Can Index Decomposition Analysis Give a Clue in Understanding Industry’s Greenhouse Gas Footprint?†

Whan-Sam Chung* and Susumu Tohno**

ABSTRACT: Korea is one of the few OECD countries having no binding Greenhouse gas (GHG) emissions reduction obligations under the Kyoto Protocol. Korea is going to enforce a powerful greenhouse gas emissions control to the industry from 2015. Current GHG reduction policies do not take into account the trade-off between economic growth and GHG mitigation, this approach will not be sustainable. Sectoral approach, considering industry by industry may be more eco-friendly approach. This study verified the validity of the analysis results counted from whole procedure of energy input-output analysis and decomposition analysis to sector ‘Organic basic chemical products’ and ‘Cement and concrete products’. Empirical test was performed using changes in energy consumption, production, process improvements and new facilities. Although the results showed unstable fluctuations from Divisia index decomposition analysis, it was verified that the entire procedure can provide a clue in understanding of the industry’s energy and GHG footprint.

Keywords: Index decomposition analysis, Divisia, greenhouse gas, Empirical analysis, Energy IO analysis, Organic basic chemical products, Cement and concrete products

JEL 분류: Q4, C0
산업의 온실가스 배출 형태 이해를 위한 지수분해분석 적합성 실증 연구†

정환삼* · 東野 達**

요 약 : 한국은 OECD 국가 가운데 교토협약에 따른 온실가스 감축의무를 갖지 않는 몇 안 되는 국가이다. 한국은 지방적으로 2015년부터 강력한 온실가스 감축을 단행하기로 하였다. 정부의 현정책들은 온실가스 감축에 따른 경제성장의 저해를 감안하지 않고 있어, 이 정책의 지속성이 제약된다. 이 점에서 산업의 부문별 특성을 감안한 감축전략이 더욱 친환경적 전략이 될 수 있다. 이 연구는 혼합단위를 사용한 에너지 산업연관분석에서부터 온실가스 배출에 유의미한 산업을 선정해 분해분석을 함으로써 유용성을 검증하였다. 유의미한 산업은 '유기화학기초제품군'과 '시멘트 및 콘크리트 산업'을 대상으로 삼았다. 변이는 에너지 소비, 생산, 공정개선 그리고 신시설의 도입 효과로 구분해 실증되었다. 이 연구에서 디비지아 분해분석 결과치들이 부분적으로 불안정적 시계열 패턴을 보였으나, 전체분석 과정으로 보면 일련의 분석과정은 대상산업의 에너지 사용과 온실가스 배출의 형태를 이해하기에 충분한 정보를 제공하였다.

주제어 : 지수분해분석, 디비지아, 온실가스, 실증분석, 유기화학기초제품, 시멘트 및 콘크리트 제품

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I. Introduction

1. Current status of Korea’s energy and environment

According to the energy statistics of KEEI (KEEI 2012b), even though the Asian financial crisis of 1997-1998 hit Korea particularly hard, Korea’s primary energy consumption more than quadrupled during the past 24 years, from 56.3 million tons of oil equivalent (M-TOE) in 1985 to 243.3 M-TOE in 2009. This amounts to a 6.3% compound annual growth rate (CAGR), the consumption of high carbon containing coal and petroleum decreased from 39.1% and 45.6% in 1985 to 28.2% and 37.5% in 2009 of the total primary energy consumption. In contrast, low carbon containing gas and renewable energies, except for hydro power, increased from 2.6% and 3.6% in 1985 to 18.5% and 2.3% in 2009, as shown in Table 1.

(Table 1) Trend of total primary energy consumption in Korea (kTOE)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>22,022</td>
<td>24,385</td>
<td>28,091</td>
<td>42,911</td>
<td>54,788</td>
<td>68,604</td>
</tr>
<tr>
<td>Petroleum</td>
<td>25,675</td>
<td>46,574</td>
<td>87,280</td>
<td>91,635</td>
<td>92,042</td>
<td>91,257</td>
</tr>
<tr>
<td>Gas</td>
<td>1467</td>
<td>6,624</td>
<td>15,888</td>
<td>27,568</td>
<td>39,839</td>
<td>44,987</td>
</tr>
<tr>
<td>Atomic power generation</td>
<td>4,186</td>
<td>13,222</td>
<td>16,757</td>
<td>27,241</td>
<td>36,695</td>
<td>31,771</td>
</tr>
<tr>
<td>Water power generation</td>
<td>915</td>
<td>1,590</td>
<td>1,369</td>
<td>1,402</td>
<td>1,297</td>
<td>1,213</td>
</tr>
<tr>
<td>Fire woods and others</td>
<td>2,031</td>
<td>797</td>
<td>1,051</td>
<td>2,130</td>
<td>3,961</td>
<td>5,480</td>
</tr>
<tr>
<td>Total</td>
<td>56,296</td>
<td>93,192</td>
<td>150,436</td>
<td>192,887</td>
<td>228,622</td>
<td>243,311</td>
</tr>
</tbody>
</table>

Korea’s Greenhouse gas (GHG) emissions, including final demand, amounted to a CAGR of 4.0% in the energy sector during 1990–2009(KEEI 2012a). Over this period, the GHG emissions from the energy industry and transport industry increased by 8.5% and 4.6% per annum, respectively. However, the rate of GHG emissions fell down for the energy industry (5.9%), manufacturing and construction industries (0.9%), and transport industry (1.8%) from 2000 until 2009 compared to the entire period (as shown
in Figure 1, ROK 2012).

![GHG emissions in Korea (Mt-CO2)](image)

Remarks) Official GHG emission data is available from 1990 in Korea.

Surprisingly, since 1975, Korea’s energy intensity has not been improved. Improvement rate in terms of the CAGR was the highest at -1.7% and -1.8%, respectively in Germany and the United States. GHG intensity of Korea has recorded a decrease of -0.7% in CAGR compared to this. This is due to the introduction of low-carbon power sources such as nuclear power plants. During the same period, Germany, USA, France has recorded a decrease of -2.5% and -1.9% and -1.6% respectively as shown in Figure 2 (IEA 2013).
2. Issues on energy and GHG policy in Korea

Korea ranks in the top 10 countries for its GHG emissions from energy use. What is more important is the fact that the increased rate of Korea’s GHG emissions has reached the highest in the world since 1990, when global GHGs mitigation efforts were in stage. Over 80% of the GHG emissions in Korea have come from the energy sector. Then the policy for the energy sector is very important among Korea’s policies for global climate change. 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 the non-Annex I countries like Korea under the Kyoto Protocol, it is more important to have the capability to analyze the emission characteristics in each industrial sector rather than to engage in declarations pertaining to a reduction in total emissions, because it will lead to a better position to prevent a loss of economic competitiveness in the post-Kyoto era.
Without proper understanding and knowledge about the interactions among economy, energy, and environment, any energy policy for coping with climate change may fall into less efficient implementation.

As a first step in establishing an efficient policy in energy conservation, mitigating GHG emissions and understanding the changes, it is important to understand the interrelations among economic activities, energy use, and GHG emissions in Korea. Then a fundamental model describing the situation of national energy use and GHG emissions on sectoral basis should be prepared with harmonizing national statistics and model estimation. Energy input-output (E-IO) and factor analysis play an important role in the estimation for an energy and climate change policy.

They 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. And it is easy to minimize the time gap of economic data collecting and preparing policy plan 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.

3. Statement of purpose

The purpose of this study is to verify and validity of the quantitative results come from whole span from E-IO analysis to factor analysis. This process is necessary for the application of IO analysis that has been already proved useful in economics in energy and environmental analysis. The reason is because there is a tendency for the reduction of GHG policy will often result in a decrease in GDP as a tradeoff. The verification was applied to 2 specific sectors which have shown opposite changing pattern. These procedures will help to relieve some of the conflicting concepts of GDP and a reduction of GHG emissions reductions in developing countries. It is because that establishment of
a sectoral approach to policy based on the understanding of the characteristics of each sector is available with these procedures.

In this study, we chose to analyze ‘Organic basic chemical products’ sector and ‘Cement and concrete products’ sector. Empirical analysis has been conducted for social- and technical effect. Thus, the analysis suggests that through the E-IO and the Index Decomposition Analysis (IDA), it will be the clue to solve the energy consumption and GHG emissions footprint of the industry.

The overall concept of this study is to establish a model that determines the relationship between economic activity, energy use, and the emission of GHG in Korea. Endogenous variables are generated for energy use over time and changes in GHG emission patterns, followed by an analysis of influencing factors. Socio-technical impacts on industry are analyzed. This 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 is adopted because the approach can offer an insight on relationship between economy, energy and GHG. E-IO tables are constructed using the hybrid approach. Policies on energy and climate change affect many aspects and alter the structure of economies. This requires holistic approach in studying the policies. IDA provides a tool in the approach utilizing IO tables. To identify influencing effects, IDA is performed for the GHG emissions derived from time-series E-IO tables.

In this study, the analysis limited to only direct energy consumption and GHG emissions that can be verified in the real economy.

II. Literature review

There are numerous cases around the world that use an energy and/or environmental analysis with an IO approach. Table 2 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 (1993) 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 (1998) reported on the intensities of primary energy and GHGs (CO$_2$, CH$_4$, N$_2$O, CF$_4$, and C$_2$F$_6$) in terms of MJ/$ and kg CO$_2$ equivalent/$, respectively, using Australia’s IO table from 1992/93. Cruz (2002) 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 (1996); the second was written by the Center for Global Environmental Research (CGER) in the National Institute for Environmental Studies (NIES) (2002); and the third case was prepared by the Socio-economic Research Center in the Central Research Institute of Electric Power Industry (CRIEPI) (2002). Based on these reports, Kim (2006), Nansai (2003), and Hondo (2002) issued their academic papers.

<table>
<thead>
<tr>
<th>Units in IO table</th>
<th>Single unit</th>
<th>Hybrid units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time span</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

non-energy sectors. Choi and Lee (2004) 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 (2009) 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 (2009). While Tsukamoto (2008) and Wiedmann (2010) 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 (2004) 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 3).
Besides numerous examples of decomposition studies with aggregated coefficients for national CO$_2$ emissions (or emission intensities), Lin et al. (2006) of Taiwan and Sands and Schumacher (2009) of Germany are notable examples that have used input-output tables. Rhee and Chung (2006) 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 (2011) 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 3) Recent weighted decomposition cases of input–output coefficients

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Publication year</th>
<th>Country/Region</th>
<th>Calculation</th>
<th>Time span</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lin et al.</td>
<td>2006</td>
<td>Taiwan</td>
<td>Additive LMDI</td>
<td>1991-2001</td>
<td>CO$_2$ emissions</td>
</tr>
<tr>
<td>Rhee and Chung</td>
<td>2005</td>
<td>Korea and Japan</td>
<td>MRCI</td>
<td>1990-1995</td>
<td>CO$_2$ emissions</td>
</tr>
<tr>
<td>Sands and Schumacher</td>
<td>2009</td>
<td>Germany</td>
<td>Additive LMDI</td>
<td>1995-2006</td>
<td>GHG emissions</td>
</tr>
<tr>
<td>Chung, Tohno and Choi</td>
<td>2011</td>
<td>Korea</td>
<td>Multiplicative LMDI</td>
<td>1985-2005</td>
<td>Energy intensity and GHG emissions</td>
</tr>
</tbody>
</table>
III. E–IO analysis

1. Brief procedure of E-IO analysis

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 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. Table 4 represents a schematic formation of E-IO table.

<table>
<thead>
<tr>
<th>To From</th>
<th>Energy group</th>
<th>Non-energy group</th>
<th>Final use group</th>
<th>Total output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy group</td>
<td>$E_k$</td>
<td>$E_k$</td>
<td>$e_k$</td>
<td>$F_k$</td>
</tr>
<tr>
<td>Non-energy group</td>
<td>$Z_j$</td>
<td>$Z_j$</td>
<td>$Y_j$</td>
<td>$X_j$</td>
</tr>
<tr>
<td>Total input</td>
<td>Total input for energy sector (TOE)</td>
<td>Total input non-energy sector (KRW)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

E-IO concept behind this study is widespread and is composed of well-organized form by Miller and Blair (1985 and 2009).1) We will have a brief introduction in this study.

1) The detailed process, please refer to the previous studies (Chung and Tohno, 2009).
Hereafter the computation procedure is summarized. The input coefficient matrix consists of four sub-matrices of heterogeneous characteristics. In the E-IO tables, matrix A* can be easily calculated, as shown in Eq. (1).

\[
A^* = Z^* (\hat{X}^*)^{-1} = \begin{bmatrix} \text{TOE/TOE} & \text{TOE/KRW} \\ \text{KRW/TOE} & \text{KRW/KRW} \end{bmatrix}
\]

(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 TOE. X* represents a total output vector that is mixed with monetary units and energy units according to sectors as well. The hat (\(^\wedge\)) 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 intensity (EI\(_d\)) and GHG emissions intensity (GI\(_d\)) can be found using Eq. (2) and Eq. (3), respectively.

\[
EI_d = \hat{F}^* (\hat{X}^*)^{-1} A^* \\
GI_d = \hat{F}^* (\hat{X}^*)^{-1} MA^*
\]

(2) (3)

\(\hat{F}\) and \(\hat{X}\) are vectors and each are defined as the total energy consumption for an economy (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. \(\hat{F}^*\) and \(\hat{X}^*\) are matrices of the \(k \times n\) that designate the GHG emissions intensity caused by direct energy use and total energy use, respectively.
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Of course, calculation of \((I - A^*)^{-1}\) reaches total or embodied intensities for each variable easily. However, since the verification test of selected industries was suggested, we use the direct intensities only in this study.

(Table 5) Sector classification of intermediate industries in Korea

<table>
<thead>
<tr>
<th>Group</th>
<th>Code and sector name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy group</td>
<td>1-Coal, 2-Fuel, 3-Nfuel, 4-Gas, 5-Lelec, 6-Felec, 7-Nap, 8-Heat</td>
</tr>
<tr>
<td>Energy intensive group</td>
<td>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</td>
</tr>
<tr>
<td>Non-energy group</td>
<td>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</td>
</tr>
</tbody>
</table>

Remarks) Suffix ‘-p’ represents partial amounts of one sector which described in original IO table published by BOK.
2. Results of E-IO analysis

Figure 3 shows the relationship between direct energy and GHG emissions intensities for 90-sector classification. X-axis and Y-axis represents energy consumption intensity and GHG emissions intensity, respectively. And figure on the red line indicates the average of energy intensities and GHG emissions intensities of 90 sectors, respectively.

(Figure 3) Changes in the spatial distribution with time
Value changes along the flow of Years means the change tendency of changes in energy consumption intensity and GHG emissions intensity of 90 industries. In other words, an increase in the average value means a deterioration of the intensity, on the other hand the decrease of the average value represents the results the improvement of its intensity.

In terms of CAGR, $EI_I$ has achieved a reduction of -1.92% per year, while $GI_J$ was a decrease of -2.65% during the analysis period. This means that rather than energy savings, GHG effect through a transfer to low-carbon energies appeared larger in the E & E policy in Korea. In addition, the Euclidean distance from the origin to each sector has a message in policy developer. Distance from the original point represents the worsening state of energy and/or the GHG emissions intensities of the sector in question, while getting close to the original point represents an improving state in term of both intensities.

IV. Decomposition analysis

In this study, 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.

1. Brief process of IDA

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

$$GHG_i = \sum_j GHG_{i,j} = \sum_j E \cdot \frac{E_j}{E} \cdot \frac{GHG_{i,j}}{E_j} = \sum_j E \cdot S_j \cdot G_{i,j}$$

The ratio of the aggregate GHG emission of year $t$ to that of year $t-1$ is termed the aggregate energy intensity index. And it can be expressed in the multiplicative form as
Eq. (4).

\[ D_{GHG} = \frac{GHG^t}{GHG^{t-1}} = D_{tot} \cdot D_{soc} \cdot D_{tech} \]  

where

\[ D_{tot} = \frac{E_t^t}{E_{t-1}^t} = \frac{\sum E_j^t}{\sum E_j^{t-1}} \]  

\[ D_{soc} = \exp \left[ \sum \omega_{j,t}^* \ln \frac{S_j^t}{S_j^{t-1}} \right] = \prod_j \exp \left( \omega_{j,t}^* \ln \frac{S_j^t}{S_j^{t-1}} \right) = \prod_j D_{SOC,j} \]  

\[ D_{tech} = \exp \left[ \sum \omega_{j,t}^* \ln \frac{G_j^t}{G_j^{t-1}} \right] = \prod_j \exp \left( \omega_{j,t}^* \ln \frac{G_j^t}{G_j^{t-1}} \right) = \prod_j D_{tech,j} \]  

Eq. (5) is obtained with a simple ratio of \( E_j \) without a complex operation; the structural factor of Eq. (6) denotes the energy use structure in the society, implying a social effect. The emissions factor of Eq. (7) shows the GHG emissions intensity, which depends on the specific technologies relevant to energy use in sector \( j \), implying a technical effect.

To fulfill the basic property of the weight functions, the applied weight \( \omega_{j,t}^* \), as suggested in Ang and Choi (1997) in Eqs. (5), (6), and (7), is as follows:

\[ \omega_{j,t}^* = \frac{L(\omega_j^t, \omega_{j,t-1}^t)}{\sum_{k,v} L(\omega_{k,v}^t, \omega_{k,v}^{t-1})} \]
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\[ \omega_j^t = \frac{G_j^t}{G^t}, \quad \omega_j^{t-1} = \frac{G_j^{t-1}}{G^{t-1}} \]

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

Summation in the denominator on the right side of Eq. (8) is taken over all final energy types and sectors. Here, the residual is equal to unity.

2. Results of IDA

The decomposition results with respect to 4 analysis periods are depicted in Figure 4 (Chung et al. 2011).

Figure 4 shows decomposition analysis of the changes in GHG emissions based on the E-IO tables for the years 1985 and 2005 revealed that the energy consumption effect ($D_{tot}$) had a positive impact while there were higher frequency with a negative value in the technology change effect ($D_{tech}$). The social factor effect ($D_{soc}$) varied according to the sector.

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 $D_{tech}$ was found to be negative impact in most sectors except for sector 18 during 1990-1995. 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 period 1985-1995, has tended to decrease gradually, whereas the relative levels of importance of $D_{soc}$ and $D_{tech}$ increased during 2000-2005.
Figure 4: Decomposition stacks of 4 analysis periods
V. Empirical analysis for specific sectors

Acceptability of an E-IO analysis up to 2005 was evaluated with backward comparison. Two sectors were chosen specifically in terms of specificity of the distribution pattern based on energy intensity and GHG emissions intensity for 90 sectors. And the significance of industrial policies will be evaluated by utilizing only the direct analysis results of energy use and GHG emissions also. A structural analysis of social- and technical- impacts on the significant sectors is attempted for the empirical analysis of industry.

1. Selection of distinct sector

In an effort to analyze the results of energy consumption and GHG emissions, as well as the implications of industrial policies, distinct sectors were selected from non-energy and energy intensive group (sector 9-39) that have relatively high percentages of energy use. 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 following specific sectors are selected based on the temporal distribution patterns of sectors and IDA results as shown in Figs. 6 and 7: 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.

Figures on the red lines in Figure 5 decreased over time. It shows GHG emissions intensities from the industrial sectors are improving. Sector-18 shows improvement by moving towards the origin from 1985 to 1990, and thereafter has gradually moved away from the origin by 2005. In contrast, sector-26 has continuously shifted towards the origin since 1985.
Table 6 shows estimators generated from the E-IO analysis were compared with actual data (KEEI 2012a) during the analysis period for validation of E-IO analysis.

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

Energy consumption of the Sector-26 in KEEI was based on sample survey, not complete survey data. Therefore, the data does not indicate the overall energy consumption of the sector. Thus the data KEEI 2012c in Table 5 was partly extrapolated on the assumption that data is proportional to the amount of cement production. Our estimate was found to acceptable with national data. The reason of the estimation errors of two sectors is due to the difference in the aggregated sectors in general.
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$D_{soc}$, used in this study, indicates a change of energy consumption share of a sector in the country’s total energy consumption. This is intended to measure the relative changes in energy efficiency and production of the sector compared to the changes of social and economic environment. While $D_{tech}$ is showing the GHG emissions from energy sources used in the sector. Therefore, this means a change in energy as low-carbon energy sources.

(Figure 6) IDA results for the two sectors in energy intensive group

Figure 6 demonstrates that even if energy and GHG emission intensities of a sector showed continual improvement over time, the decomposition factors don’t necessarily produce consistent values. For example, the intensities of sector-26 between 1990 and 1995 improved, but the $D_{tot}$ and $D_{soc}$ increased (+) while $D_{tech}$ decreased (-).

IDA results shown in Figure 6 are difficult to analyze statistical trends. This is why lack number of observations to obtain a statistical significance and unstable estimate.
results along the time series analysis. IDA results will be analyzed empirically through
the investigation of the circumstance changes of 2 specific industries in the next section.

2. Empirical analysis of two specific sectors

2.1 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 of intermediate goods,
production of ammonia used as fertilizer, and 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 developing
high value-added intermediate goods in high performance engineering plastics and fine
chemicals.

GHG emissions from sector-18 have been increasing due to the growth in demand for
industrial gas, 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 Korea, the national GHG reduction policy must include this
sector (KIET 2008). The raw material of the petrochemical industry is naphtha, which
has high carbon content. After oxygen combines with carbon, GHGs are emitted in this
process. Unlike other industries, the petrochemical industries’ overall GHG emissions in
manufacturing process accounts for more than 10% of whole GHG inventory in sector-18.

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

As shown in Figure 6, over time the distribution pattern of sector-18 shows a trend upward to the right. Deteriorating pattern of this sector can be explained in real economy in terms of the following two aspects: social and technical.

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

In the total effect, annual average growth rate of final energy consumption was 6.7% during the analysis period. Especially the rates of Gas and Naphtha were 15.6% and 11.2% respectively. Such high growth rates of two sectors have influenced a positive direction in $D_{10t}$.

In the social effect, due to the entry barrier, few companies have been managing the business for the domestic demand until 1995. Through the improvement of the process, the company has been working to improve energy efficiency. Energy consumption per unit production has been improved by 3% per year during this period. Large-scale petrochemical complex was built in 1991. Movement of raw materials and intermediate goods is reduced by integrating related industries, where energy efficiency has been significantly improved as a result. Development of new technology and new process has not been carried out since the currency crisis of 1997, large-scale capital investment is reduced. Therefore, in this industry, improvement of energy efficiency has stagnated.
Ethylene production capacity stood at 5.75 million tons in 2005 from 5.02 million tons in 1999. Trends of these changes in sector-18 affected the share of energy consumption. This is a pattern that matches the changing social effect.

In the technical effect, 6 new companies entered the market due to deregulations in the early 1990s. The new companies, having a similar pattern of energy use, GHG emissions have increased rapidly. These efforts, which mean that the profile can lead to an increase in GHG emissions directly in the event of the entry of new comer of this industry or delay improvement of energy efficiency. Change in the structure of energy consumption is needed in this industry. This means that the conversion effort is required to lower carbon containing energy sources.

In addition, the development of high value-added products in the industry is an important factor too. This is because the common denominator of energy intensity and GHG emissions intensity is the volume of added value, which means that if further reduction of energy use and/or GHG emissions is difficult, higher value-added products should be developed. As an example, while 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% level compared to the United States, and at 60% to the Europe and Japan.

2.2 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 is closely related to construction activity, and therefore to general economic activity. Cement is one of the most produced materials around the world.

Three production steps are distinguished in the description of the production of cement: preparing raw materials: mixing/homogenizing, grinding and preheating
(drying) produces the raw meal; burning raw meal to form cement clinker in the 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 of 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 global primary energy consumption, or almost 5% of the total global industrial energy consumption. Due 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. Besides energy consumption, the clinker making process also emits GHG due to the calcining process. The cement industry contributes 5% of total global CO₂ emissions.

The major source of its CO₂ emission is the chemical reaction in the production process. However, this study focuses on the CO₂ emissions associated with energy use of the cement industry. The main energy sources in the cement manufacturing process are B-C oil, coal, electricity and alternative energy (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 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 wet to dry process in order to improve energy efficiency. This process substitution can reduce energy consumption up to 50%. Energy costs account for 20–40% of the cement production cost. Energy consumption required to produce one ton of clinker, is 5.9 ~ 6.7GJ for wet process and only 2.9 ~ 4.6GJ for dry process.
As shown in Figure 6, over time the distribution pattern of sector-26 shows a trend downward to the left. Deteriorating pattern of this sector can be explained in real economy in terms of the following two aspects: social and technical.

In the total effect, annual average growth rate of final energy consumption was 6.7% during the analysis period. Especially the rate of \( N_{\text{fuel}} \) and electricity were 17.6% and 9.9% respectively. Such high growth rates of the two sectors have influenced a positive direction in \( D_{\text{tot}} \).

In the social effect, process improvement influenced \( D_{\text{soc}} \) to reduce the GHG emissions in general. However, \( D_{\text{soc}} \) has increased during 1990-1995. Construction of 2 million housing units along the government’s expansionary policy in 1988 led to a surge in cement production with 10.4% annual average growth rate. Negative figures showed that process improvements effect was discharged, and it was 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. It means an annual average growth rate of -1.5%.

In contrast, in the technical aspect, process improvements have influence on energy efficiency and alternative energy. During 1985-1995, switching coal to electricity affected the change in \( D_{\text{tech}} \). Therefore process improvement made negative factor during this period. During the economic downturn of sector-26 since 1995, the change of \( D_{\text{tech}} \) 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 Korea. Thus, the proportion of the waste fuel at cement sector has remained at 2.5% since the 1990s. This is significantly lower than the levels of German (38%), France (33%) and Japan (16%) (Park S.B. 2009). Deregulation will lead to the increase in utilization of waste fuel instead of coal, and it is expected to have additional reduction of GHG emissions from cement sector.
VI. Conclusion: political recommendations

This holistic approach is useful in understanding of industry’s energy and GHG footprint.

In order to move in the direction of the origin the average values of both intensities in energy consumption and GHG emissions, following efforts are required to improve the aforementioned two sectors cited as examples:

One is the reduction of energy consumption through energy conservation and efficiency improvement of sector-18. Even domestic petrochemical production companies produce the same products, there are large differences in 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 150% higher intensity than the most efficient company in benzene production. Even they have different operating conditions, it is evident that the process improvement for energy reduction is urgent. NCC (Naphtha Cracking Center) is 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. That exploitation should cover efforts to convert low-price raw materials into high-value added products, as well as to create of higher-value added products.

The temporal plot of energy and GHG emission intensities makes it easier to find out improvement opportunities where a large effect can be expected with less effort. As shown in Figure 6, 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 efforts such as: improvement of the energy efficiency of the process; shift to a more energy efficient process (e.g. from (semi) wet to (semi) dry process); replacement of
high carbon fuels by low carbon fuels; application of the lower clinker/cement ratio (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 limit of IDA analysis should be recognized. In IDA analysis, a slight change in data could excessively influence the result of 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 value.

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

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