | Primary iron, steel products | 0.2409 | 0.1936 | 0.1398 | 0.1125 | 0.0886 | 4.9757 | 4.0218 | 4.5662 | 4.2851 | 4.0764 |
| | 30 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.5750 | 0.3256 | 0.1840 | 0.0832 | 0.1049 | 1.5282 | 0.8836 | 0.6578 | 0.5000 | 0.5987 |
| | 31 | Fabricated metal products-p | 0.1545 | 0.0849 | 0.1547 | 0.1621 | 0.2020 | 2.0276 | 1.5572 | 1.6379 | 1.4068 | 1.5860 |
| | 32 | Machinery, equipment of general purpose-p | 0.0946 | 0.0364 | 0.0597 | 0.0823 | 0.0591 | 1.0536 | 0.7991 | 0.8563 | 0.9033 | 0.1899 |
| | 33 | Wholesale, retail trade | 0.2799 | 0.2652 | 0.2511 | 0.1291 | 0.1310 | 0.9188 | 0.8022 | 0.8154 | 0.5580 | 0.6843 |
| | 34 | Eating, drinking places, hotels, other lodging places | 0.3280 | 0.3266 | 0.1963 | 0.2044 | 0.1668 | 0.9825 | 0.9951 | 0.8662 | 0.8204 | 0.7763 |
| | 35 | Transportation & warehousing-p | 1.1645 | 1.3721 | 1.5601 | 1.4817 | 1.0834 | 2.4817 | 2.6217 | 3.1757 | 3.2003 | 2.7046 |
| | 36 | Public administration, defense | 0.2640 | 0.2272 | 0.1715 | 0.1269 | 0.0669 | 1.0415 | 0.8549 | 0.7365 | 0.5487 | 0.4139 |
| | 37 | Gas, water supply | 0.0262 | 0.0266 | 0.0530 | 0.0599 | 0.0510 | 1.7555 | 1.0140 | 1.3899 | 1.3426 | 1.3529 |
| | 38 | Medical, health services, social security-p | 0.2682 | 0.5540 | 0.4715 | 0.4150 | 0.0000 | 0.9527 | 1.3350 | 1.2550 | 1.2617 | 0.0000 |
| | 39 | Other services-p | 0.1106 | 0.1624 | 0.2519 | 0.1960 | 0.1338 | 0.5142 | 0.5979 | 0.9181 | 0.8485 | 0.7660 |
| non energy and energy less intensive | 40 | Crops-p | 0.0372 | 0.0462 | 0.0603 | 0.0779 | 0.1991 | 0.2663 | 0.3083 | 0.3513 | 0.3943 | 0.5989 |
| | 41 | Livestock breeding | 0.1711 | 0.1237 | 0.1776 | 0.1657 | 0.0529 | 0.8077 | 0.8384 | 0.7739 | 0.8101 | 0.7662 |
| | 42 | Forestry products | 0.0032 | 0.0229 | 0.0166 | 0.0358 | 0.0265 | 0.0982 | 0.1256 | 0.1355 | 0.2239 | 0.1491 |
| | 43 | Meat, dairy products | 0.0583 | 0.0548 | 0.0571 | 0.0460 | 0.0295 | 0.8540 | 0.7812 | 0.8057 | 0.6928 | 0.6200 |
| | 44 | Processed seafood products | 0.1236 | 0.0785 | 0.0726 | 0.0692 | 0.0398 | 1.2730 | 1.3874 | 1.3593 | 1.1371 | 0.9369 |
| | 45 | Polished grains, flour, milled cereals | 0.0089 | 0.0130 | 0.0161 | 0.0153 | 0.0085 | 0.3203 | 0.3953 | 0.4416 | 0.4526 | 0.6289 |
| | 46 | Bakery, confectionery products, noodles | 0.1759 | 0.1537 | 0.1359 | 0.1513 | 0.0830 | 1.0959 | 0.9223 | 0.7938 | 0.8729 | 0.7674 |
| | 47 | Seasonings, fats and oils | 0.2973 | 0.2116 | 0.1472 | 0.1695 | 0.0776 | 1.3761 | 0.9856 | 0.8152 | 0.8730 | 0.7329 |
| | 48 | Canned or cured fruits, vegetables, misc. food preparations | 0.1992 | 0.2032 | 0.1729 | 0.1579 | 0.0740 | 0.8970 | 0.7517 | 0.7431 | 0.7039 | 0.6032 |
| | 49 | Beverages | 0.1764 | 0.1217 | 0.1021 | 0.0849 | 0.0432 | 0.8785 | 0.6526 | 0.6834 | 0.6070 | 0.5009 |
| | 50 | Prepared livestock feeds | 0.0167 | 0.0351 | 0.0465 | 0.0550 | 0.0424 | 0.6191 | 0.6377 | 0.6189 | 0.6084 | 0.8293 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 51 | Tobacco products | 0.0131 | 0.0182 | 0.0145 | 0.0151 | 0.0119 | 0.1828 | 0.1809 | 0.1391 | 0.1561 | 0.1973 |
| 52 | Fiber yarn-p | 0.1170 | 0.1459 | 0.1544 | 0.1241 | 0.0637 | 1.6351 | 1.4738 | 1.5563 | 1.3512 | 1.0673 |
| 53 | Wearing apparels, apparel accessories | 0.0851 | 0.0950 | 0.0801 | 0.0761 | 0.0329 | 1.3932 | 1.2343 | 0.9176 | 0.8951 | 0.4968 |
| 54 | Other fabricated textile products | 0.0914 | 0.1038 | 0.1143 | 0.0831 | 0.0511 | 1.4760 | 1.2791 | 1.1628 | 1.2804 | 0.9429 |
| 55 | Leather, fur products | 0.0562 | 0.0581 | 0.0603 | 0.0668 | 0.0322 | 0.6863 | 0.6807 | 0.6494 | 0.7474 | 0.8640 |
| 56 | Wood, wooden products-p | 0.0542 | 0.1011 | 0.1229 | 0.1132 | 0.0508 | 0.7112 | 0.6594 | 0.7769 | 0.8159 | 0.7137 |
| 57 | Pulp, paper-p | 0.1539 | 0.1327 | 0.0847 | 0.0984 | 0.0902 | 1.3353 | 1.0199 | 0.8547 | 1.0997 | 1.0055 |
| 58 | Printing, publishing, reproduction of recorded media | 0.0378 | 0.0380 | 0.0524 | 0.0585 | 0.0550 | 0.8262 | 0.6440 | 0.6635 | 0.8244 | 0.7681 |
| 59 | Synthetic resins, synthetic rubber-p | 0.1367 | 0.1435 | 0.1204 | 0.0963 | 0.0468 | 2.8381 | 2.5115 | 2.7214 | 2.9549 | 2.5845 |
| 60 | Fertilizers, agricultural chemicals-p | 0.0689 | 0.0608 | 0.0943 | 0.0959 | 0.0526 | 1.5133 | 1.6463 | 1.9843 | 2.3527 | 1.8790 |
| 61 | Drugs, cosmetics, soap | 0.0920 | 0.0701 | 0.0765 | 0.0647 | 0.0362 | 1.0812 | 0.8580 | 0.9457 | 0.8753 | 0.6484 |
| 62 | Plastic products | 0.1356 | 0.1121 | 0.1809 | 0.1413 | 0.0737 | 1.8527 | 1.4595 | 1.6815 | 1.7693 | 1.2190 |
| 63 | Rubber products | 0.2287 | 0.1631 | 0.1532 | 0.1721 | 0.1010 | 1.7303 | 1.2015 | 1.1736 | 1.2547 | 1.0977 |
| 64 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.1938 | 0.1749 | 0.1432 | 0.0855 | 0.0695 | 1.4589 | 0.9560 | 0.8511 | 0.6062 | 0.6315 |
| 65 | Fabricated metal products-p | 0.1295 | 0.0565 | 0.0637 | 0.0659 | 0.0539 | 2.9325 | 1.7610 | 1.9181 | 1.9195 | 1.6960 |
| 66 | Machinery, equipment of general purpose-p | 0.0530 | 0.0515 | 0.0401 | 0.0536 | 0.0414 | 0.8200 | 0.8925 | 0.7926 | 0.8618 | 0.8266 |
| 67 | Machinery, equipment of special purpose | 0.0663 | 0.0267 | 0.0358 | 0.0457 | 0.0273 | 0.8684 | 0.5886 | 0.6485 | 0.7422 | 0.5811 |
| 68 | Electronic machinery, equipment, supplies | 0.0682 | 0.0734 | 0.0557 | 0.0546 | 0.0426 | 0.9306 | 0.8393 | 0.7118 | 0.6460 | 0.5596 |
| 69 | Electronic components, accessories | 0.0589 | 0.0379 | 0.0334 | 0.0179 | 0.0075 | 1.2414 | 1.0160 | 0.7624 | 0.3867 | 0.2171 |
| 70 | Radio, television, communications equipment | 0.0297 | 0.0297 | 0.0213 | 0.0160 | 0.0080 | 1.0540 | 0.8935 | 0.6342 | 0.3992 | 0.2753 |
| 71 | Computer, office equipment | 0.0393 | 0.0154 | 0.0098 | 0.0066 | 0.0026 | 0.9151 | 0.9213 | 0.5702 | 0.3344 | 0.1549 |
| 72 | Household electrical appliances | 0.0766 | 0.0534 | 0.0387 | 0.0358 | 0.0299 | 1.6919 | 1.2787 | 0.9535 | 0.7750 | 0.7203 |
| 73 | Precision instruments | 0.0277 | 0.0130 | 0.0159 | 0.0190 | 0.0108 | 0.3739 | 0.2863 | 0.2654 | 0.2787 | 0.2249 |
| 74 | Motor vehicles | 0.0994 | 0.0685 | 0.0487 | 0.0512 | 0.0315 | 1.4639 | 1.2639 | 1.0357 | 1.0643 | 0.8491 |
| 75 | Ship building, repairing | 0.0424 | 0.0389 | 0.0285 | 0.0354 | 0.0325 | 1.4453 | 1.1895 | 0.8860 | 0.8282 | 1.2365 |
| 76 | Other transportation equipment | 0.0437 | 0.0257 | 0.0311 | 0.0360 | 0.0263 | 0.5691 | 0.4188 | 0.3909 | 0.4877 | 0.4087 |
| 77 | Furniture | 0.0666 | 0.0993 | 0.0894 | 0.0937 | 0.0384 | 1.2157 | 0.9640 | 0.9432 | 0.9075 | 0.7304 |
| 78 | Other manufacturing products | 0.0959 | 0.0821 | 0.0769 | 0.0768 | 0.0618 | 1.1462 | 0.8566 | 0.7386 | 0.7801 | 0.6132 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 79 | Building construction, repair | 0.0291 | 0.0302 | 0.0353 | 0.0431 | 0.0729 | 0.9384 | 0.7113 | 0.8841 | 0.9437 | 0.9279 |
| 80 | Civil Engineering | 0.1425 | 0.1444 | 0.1017 | 0.1021 | 0.2735 | 1.1336 | 0.9124 | 1.0797 | 1.1388 | 1.4792 |
| 81 | Transportation, warehousing-p | 0.1036 | 0.2225 | 0.1111 | 0.0895 | 0.0000 | 0.3615 | 0.5857 | 0.3245 | 0.2742 | 0.0000 |
| 82 | Communications, broadcasting | 0.1114 | 0.0636 | 0.0429 | 0.0281 | 0.0263 | 0.6206 | 0.3854 | 0.3384 | 0.3169 | 0.3348 |
| 83 | Finance, insurance | 0.0500 | 0.0569 | 0.0367 | 0.0266 | 0.0197 | 0.4181 | 0.3665 | 0.2956 | 0.2273 | 0.2135 |
| 84 | Real estate agencies, rental | 0.0464 | 0.0303 | 0.0319 | 0.0183 | 0.0259 | 0.3658 | 0.3252 | 0.4168 | 0.2875 | 0.3210 |
| 85 | Business services | 0.1041 | 0.0932 | 0.1026 | 0.0666 | 0.0503 | 0.6143 | 0.5164 | 0.4671 | 0.3355 | 0.3254 |
| 86 | Educational, research services | 0.0836 | 0.0887 | 0.0975 | 0.1171 | 0.0909 | 0.2593 | 0.2756 | 0.3638 | 0.4381 | 0.4691 |
| 87 | Medical, health services, social security | 0.1658 | 0.1141 | 0.1003 | 0.0665 | 0.1137 | 0.6752 | 0.5152 | 0.5409 | 0.5610 | 0.6966 |
| 88 | Culture, recreational services | 0.2158 | 0.1472 | 0.1260 | 0.1003 | 0.1061 | 0.8895 | 0.6420 | 0.6773 | 0.5269 | 0.5010 |
| 89 | Other services | 0.1892 | 0.1893 | 0.0981 | 0.1172 | 0.0951 | 1.0147 | 0.9363 | 0.7102 | 0.7202 | 0.6123 |
| 90 | Unclassified activities | 0.0582 | 0.0537 | 0.0683 | 0.0557 | 0.0106 | 0.9044 | 0.9325 | 0.9354 | 0.9058 | 0.7246 |

# Appendix 7. Decomposition Results of the Direct GHG Emissions for Three Effects

| | | sector | total effect ($D_{tot}$) | | | | social effect ($D'_{soc}$) | | | | technical effect ($D'_{tech}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | '85-'90 | '90-'95 | '95-'00 | '00-'05 | '85-'90 | '90-'95 | '95-'00 | '00-'05 | '85-'90 | '90-'95 | '95-'00 | '00-'05 |
| energy | 1 | coal | 0.0003 | 0.0001 | 0.0001 | 0.0001 | -0.0007 | -0.0015 | -0.0004 | 0.0000 | 0.0015 | 0.0018 | -0.0013 | 0.0000 |
| | 2 | fuel | 0.0053 | 0.0125 | 0.0055 | -0.0003 | -0.0014 | 0.0028 | -0.0004 | -0.0026 | -0.0052 | 0.0079 | -0.0001 | -0.0039 |
| | 3 | nfuel | 0.0037 | 0.0015 | 0.0003 | 0.0014 | 0.0010 | -0.0004 | -0.0003 | 0.0011 | -0.0050 | -0.0014 | -0.0003 | 0.0000 |
| | 4 | gas | 0.0352 | 0.0296 | 0.0072 | 0.0010 | 0.0307 | 0.0146 | 0.0040 | 0.0007 | -0.0045 | -0.0181 | -0.0213 | -0.0042 |
| | 5 | lelec | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 6 | felec | 0.1044 | 0.4525 | 0.2599 | 0.1098 | -0.1608 | 0.1322 | 0.0702 | 0.0121 | -0.1136 | 0.0346 | 0.0881 | -0.0864 |
| | 7 | nap | 0.0007 | 0.0006 | 0.0005 | 0.0000 | 0.0002 | 0.0001 | 0.0003 | 0.0000 | -0.0006 | -0.0005 | -0.0002 | -0.0001 |
| | 8 | heat | 0.0032 | 0.0053 | 0.0092 | -0.0009 | 0.0007 | 0.0026 | 0.0068 | -0.0025 | -0.0027 | -0.0032 | 0.0043 | -0.0038 |
| non energy and energy intensive | 9 | Crops-p | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| | 10 | Fishery products | 0.0042 | 0.0012 | -0.0010 | -0.0002 | 0.0010 | -0.0033 | -0.0023 | -0.0005 | 0.0029 | 0.0004 | -0.0002 | -0.0006 |
| | 11 | Metallic minerals | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 12 | Nonmetallic minerals | 0.0007 | 0.0005 | -0.0002 | 0.0001 | 0.0003 | -0.0002 | -0.0004 | 0.0000 | 0.0001 | 0.0002 | -0.0001 | 0.0001 |
| | 13 | Sugar, starches | 0.0003 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0003 | 0.0000 | 0.0000 | 0.0000 | -0.0002 | 0.0000 | -0.0001 |
| | 14 | Fiber yarn | 0.0001 | -0.0002 | 0.0001 | 0.0000 | -0.0001 | -0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 |
| | 15 | Fiber fabrics-p | 0.0018 | 0.0023 | -0.0013 | 0.0002 | 0.0008 | 0.0007 | -0.0018 | 0.0001 | -0.0007 | 0.0004 | -0.0004 | -0.0004 |
| | 16 | Wood, wooden products-p | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 17 | Pulp, paper-p | 0.0009 | 0.0003 | 0.0002 | 0.0000 | 0.0002 | -0.0004 | 0.0000 | 0.0000 | -0.0003 | -0.0004 | 0.0000 | -0.0002 |
| | 18 | Organic basic chemical products | 0.0248 | 0.0590 | 0.0297 | 0.0240 | 0.0089 | 0.0286 | 0.0085 | 0.0126 | -0.0126 | 0.0148 | -0.0020 | -0.0015 |
| | 19 | Inorganic basic chemical products | 0.0027 | 0.0006 | 0.0007 | 0.0002 | -0.0004 | -0.0016 | 0.0002 | 0.0000 | -0.0031 | -0.0018 | -0.0003 | -0.0004 |
| | 20 | Synthetic resins, synthetic rubber-p | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 21 | Chemical fibers | 0.0001 | -0.0002 | 0.0001 | -0.0001 | -0.0009 | -0.0007 | 0.0000 | -0.0001 | -0.0010 | -0.0004 | -0.0001 | 0.0000 |
| | 22 | Fertilizers, agricultural chemicals-p | -0.0005 | 0.0000 | -0.0003 | -0.0001 | -0.0027 | -0.0014 | -0.0006 | -0.0002 | -0.0012 | -0.0004 | -0.0003 | -0.0002 |
| | 23 | Other chemical products | 0.0004 | 0.0001 | 0.0001 | 0.0000 | 0.0003 | -0.0001 | 0.0000 | 0.0000 | 0.0001 | -0.0002 | 0.0000 | -0.0001 |
| | 24 | Glass products | 0.0033 | 0.0007 | 0.0002 | -0.0001 | 0.0010 | -0.0015 | -0.0003 | -0.0002 | 0.0000 | -0.0021 | -0.0003 | -0.0007 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 25 | Pottery, clay products | 0.0056 | 0.0004 | -0.0009 | -0.0003 | 0.0029 | -0.0028 | -0.0017 | -0.0004 | -0.0009 | -0.0004 | -0.0004 | -0.0006 |
| | 26 | Cement, concrete products | 0.0130 | 0.0127 | -0.0026 | 0.0011 | -0.0214 | -0.0101 | -0.0085 | -0.0011 | -0.0350 | -0.0166 | -0.0001 | 0.0003 |
| | 27 | Other nonmetallic mineral products | 0.0070 | 0.0045 | 0.0002 | 0.0000 | 0.0037 | -0.0003 | -0.0017 | -0.0006 | -0.0011 | -0.0004 | -0.0003 | -0.0016 |
| | 28 | Pig iron & crude steel | 0.0416 | 0.0485 | 0.0099 | 0.0359 | 0.0039 | 0.0001 | -0.0116 | 0.0232 | -0.0161 | 0.0079 | 0.0017 | 0.0221 |
| | 29 | Primary iron, steel products | 0.0011 | 0.0007 | 0.0002 | 0.0001 | 0.0002 | -0.0003 | 0.0000 | 0.0000 | -0.0005 | -0.0005 | -0.0002 | -0.0002 |
| | 30 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.0004 | 0.0002 | 0.0000 | 0.0001 | -0.0001 | -0.0001 | -0.0001 | 0.0000 | -0.0006 | -0.0004 | -0.0002 | 0.0000 |
| | 31 | Fabricated metal products-p | 0.0001 | 0.0003 | 0.0001 | 0.0004 | 0.0000 | 0.0002 | 0.0000 | 0.0003 | -0.0001 | 0.0002 | 0.0000 | 0.0001 |
| | 32 | Machinery, equipment of general purpose-p | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 33 | Wholesale, retail trade | 0.0041 | 0.0015 | -0.0003 | 0.0006 | 0.0012 | -0.0019 | -0.0011 | 0.0003 | -0.0003 | -0.0003 | -0.0018 | 0.0000 |
| | 34 | Eating, drinking places, hotels, other lodging places | 0.0046 | 0.0004 | 0.0008 | 0.0000 | 0.0030 | -0.0016 | 0.0002 | -0.0003 | -0.0001 | -0.0018 | 0.0001 | -0.0003 |
| | 35 | Transportation & warehousing-p | 0.0656 | 0.0560 | 0.0211 | 0.0026 | 0.0151 | -0.0197 | -0.0104 | -0.0088 | 0.0182 | 0.0172 | -0.0055 | -0.0249 |
| | 36 | Public administration, defense | 0.0015 | 0.0006 | 0.0001 | -0.0001 | 0.0003 | -0.0006 | -0.0002 | -0.0002 | -0.0004 | -0.0006 | -0.0003 | -0.0003 |
| | 37 | Gas, water supply | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 38 | Medical, health services, social security-p | 0.0007 | 0.0008 | 0.0001 | -0.0007 | 0.0005 | 0.0002 | -0.0001 | -0.0007 | 0.0003 | -0.0002 | -0.0001 | 0.0000 |
| | 39 | Other services-p | 0.0003 | 0.0011 | 0.0003 | -0.0001 | 0.0001 | 0.0006 | 0.0000 | -0.0002 | 0.0001 | 0.0004 | -0.0003 | -0.0003 |
| non energy and energy less intensive | 40 | Crops-p | 0.0001 | 0.0000 | 0.0000 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0003 |
| | 41 | Livestock breeding | 0.0000 | 0.0003 | 0.0000 | -0.0001 | -0.0001 | 0.0001 | -0.0001 | -0.0001 | -0.0001 | 0.0001 | 0.0000 | -0.0001 |
| | 42 | Forestry products | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 43 | Meat, dairy products | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 44 | Processed seafood products | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 45 | Polished grains, flour, milled cereals | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 46 | Bakery, confectionery products, noodles | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 47 | Seasonings, fats and oils | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0002 | -0.0001 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | 0.0000 | 0.0000 |
| | 48 | Canned or cured fruits, vegetables, misc. food preparations | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 |
| | 49 | Beverages | 0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 |
| | 50 | Prepared livestock feeds | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 51 | Tobacco products | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 52 | Fiber yarn-p | 0.0003 | 0.0002 | 0.0000 | -0.0001 | 0.0000 | -0.0002 | -0.0001 | -0.0001 | 0.0001 | 0.0000 | -0.0001 | -0.0001 |
| 53 | Wearing apparels, apparel accessories | 0.0002 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 54 | Other fabricated textile products | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 55 | Leather, fur products | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 56 | Wood, wooden products-p | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 57 | Pulp, paper-p | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 |
| 58 | Printing, publishing, reproduction of recorded media | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 59 | Synthetic resins, synthetic rubber-p | 0.0005 | 0.0000 | 0.0001 | 0.0000 | 0.0003 | -0.0002 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | -0.0001 |
| 60 | Fertilizers, agricultural chemicals-p | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 61 | Drugs, cosmetics, soap | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 62 | Plastic products | 0.0002 | 0.0004 | 0.0001 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | -0.0001 | -0.0001 | 0.0002 | -0.0001 | -0.0002 |
| 63 | Rubber products | 0.0001 | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | 0.0000 | 0.0000 | -0.0001 |
| 64 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.0003 | 0.0002 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | 0.0000 |
| 65 | Fabricated metal products-p | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 66 | Machinery, equipment of general purpose-p | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 67 | Machinery, equipment of special purpose | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 68 | Electronic machinery, equipment, supplies | 0.0001 | 0.0001 | 0.0001 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 69 | Electronic components, accessories | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 70 | Radio, television, communications equipment | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 71 | Computer, office equipment | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 72 | Household electrical appliances | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 73 | Precision instruments | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 74 | Motor vehicles | 0.0004 | 0.0002 | 0.0001 | 0.0000 | 0.0002 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | 0.0000 | -0.0001 |
| 75 | Ship building, repairing | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 76 | Other transportation equipment | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 77 | Furniture | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 78 | Other manufacturing products | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 79 | Building construction, repair | 0.0001 | 0.0000 | 0.0000 | 0.0002 | 0.0001 | -0.0001 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0001 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | Civil Engineering | 0.0008 | -0.0002 | 0.0001 | 0.0010 | 0.0001 | -0.0008 | 0.0000 | 0.0008 | 0.0000 | -0.0004 | 0.0000 | 0.0012 |
| 81 | Transportation, warehousing-p | 0.0003 | 0.0000 | 0.0000 | -0.0001 | 0.0002 | -0.0001 | 0.0000 | -0.0001 | 0.0002 | -0.0002 | 0.0000 | 0.0000 |
| 82 | Communications, broadcasting | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 83 | Finance, insurance | 0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 |
| 84 | Real estate agencies, rental | 0.0001 | 0.0001 | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | -0.0001 | 0.0000 |
| 85 | Business services | 0.0003 | 0.0004 | 0.0001 | 0.0000 | 0.0001 | 0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0002 | -0.0001 |
| 86 | Educational, research services | 0.0002 | 0.0003 | 0.0003 | 0.0003 | 0.0001 | 0.0000 | 0.0001 | 0.0002 | 0.0000 | 0.0000 | 0.0001 | -0.0002 |
| 87 | Medical, health services, social security | 0.0001 | 0.0002 | 0.0001 | 0.0003 | -0.0001 | 0.0000 | 0.0000 | 0.0003 | -0.0001 | 0.0000 | -0.0001 | 0.0002 |
| 88 | Culture, recreational services | 0.0001 | 0.0001 | 0.0001 | 0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 89 | Other services | 0.0001 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 |
| 90 | Unclassified activities | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 |

# Appendix 8. Decomposition Results of the Embodied GHG Emissions for Three Effects

| sector | | | total effect ($D_{tot}$) | | | | social effect ($D'_{soc}$) | | | | technical effect ($D'_{tech}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | '85-'90 | '90-'95 | '95-'00 | '00-'05 | '85-'90 | '90-'95 | '95-'00 | '00-'05 | '85-'90 | '90-'95 | '95-'00 | '00-'05 |
| energy | 1 | coal | 0.0175 | 0.0027 | 0.0031 | 0.0067 | -0.0490 | -0.0538 | -0.0152 | -0.0012 | 0.0004 | 0.0004 | -0.0007 | -0.0001 |
| | 2 | fuel | 0.0821 | 0.1765 | 0.0668 | -0.0045 | -0.0212 | 0.0395 | -0.0047 | -0.0369 | -0.0047 | 0.0018 | -0.0017 | -0.0050 |
| | 3 | nfuel | 0.0037 | 0.0021 | 0.0005 | 0.0029 | 0.0010 | -0.0006 | -0.0006 | 0.0022 | -0.0024 | -0.0005 | -0.0001 | 0.0000 |
| | 4 | gas | 0.0294 | 0.0330 | 0.0229 | 0.0217 | 0.0257 | 0.0163 | 0.0127 | 0.0152 | -0.0022 | -0.0062 | -0.0082 | -0.0016 |
| | 5 | lelec | 0.0006 | 0.0001 | -0.0001 | 0.0000 | 0.0006 | -0.0002 | -0.0002 | 0.0000 | 0.0002 | -0.0001 | -0.0001 | 0.0000 |
| | 6 | felec | 0.0463 | 0.2037 | 0.1209 | 0.0492 | -0.0713 | 0.0595 | 0.0326 | 0.0054 | -0.0401 | 0.0250 | 0.0068 | -0.0550 |
| | 7 | nap | 0.0046 | 0.0059 | 0.0078 | 0.0009 | 0.0012 | 0.0010 | 0.0046 | -0.0010 | -0.0002 | -0.0002 | -0.0001 | 0.0000 |
| | 8 | heat | 0.0017 | 0.0030 | 0.0066 | -0.0006 | 0.0004 | 0.0015 | 0.0049 | -0.0017 | -0.0019 | -0.0007 | 0.0024 | -0.0036 |
| non energy and energy intensive | 9 | Crops-p | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 10 | Fishery products | 0.0026 | 0.0007 | -0.0007 | -0.0001 | 0.0006 | -0.0020 | -0.0016 | -0.0004 | 0.0013 | 0.0006 | 0.0000 | -0.0003 |
| | 11 | Metallic minerals | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 12 | Nonmetallic minerals | 0.0006 | 0.0004 | -0.0002 | 0.0001 | 0.0003 | -0.0002 | -0.0004 | 0.0000 | -0.0001 | 0.0002 | -0.0001 | 0.0002 |
| | 13 | Sugar, starches | 0.0003 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0003 | 0.0000 | -0.0001 | -0.0001 | -0.0001 | 0.0000 | -0.0001 |
| | 14 | Fiber yarn | 0.0006 | -0.0005 | 0.0002 | -0.0001 | -0.0004 | -0.0011 | 0.0001 | -0.0002 | -0.0002 | -0.0005 | 0.0001 | -0.0001 |
| | 15 | Fiber fabrics-p | 0.0014 | 0.0018 | -0.0013 | 0.0003 | 0.0006 | 0.0005 | -0.0018 | 0.0001 | -0.0007 | 0.0007 | 0.0001 | -0.0004 |
| | 16 | Wood, wooden products-p | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 17 | Pulp, paper-p | 0.0011 | 0.0003 | 0.0003 | 0.0001 | 0.0002 | -0.0005 | -0.0001 | -0.0001 | -0.0008 | 0.0000 | 0.0002 | -0.0001 |
| | 18 | Organic basic chemical products | 0.0315 | 0.0767 | 0.0405 | 0.0364 | 0.0113 | 0.0372 | 0.0116 | 0.0190 | -0.0037 | 0.0078 | 0.0073 | 0.0000 |
| | 19 | Inorganic basic chemical products | 0.0024 | 0.0005 | 0.0009 | 0.0003 | -0.0003 | -0.0015 | 0.0002 | 0.0000 | -0.0026 | -0.0009 | -0.0002 | -0.0004 |
| | 20 | Synthetic resins, synthetic rubber-p | -0.0001 | 0.0001 | 0.0001 | 0.0002 | -0.0001 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 21 | Chemical fibers | 0.0003 | -0.0009 | 0.0003 | -0.0007 | -0.0023 | -0.0025 | -0.0001 | -0.0008 | -0.0009 | -0.0002 | 0.0000 | -0.0002 |
| | 22 | Fertilizers, agricultural chemicals-p | -0.0008 | 0.0000 | -0.0005 | -0.0002 | -0.0042 | -0.0019 | -0.0009 | -0.0003 | -0.0021 | -0.0011 | -0.0002 | -0.0003 |
| | 23 | Other chemical products | 0.0012 | 0.0003 | 0.0004 | 0.0000 | 0.0007 | -0.0004 | 0.0001 | -0.0001 | -0.0001 | -0.0001 | 0.0000 | -0.0002 |
| | 24 | Glass products | 0.0025 | 0.0005 | 0.0002 | -0.0002 | 0.0007 | -0.0011 | -0.0003 | -0.0003 | -0.0006 | -0.0010 | -0.0002 | -0.0007 |
| | 25 | Pottery, clay products | 0.0037 | 0.0003 | -0.0007 | -0.0003 | 0.0019 | -0.0018 | -0.0013 | -0.0004 | -0.0009 | 0.0003 | -0.0002 | -0.0004 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 26 | Cement, concrete products | 0.0067 | 0.0074 | -0.0019 | 0.0008 | -0.0111 | -0.0059 | -0.0063 | -0.0008 | -0.0182 | -0.0020 | -0.0005 | 0.0002 |
| | 27 | Other nonmetallic mineral products | 0.0057 | 0.0034 | 0.0001 | 0.0000 | 0.0030 | -0.0003 | -0.0013 | -0.0005 | -0.0014 | -0.0008 | -0.0001 | -0.0007 |
| | 28 | Pig iron & crude steel | 0.0461 | 0.0559 | 0.0121 | 0.0393 | 0.0043 | 0.0002 | -0.0142 | 0.0254 | -0.0148 | 0.0180 | -0.0080 | 0.0064 |
| | 29 | Primary iron, steel products | 0.0069 | 0.0049 | 0.0026 | 0.0020 | 0.0012 | -0.0020 | -0.0005 | 0.0005 | -0.0027 | 0.0015 | -0.0007 | -0.0005 |
| | 30 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.0004 | 0.0002 | 0.0000 | 0.0001 | -0.0001 | -0.0001 | -0.0001 | 0.0001 | -0.0005 | -0.0002 | -0.0001 | 0.0001 |
| | 31 | Fabricated metal products-p | 0.0003 | 0.0013 | 0.0004 | 0.0010 | -0.0002 | 0.0007 | 0.0000 | 0.0008 | -0.0003 | 0.0001 | -0.0002 | 0.0002 |
| | 32 | Machinery, equipment of general purpose-p | 0.0000 | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0002 |
| | 33 | Wholesale, retail trade | 0.0038 | 0.0014 | -0.0003 | 0.0009 | 0.0011 | -0.0018 | -0.0012 | 0.0005 | -0.0008 | 0.0001 | -0.0012 | 0.0005 |
| | 34 | Eating, drinking places, hotels, other lodging places | 0.0041 | 0.0004 | 0.0011 | -0.0001 | 0.0027 | -0.0016 | 0.0003 | -0.0004 | 0.0000 | -0.0005 | -0.0001 | -0.0001 |
| | 35 | Transportation & warehousing-p | 0.0391 | 0.0321 | 0.0138 | 0.0020 | 0.0090 | -0.0113 | -0.0068 | -0.0067 | 0.0036 | 0.0147 | 0.0005 | -0.0101 |
| | 36 | Public administration, defense | 0.0017 | 0.0007 | 0.0001 | -0.0001 | 0.0003 | -0.0007 | -0.0003 | -0.0003 | -0.0006 | -0.0004 | -0.0004 | -0.0002 |
| | 37 | Gas, water supply | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | 0.0000 | -0.0003 | 0.0001 | 0.0000 | 0.0000 |
| | 38 | Medical, health services, social security-p | 0.0006 | 0.0006 | 0.0001 | -0.0007 | 0.0004 | 0.0002 | -0.0001 | -0.0007 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| | 39 | Other services-p | 0.0004 | 0.0012 | 0.0004 | -0.0001 | 0.0002 | 0.0006 | 0.0000 | -0.0003 | 0.0001 | 0.0004 | -0.0001 | -0.0001 |
| non energy and energy less intensive | 40 | Crops-p | 0.0001 | 0.0001 | 0.0001 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.0000 | 0.0000 | 0.0000 | 0.0002 |
| | 41 | Livestock breeding | 0.0000 | 0.0004 | -0.0001 | -0.0001 | -0.0002 | 0.0001 | -0.0002 | -0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 42 | Forestry products | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 43 | Meat, dairy products | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 44 | Processed seafood products | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 45 | Polished grains, flour, milled cereals | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 46 | Bakery, confectionery products, noodles | 0.0002 | 0.0001 | 0.0000 | -0.0001 | 0.0000 | -0.0001 | 0.0000 | -0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0000 |
| | 47 | Seasonings, fats and oils | 0.0001 | 0.0000 | 0.0000 | -0.0001 | -0.0002 | -0.0002 | 0.0000 | -0.0001 | -0.0002 | -0.0001 | 0.0000 | 0.0000 |
| | 48 | Canned or cured fruits, vegetables, misc. food preparations | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0001 | -0.0001 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 49 | Beverages | 0.0001 | 0.0001 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | -0.0001 | -0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0000 |
| | 50 | Prepared livestock feeds | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 51 | Tobacco products | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | 52 | Fiber yarn-p | 0.0009 | 0.0004 | 0.0002 | -0.0003 | 0.0001 | -0.0005 | -0.0002 | -0.0004 | -0.0002 | 0.0001 | -0.0002 | -0.0002 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53 | Wearing apparels, apparel accessories | 0.0007 | -0.0002 | 0.0000 | -0.0001 | 0.0001 | -0.0007 | -0.0001 | -0.0001 | -0.0002 | -0.0003 | 0.0000 | -0.0001 |
| 54 | Other fabricated textile products | 0.0002 | 0.0003 | 0.0001 | 0.0000 | 0.0001 | 0.0001 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0001 |
| 55 | Leather, fur products | 0.0003 | -0.0001 | 0.0000 | 0.0000 | 0.0001 | -0.0003 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 56 | Wood, wooden products-p | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 57 | Pulp, paper-p | 0.0003 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | -0.0002 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | 0.0001 | 0.0000 |
| 58 | Printing, publishing, reproduction of recorded media | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 59 | Synthetic resins, synthetic rubber-p | 0.0026 | 0.0000 | 0.0009 | -0.0002 | 0.0016 | -0.0014 | 0.0004 | -0.0005 | -0.0003 | 0.0002 | 0.0002 | -0.0003 |
| 60 | Fertilizers, agricultural chemicals-p | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 61 | Drugs, cosmetics, soap | 0.0003 | 0.0002 | 0.0001 | 0.0000 | 0.0001 | -0.0001 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | -0.0001 |
| 62 | Plastic products | 0.0009 | 0.0013 | 0.0005 | -0.0001 | 0.0004 | 0.0004 | -0.0001 | -0.0003 | -0.0003 | 0.0002 | 0.0001 | -0.0005 |
| 63 | Rubber products | 0.0003 | 0.0003 | 0.0002 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0002 | -0.0002 | 0.0000 | 0.0000 | -0.0001 |
| 64 | Nonferrous metal ingots, primary nonferrous metal products-p | 0.0005 | 0.0003 | 0.0000 | 0.0000 | 0.0002 | 0.0000 | -0.0001 | 0.0000 | -0.0002 | -0.0001 | -0.0001 | 0.0000 |
| 65 | Fabricated metal products-p | 0.0000 | 0.0006 | -0.0001 | 0.0001 | -0.0003 | 0.0002 | -0.0002 | 0.0001 | -0.0003 | 0.0000 | 0.0000 | -0.0001 |
| 66 | Machinery, equipment of general purpose-p | 0.0005 | 0.0003 | 0.0001 | 0.0000 | 0.0003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | 0.0000 |
| 67 | Machinery, equipment of special purpose | 0.0001 | 0.0003 | 0.0002 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | -0.0001 | -0.0001 | 0.0000 | 0.0001 | -0.0001 |
| 68 | Electronic machinery, equipment, supplies | 0.0005 | 0.0002 | 0.0003 | 0.0000 | 0.0003 | -0.0001 | 0.0001 | -0.0001 | -0.0001 | -0.0001 | 0.0000 | -0.0001 |
| 69 | Electronic components, accessories | 0.0005 | 0.0005 | 0.0003 | 0.0001 | 0.0002 | 0.0002 | 0.0002 | 0.0001 | -0.0001 | -0.0002 | -0.0003 | -0.0002 |
| 70 | Radio, television, communications equipment | 0.0003 | 0.0000 | 0.0001 | 0.0000 | 0.0002 | -0.0001 | 0.0001 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | 0.0000 |
| 71 | Computer, office equipment | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 72 | Household electrical appliances | 0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 73 | Precision instruments | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 74 | Motor vehicles | 0.0018 | 0.0011 | 0.0007 | 0.0001 | 0.0012 | 0.0000 | 0.0002 | -0.0001 | -0.0002 | -0.0004 | 0.0000 | -0.0004 |
| 75 | Ship building, repairing | -0.0001 | 0.0001 | 0.0001 | 0.0001 | -0.0002 | 0.0000 | 0.0001 | 0.0000 | -0.0001 | 0.0000 | 0.0000 | 0.0001 |
| 76 | Other transportation equipment | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 77 | Furniture | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 78 | Other manufacturing products | 0.0002 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | 0.0000 | -0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 79 | Building construction, repair | 0.0010 | 0.0002 | -0.0001 | 0.0009 | 0.0005 | -0.0004 | -0.0003 | 0.0008 | -0.0003 | 0.0003 | 0.0001 | 0.0000 |
| 80 | Civil Engineering | 0.0017 | -0.0004 | 0.0004 | 0.0024 | 0.0002 | -0.0018 | -0.0001 | 0.0020 | -0.0007 | 0.0004 | 0.0001 | 0.0008 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 81 | Transportation, warehousing-p | 0.0002 | 0.0000 | 0.0000 | -0.0001 | 0.0002 | -0.0001 | 0.0000 | -0.0001 | 0.0001 | -0.0001 | 0.0000 | 0.0000 |
| 82 | Communications, broadcasting | 0.0001 | 0.0001 | 0.0001 | 0.0002 | 0.0000 | 0.0000 | 0.0001 | 0.0001 | -0.0001 | 0.0000 | 0.0000 | 0.0000 |
| 83 | Finance, insurance | 0.0004 | 0.0001 | 0.0000 | 0.0000 | 0.0002 | -0.0001 | 0.0000 | 0.0000 | 0.0000 | -0.0001 | -0.0001 | 0.0000 |
| 84 | Real estate agencies, rental | 0.0002 | 0.0004 | 0.0002 | 0.0003 | 0.0000 | 0.0001 | 0.0001 | 0.0002 | -0.0001 | 0.0001 | -0.0002 | 0.0001 |
| 85 | Business services | 0.0005 | 0.0006 | 0.0001 | 0.0001 | 0.0002 | 0.0002 | -0.0001 | 0.0000 | -0.0001 | -0.0001 | -0.0002 | 0.0000 |
| 86 | Educational, research services | 0.0002 | 0.0003 | 0.0003 | 0.0005 | 0.0001 | 0.0000 | 0.0001 | 0.0003 | 0.0000 | 0.0001 | 0.0001 | 0.0001 |
| 87 | Medical, health services, social security | 0.0001 | 0.0002 | 0.0001 | 0.0007 | -0.0001 | 0.0000 | 0.0000 | 0.0006 | -0.0001 | 0.0000 | 0.0000 | 0.0002 |
| 88 | Culture, recreational services | 0.0001 | 0.0002 | 0.0001 | 0.0002 | -0.0001 | 0.0000 | 0.0000 | 0.0002 | -0.0001 | 0.0000 | -0.0001 | 0.0000 |
| 89 | Other services | 0.0001 | -0.0001 | 0.0001 | 0.0000 | 0.0000 | -0.0001 | 0.0001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| 90 | Unclassified activities | 0.0003 | 0.0004 | 0.0002 | -0.0004 | 0.0001 | 0.0001 | 0.0000 | -0.0004 | 0.0000 | 0.0000 | 0.0000 | -0.0001 |

# List of Publications

## Original papers

(1) Whan-Sam Chung, Susumu Tohno and Sang Yul Shim, 2008: Analysis of Sectoral Energy Use Pattern with Energy Input-Output Analysis, *J. of KOSEE*, 2008;17(3):pp145-152. (Chapter 2)

(2) Whan-Sam Chung and Susumu Tohno, 2008: Convertibility of Monetary and Physical Input-output Analysis- an Application to Energy Sources -, *Korean J. of LCA*, 2008;9(1):pp 47-55. (Chapter 2)

(3) Whan-Sam Chung, Susumu Tohno and Sang Yul Shim, 2008: An Estimation of GHG Emission Intensities from Energy Use- Energy Input-output Approach -, *Korean J. of LCA*, 2008;9(1):pp 69-77. (Chapter 3)

(4) Whan-Sam Chung, Susumu Tohno and Sang Yul Shim, 2008: An Analysis of Sectoral GHG Emission Intensity from Energy Use in Korea, *J. of KOTIS*, 2008; 11(2): pp264-286. (Chapter 3)

(5) Whan-Sam Chung, Susumu Tohno and Sang Yul Shim, 2009: An estimation of energy and GHG emission intensity caused by energy consumption in Korea: An energy IO approach, *Applied Energy*, 2009;86:1902-1914. (Chapter 3)

(6) Whan-Sam Chung and Susumu Tohno, 2009: A time-series energy input-output analysis for building an infrastructure for the energy and environment policy in Korea, *Energy and Environment*, 2009;20(6):875-899. (Chapter 4)

(7) Whan-Sam Chung, Susumu Tohno and Ki-Hong Choi, 2011: Socio-Technological Impact Analysis using an Energy IO Approach to GHG Emissions Issues in Korea, *Applied Energy* , 2011;88:3747-3758. (Chapter 5)

(8) Whan-Sam Chung and Susumu Tohno, 2013: Can IDA give a clue in understanding industry's GHG footprint ?, *Energy and Environment* , in submission. (Chapter 6)

# Acknowledgement

A goal towards fulfilling the purpose of my studies might have been easier to achieve if I were merely following 'what I can' rather than 'what I have to do'. I surmise I have surmounted a peak. I would like to enjoy the song of a blue bird at this moment. The time is prime to summarize, and perhaps plan for the next trail of study.

Firstly, I would like to express my deep gratitude to Professor Mikio KASAHARA for the opportunity to join on this significant academic subject. Researchers graduated from Kyoto University participated in the study, Embodied Energy and Emission Intensity Data (3EID), first published in 2002 by the Center for Global Environmental Research, National Institute for Environmental Studies, which was the motivation to my study, although it led me to a somewhat different analysis.

It has been a privilege to conduct my further studies at the Graduate School of Energy Science, Kyoto University, renowned for its advanced research in the field. First of all I would like to express my deep appreciation to thank two prominent professors, Keiichi N. ISHIHARA and Tetsuo TEZUKA, for their patient and careful guidance as referees. Furthermore I would also like to acknowledge with much appreciation the crucial role of Assistant Professor Kouhei YAMAMOTO, who provided great support by setting up my research environment and offering boundless encouragement. And my thanks also go to Dr. Motonori OKUMURA and Dr. Atsushi MORIKAWA who provided assistance in networking with the relatively youthful student body at the graduate school, for whom I also wish the best of all in their academic careers.

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On a personal note, I cherish the memory of climbing Mt. Daimonji in the background of Yoshida Campus, together with the students in the lab. The vitality of young students' laughter as they leaped the big jump in the kanji Dai(大) formation, high up into the sky, still flashes before my eyes and resound in my ears. Their exotic-sounding names, sometimes mismatched with their familiar-looking faces, are forever etched onto my cerebral cortex like hologram tatoos, and will remain with me forever. I hope to see them again one day. I picture them dreaming great dreams for our global village, as well as their endeared homeland, and bearing much fruit in their endeavors to benefit all.

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Kyoto University is known for nurturing an academic tradition excelling in both liberty and responsibility, and so has my research lab. I pledge to be an alumnus adding to the reputation of this great tradition.