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기후변화 협약 대응을 위한 산업별 온실가스 배출 특성 분석

An Analysis of Sectoral GHG Emission Intensity from Energy Use in Korea

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국 문 요 약

2006년 우리나라의 에너지 사용은 총수입액(28%), 해외의존(97%), 온실가스배출(83%-year 2004)의 비중을 차지하고 있어, 경제나 환경 정책에서 매우 중요한 산업분야이다. 그러나 현실적으로 국내 에너지사용에 따른 온실가스 배출 추계는 산업별 사용량에 국제기구가 권고한 계수를 곱해 사용하는 수준에 머물고 있다. 이러한 수준으로는 post Kyoto Protocol을 통한 개도국의 참여를 강제하려는 새로운 패러다임에 대응할 논리와 정책을 바르게 수립할 수 없다.

본 연구는 한국은행이 발간한 2000년 산업연관표를 기반으로 이형단위 산업연관표를 작성하고, 이를 통해 경제 구성 부문별로 에너지 사용에 따른 온실가스 배출 특성을 분석하였다. 분석은 네 가지 측면에서 이루어졌으며, 이는 섹터별 온실가스 배출 밀도 추정, 각 그룹에서 온실가스 배출을 야기한 연료원별 기여도 측정, 산업별 배출계수의 산정, 그리고 국가 총배출량 추정이다. 여기서 추정한 배출량은 온실가스 배출에 관한 국가 공식 통계치와 비교 검증하였다. 연구 접근법은 에너지의 직접사용 과정에서 배출되는 온실가스의 양 뿐만 아니라 배출을 유발하는 간접원인까지도 분석하고 있어, 최근 확산되고 있는 전과정분석(Life Cycle Analysis) 개념에 적합한 모형이다. 이 모형은 향후 온실가스 저감 정책 수립의 중요한 기반이 될 것으로 기대한다.

핵심어 : 온실가스, 산업연관분석, 이형단위, 에너지산업연관표, 배출계수

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ABSTRACT

In 2006, the share of energy in Korea amounted to 28% from the total import, 97% from overseas dependency, and 83% for the national Greenhouse Gas(GHG) emission in 2004. Thus, from the aspects of economical and environmental policies, an energy analysis is very important, for the industry to cope with the imminent pressure for climate change. However, the estimation of GHG gas emissions due to an energy use is still done in a primitive way, whereby each industry's usage is multiplied by coefficients recommended from international organizations in Korea. At this level, it is impossible to formulate the prevailing logic and policies in face of a new paradigm that seeks to force participation of developing countries through so called post-Kyoto Protocol.

In this study, a hybrid energy input-output(E-IO) analysis is conducted on the basis of the input-output(IO) table of 2000 issued by the Bank of Korea in 2003. Furthermore, according to economic sectors, emission of the GHG relative to an energy use is characterized. The analysis is accomplished from four points of view as follows: 1) estimating the GHG emission intensity by 96 sectors, 2) measuring the contribution ratio to GHG emissions by 14 energy sources, 3) calculating the emission factor of 3 GHG compounds, and 4) estimating the total amount of national GHG emission. The total amount estimated in this study is compared with a national official statistical number.

The approach could be an appropriate model for the recently spreading concept of a Life Cycle Analysis as it analyzes not only a direct GHG emission from a direct energy use but also an associated emission from an indirect use. We expect this model can provide a form for the basis of a future GHG reduction policy making.

Key Words : Greenhouse gas, input-output table, energy input-output analysis, emission factor

Ⅰ. Life Cycle Concept and Input-Output Approach

Nowadays, the capability of a global environment impacts assessment is becoming more important, and an LCA analysis is seen as a significant concept from this aspect.

As seen in climate change, the reason for it is that the global environmental impacts, which come from a whole life cycle of technology, are regarded as a more urgent international issue than local and regional environment impacts, which evaluate technology at the usage stage.

Because of its usability, the concept is applied to various analyses, such as not only for an environment impacts assessment, but also for an LCC(Life Cycle Costing), an LCP(Life Cycle Planning), etc.

If the pressure of a Korea's GHG reduction obligation becomes evident, the LCA concept can provide a rational basis for our argument by quantifying burdening evasion effects such as the transfer of a pollution industry from a developed country to a developing country or transfer of an emission responsibility between a down stream industry to an upstream industry. This is because global environmental issues, such as GHG, are not local or regional problems but a global problem for reducing the total emission levels, which require recipients to cover the cost, not the generators. From this point of view, an IO analysis developed from economics can provide a useful tool.

In Korea, an environment impacts assessment using the LCA concept mainly applies to the LCA process, one of the bottom-up approaches. It is due to the unavoidable limitations of the input-output(IO) LCA method, one of the top-down approaches. The latent limitations to this method have been detailed as follows:

For a candidate IO table, if a monetary unit is converted into a physical unit, a price distortion occurs. And if products or components as the objects of the environment impacts assessment are used, the aggregation error of the analysis becomes larger, since an IO table is classified by an excessive grouping of economic sectors and a basket of the sectors is composed of various goods and services. Moreover, it is impossible to avoid errors in an environment impacts assessment if there is a lack of the statistics for candidated products or components. Despite these potential limitations to an IO approach, the IO analysis can be applied successfully in the energy sector such that the results of the analysis are generally reliable. The reasons for that are as follows: 1) The types of prices and structures are simple and the types of products in an energy sector are limited. 2) As each energy sector has a large volume, it is classified as an independent sector in a conventional IO table. Consequently, the homogeneity of a classification is significant. 3) Treatment of a large size of matrices gradually becomes easier due to the improvements of computer hardware and mathematics such as linear algebra and statistics.

Under these circumstances, an energy input-output(E-IO) analysis is conducted on the basis of the IO table(2000) issued by the Bank of Korea in 2003. Furthermore, a characterization of the emission of the Greenhouse Gas(GHG) in accordance with the energy use is identified for each economic sector.

There are many cases for an environment analysis in the world that used an IO analysis. The following are the representative examples. Miller and Blair(1985) composed a well-organized textbook on an E-IO analysis. Pachauri and Spreng(2002) determined an indirect energy requirement of India's households according to final private consumption expenditures based on India's IO tables of 1983/84, 1989/90 and 1993/94. And in Korea, the following are prominent. Kim(1998) composed an energy E-IO table for coal, petroleum, gas and electric power by using the IO tables of 1985, 1990, and 1995, and performed an analysis of the amount of energy input and the amount of CO2 emissions from 18 non-energy sectors. Choi and Lee(2004) analyzed the energy consumption of 28 non-energy sectors as to 5 primary energies and 11 final energies to determine the amount of CO2 emission accumulated in Korea's exports goods. To do this, a hybrid-unit IO table of a CO2 emission was composed.

II. Composition of the Energy Input-Output Table

1. Composition of the Energy Input–Output Table with Hybrid Units

As of 2006, the energy use in Korea amounted to 28% in relation to the total import, 97% from the overseas dependency, and 83% for the GHG emission in comparison with 2004. Thus, in view of economical and environmental policies, an energy and environment analysis is very important in the industry sectors.

Hence without knowledge and consideration of the interactions among the economy, energy, and environment, establishing an energy policy for climate change may be a less efficient policy implementation such as "aggregated policy" and it may sacrifice a national economy to save the global environment because of a negative economic feedback from a forceable implementation.

Therefore, to establish an efficient policy for mitigating GHG emissions, insights into the interactions between a GHG emission, an energy use, and economic activities in Korea's economy are necessary.

For such purposes, the following is included in this study. Based on an inter-industry transaction table of 2000, an E-IO table is composed. Note that the IO tables used in this study were issued by the Bank of Korea(BOK) in 2003. The tables are the newest ones in Korea. And from the E-IO table, the interactions among the economic sector, the energy source, and the GHG emission will be quantified.

This study composed an E-IO table with quantity data on the energy sectors by following steps:

① calculate the unit prices for each energy source from the BOK,

② in the case there are too many energy products in one sector (e.g., oil products includes various kinds of lubricants and refined petroleum products), a weighted average was applied as an unit price,

③ convert an unified unit from various kinds of units (e.g, metric ton for primary coal, kilo liters for gasoline, barrel for crude petroleum etc.) into a ton of oil equivalent(TOE),

④ calculate the total energy used from the original transaction matrix, and

⑤ substitute the energy data for the original monetary data in the corresponding energy sector.

2. Sector Re-arrangement

The classification of the industry sectors is reorganized into 96 sectors based on the 404 sectored table of the BOK(2003). These sectors are subdivided into 3 groups. The first group, as an energy industry group, includes 14 energy sources, the second, an energy intensive sectors' group and the third, an energy less-intensive sectors' group according to the non-energy sectors (〈Table 1〉).

⟨Table 1⟩ Sector Re-arrangement

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

3. Verification of the Composed Input-Output Table

This approach is comparably accurate because it uses national average values of energy sources in the case where the sectorial price variation of the energy sources is little. Meanwhile, in the case where the sectorial price variation of the energy sources is high, it would be deteriorated.

This study groups similar energy sources to compensate for this weakness. The analysis presented the actual error as acceptable. 〈Table 2〉 demonstrates the aggregated results of the differences between the energy consumption date calculated by this study(E-IO) and the data from a census of the national energy statistics(KEEI) as to the primary energy consumption by KEEI(2007).

〈Table 2〉 Comparison in Primary Energy Consumption (2000)

(Unit : K-TOE)

energy source	E-IO	KEEI(2007)	%
Coal	43,896	42,911	102
Crude petroleum	121,901	100,279	122
Natural gas	19,811	18,924	105
Water power generation	487	1,402	35
Atomic power generation	9,378	27,241	34
Woods	90	N.A.	-

As seen in 〈Table 2〉, values in the E-IO and energy balance sheet of KEEI are not always acceptable. The differences, however, are mainly from the following two reasons.

First, they have a fundamental difference for aggregating accounts. For example, energy balance sheet of KEEI includes a transformation, stock change, and exports, but excludes international bunkers. Take crude petroleum in 2000 as an example, in the above 〈Table 2〉, total supply (demand) in E-IO is 121,901 K-TOE, which means it is overestimated by 22% based on the standard of KEEI. This results from additional accounts in the calculating process as follows:

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

If these accounts are eliminated from the E-IO, the former 121,901 K-TOE becomes smaller 102,517 K-TOE, which means this error is reduced to 2%.

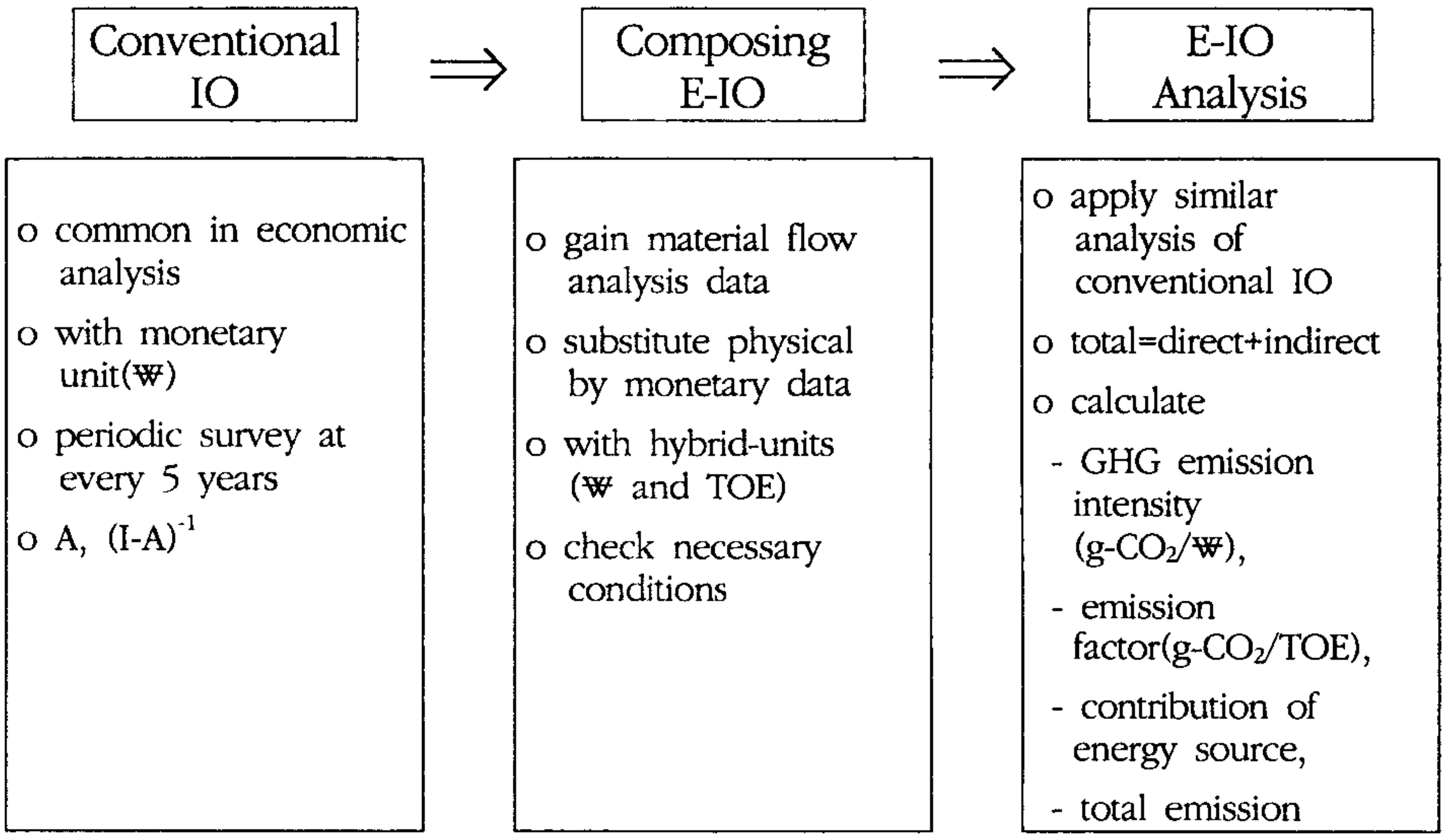
Next, aggregate standards are different. For example, errors are generated in the power generation technologies because KEEI's values were surveyed based on an energy input to a power station but E-IO's were aggregated by a power generation from a power station. Because of these reasons, the energy consumption data, used for a power sector among the 14 energy sources in the E-IO table is expressed as energy input for the quantity of a power generation. So, thermal power shows a 45% error and hydro and nuclear energy, a 35% error. Although these errors can be compensated for Exergy approach by applying thermodynamics, this study did not supplement it because electricity power energy did not emit GHGs in a usage stage by the final user and the pollutions generated in the upstream was already calculated from the emission fuel consumed.

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

Ⅲ. Energy Input-Output Analysis

1. E-IO Analysis

An analysis of the GHG emissions using the E-IO table makes few differences, compared to one using the conventional IO analysis. The overall process is as follows: 1) to complete an E-IO table on the basis of the conventional IO table; and 2) according to the table, to analyze the relationship between an energy use and pollutant emission(Figure 1). After these procedures, the relationship among an economic activity, energy use, and GHG emissions can be identified.



(Figure 1) Process Overview of the E-IO Analysis

2. Methodology

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

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

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

To obtain the energy and environmental intensities, the basic concept can be explained briefly.

By the E-IO mixed with heterogeneous units, to calculate an energy inventory and an environment inventory caused by economic activities, an additional definition is needed as follows:

Z^* is the matrix of the (n×n) dimension and it is a new transaction matrix because the k energy sectors in a conventional IO table are row-wise changed from a monetary price to an energy unit. Thus, this matrix has the original inter-sector transactions matrix (Z) in the non-energy sectors and the energy flow matrix (E) in the energy sectors.

X^* and Y^* is the (n×1) vector, which designates the total output and the final demand respectively. Two vectors are mixed with monetary units and energy units according to the sectors as well.

F^* is the (n×1) vector and, it is an artificial vector to isolate energy rows in a matrix manipulation. The definition of these quantities are as follows:

$$Z_i^* = \begin{cases} Z_j & \text{for } non-energy\ rows \\ E_k & \text{for } energy\ rows \end{cases} \quad (1)$$

$$X_i^* = \begin{cases} X_j & \text{for } non-energy\ rows \\ F_k & \text{for } energy\ rows \end{cases} \quad (2)$$

$$Y_i^* = \begin{cases} Y_j & \text{for } non-energy\ rows \\ e_{k,y} & \text{for } energy\ rows \end{cases} \quad (3)$$

$$F_i^* = \begin{cases} 0 & \text{for } non-energy\ rows \\ F_k & \text{for } energy\ rows \end{cases} \quad (4)$$

E is the (k×n) matrix and designates the energy flows. E_y and F, vectors expressed as (k×1) physical units designate the energy consumed by the final demand and the total energy consumption for 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 E) consumed by intermediate sectors and that consumed by the final demand.

This is shown in eq. (5) as follows:

$$E_i + E_y = F \tag{5}$$

When this definition is used, corresponding matrices, $A^* = Z^*(\hat{X}^*)^{-1}$ and $(I - A^*)^{-1}$can be calculated easily. However, these matrices have different characteristics from the traditional Leontief model. For example, the input coefficient matrix, A^* that means direct requirements and the inverse coefficient matrix, $(I - A^*)^{-1}$ that means total or embodied requirements have different elements because these are mixed with a matrix of heterogeneous units.

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

Here, when we calculate the input coefficient matrix, it is composed of four elements of heterogeneous characteristics as shown in eq. (6).

$$A^* = Z^*(\widehat{X^*})^{-1} = \begin{bmatrix} \frac{toe}{toe} & \frac{toe}{\$} \\ \frac{\$}{toe} & \frac{\$}{\$} \end{bmatrix} \tag{6}$$

Hat(·) that is shown here means that elements of a vector are changed into a diagonal matrix.

The Leontief matrix $(I - A^*)^{-1}$ has the same characteristic as A^* shown in eq. (6).

3. Modification of a GHG Emissions Coefficient

For the assessment of GHG emissions caused by an energy consumption, emission factors of the IPCC Guidelines revised in 1996 was applied. This study, however, partly modified the factors based on IPCC(1996) by considering the situation in Korea. The modification was performed according to the recommendations of IPCC(1996) from two points. One is to consider the fraction of carbon stored and the fraction for carbon oxidised of each fuel to reflect the difference use patterns of the 14 energy sources. The other is that since the energy sources were combined into 14 sectors, emission coefficients were modified by a weighted average as to a component rate of the included energy sources. The modification to the CO2 emission coefficient of a fuel type is explained as follows: (〈Table 2〉)

〈Table 2〉 Modified GHG Emission Coefficients by Energy Source (t-CO2/TOE)

Sector Name	Emission Coefficient	Includes
Coal	3.732	
Crude petroleum	3.009	
Natural gas	2.298	
Coal products	4.077	BKB & 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, LPG
Misc. Petroleum refinery products	0.773	Asphalt, Lubricant, Paraffin wax, etc.
Water power generation	0	
Thermal & self power generation	0	
Atomic power generation	0	
Town gas	2.334	Naphtha, Propane, LNG
Heat	0	LNG, LSWR, Bunker C, Waste burning
Woods	4.178	

In 2007, IPCC(2006) issued an emission coefficient in "IPCC 2006 Guidelines for National Greenhouse Gas Inventories," which was not formally applied for a national report. Key World Energy Statistics 2007, which was issued by OECD-IEA used IPCC Guidelines(1996), which was not used internally. This provides consistent viewpoints on the past GHG emission statistics of Korea.

In this section, we confine our focus to CO2, CH4, and N2O only, mainly because they are the direct impact compounds of global warming listed in IPCC(1996).

Also, GHG direct and total or embodied emission intensity EvI of an intermediate transaction and the final demand sectors according to energy source are shown in eqs. (7) and (8), respectively. EvI_δ and EvI_α, matrices of (k×n), designates a GHG emission intensity caused by a direct energy use and a total energy use which added an indirect one. The unit is t-GHG/₩.

$$EvI_\delta = e_m I_a A^{*-1} + e_m \tag{7}$$

$$EvI_\alpha = e_m I_a (I - A^*)^{-1} + e_m \tag{8}$$

Where e_m is the matrix of the (k×n) dimension, which designates the amount of emission of a specific compound (e.g. CO2, CH4, N2O) among the GHG emitted by a fuel of k type energy in the industry and the final demand sectors. The unit means the amount of emissions of pollutants to the amount of energy use. I_a is the diagonal matrix of the (n×n) dimension. The value of its diagonal elements is 1 for an energy industry, and 0 for the other industries. This matrix is an artificial matrix for a convenience of a calculation. And I and A^* are similar to these used in a conventional IO analysis.

Ⅳ. Estimation results

1. GHG emission intensities by the 96 sectors

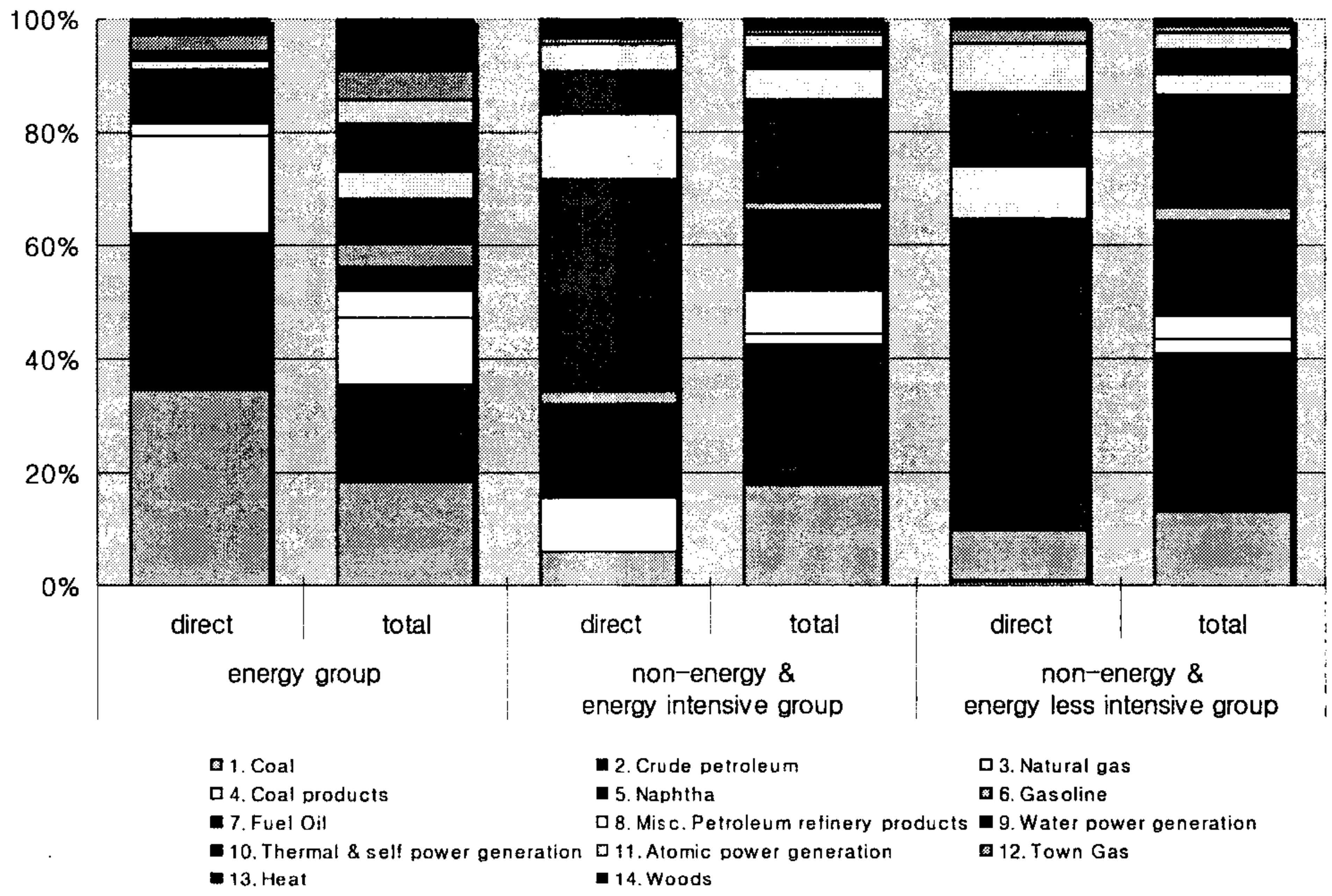
Due to big differences in the dimensions of an emission for each GHG compound, the unit has been expressed in a way that fits each level. The distinguishing sectors with the highest emission for each GHG compound are #-10(Thermal & self power generation), #-13(Heat), and #-34(Pig iron and crude steel). With respect to CO2 that takes up 99% of the national GHG emission, #-10(Thermal & self power generation) is the most dominant sector in both a direct and total emission(〈Table 3〉).

〈Table 3〉 5 Most GHG Emitting Sectors for Each GHG Compound (per M-₩)

standing	CO_2		CH_4		N_2O	
	sector	intensity ($t\text{-}CO_2$)	sector	intensity ($Kg\text{-}CH_4$)	sector	intensity ($Kg\text{-}N_2O$)
(in direct GHG emission)						
1	10	8.313	41	0.247	10	0.114
2	34	2.423	34	0.244	34	0.035
3	13	2.015	32	0.142	13	0.033
4	32	1.512	10	0.137	24	0.029
5	41	1.471	24	0.106	32	0.022
(in total GHG emission)						
1	10	11.667	14	0.000	14	0.168
2	34	8.947	34	0.244	10	0.147
3	24	4.674	47	0.042	34	0.131
4	13	4.337	41	0.247	13	0.093
5	35	4.258	13	0.105	24	0.070

2. Contribution ratio to the GHG emissions by the 14 energy sources

The total amount of GHG emissions from each energy type shows that the most contributing energy is coal which takes up 50.7% in a direct emission, 18.1% in a total emission in an energy group; fuel oil is prominent with 37.5% in a direct emission, 18.3% in a total emission in an energy intensive group; finally in an energy less-intensive group, fuel oil takes up 55.0% in a direct emission and 28.0% in a crude petroleum(Figure 2). In (Figure 2), Y-axis represents the ratio of the contributions made by each energy source in a corresponding group's total GHG emission amount.



(Figure 2) Contribution ratio for the GHG emissions by Energy Source

3. Emission Factors for 3 GHG Compounds

In recent years, as global warming is becoming more and more distinctive, in high energy consuming and bad energy intensity countries like Korea the GHG emission factor should be taken into account for the establishment of its national economic policy. Once the GHG emission factor in each sector is clearly analyzed and understood, an environment friendly energy policy is easy to establish. In other words, Korea should provide the most efficient energy policy guidelines from the perspectives of a cost-efficiency so that the country can move toward a low carbon emitting economy.

This study derive the sectoral emission factors based on the E-IO analysis and modified IPCC(1996). Therefore, the unit for the emission factors, EF_j, is the amount of GHG emission of the corresponding sector per energy used denoted TOE or joule.

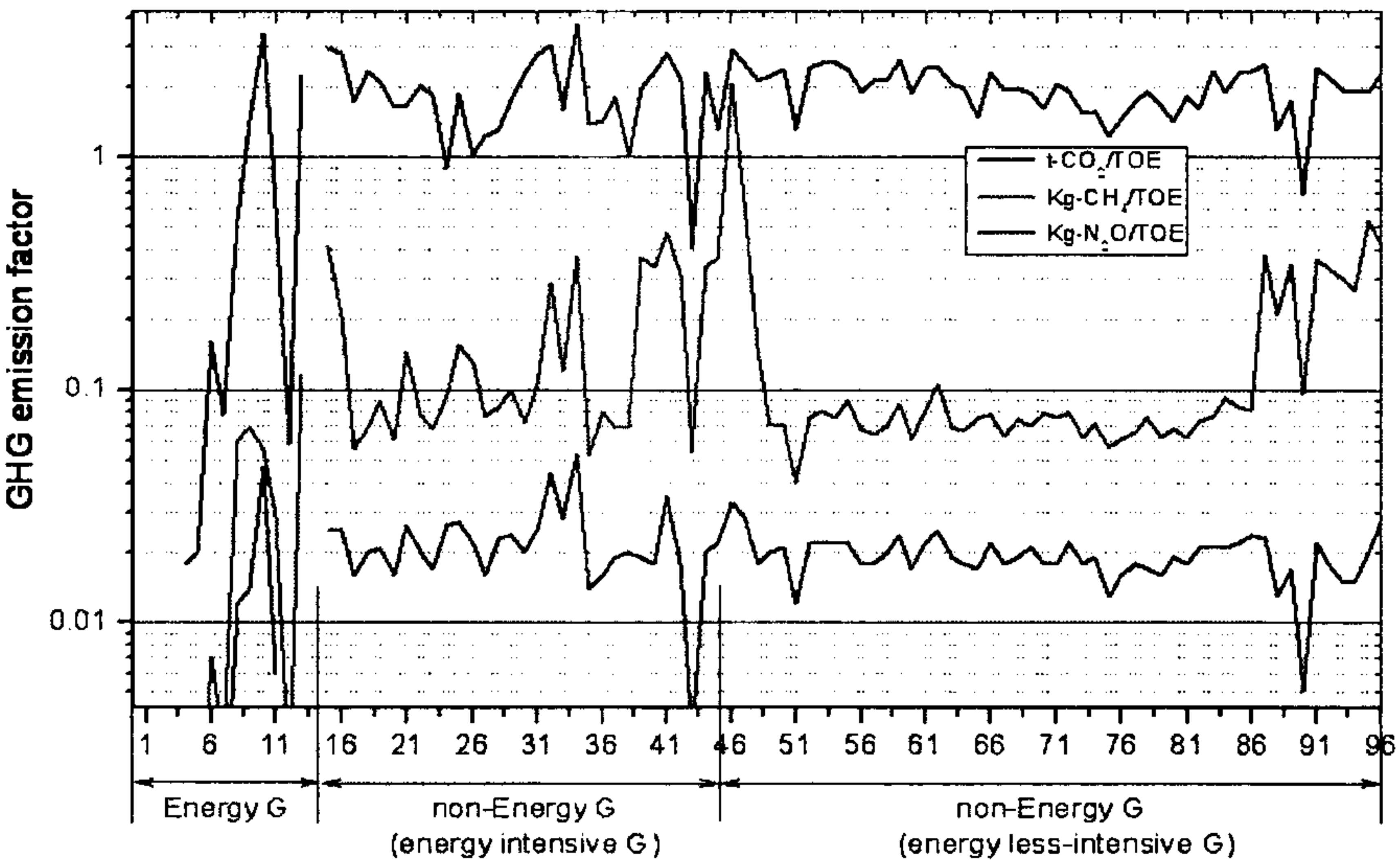
$$EF_j = \frac{\sum_{i=1}^{14}(IPCC' \times Energy_{i,j})}{\sum_{i=1}^{14} Energy_{i,j}}, \quad \text{for } j = 1,\ 2, 3,\ \cdots,\ 96 \tag{9}$$

The results of the analysis shows that the sector #-10(3.407) is the highest in the CO2 emission factor in the energy group, followed by #-13(2.232) and #-9(1.435). In the case of the CH4 emission factor, #-13(0.116) is the highest, followed by #-9(0.069) and #-8(0.060). As for the N2O emission factor, #-10(0.047) and #-13(0.037) turn out to be high.

Next, in the energy intensive group, the sector #-34 and the sector #-32 are high in the CO2 emission factor, as 3.722 and 3.047, respectively. #-43(0.410) and #-24(0.895) show the lowest CO2 emission factors in the energy intensive group. #-41(0.471) and #-15(0.416) are the highest, and #-35(0.052) and #-43(0.054) are the lowest in the CH4 emission factor. #-34(0.053) and #-32(0.044) are the highest in the N2O emission factor, whereas #-43 and #-35 mark the lowest as 0.003 and 0.014, respectively.

Finally, in the energy less-intensive group, #-46 and #-59 show the highest in the CO2 emission factor as 2.890 and 2.626, respectively. On the other hand, #-90 with 0.691 and #-75 with 1.243 show the lowest values. As for the CH4 emission factor, #-46 with 2.073 is distinctively high and #-51 with 0.040 and #-75 with 0.057 are the low ones. #-46(0.033) and #-47(0.029) show high values in the N2O emission factor and #-90 with 0.005 marks the lowest of all (Figure 3).

Even for the sectors that use the same amount of energy, one can see through (Figure 3) that the GHG emission level and compound composition ratios are quite different.



(Figure 3) Emission Factor for 3 Compounds in Each Sector

4. Total GHG Emissions in 2000

On the basis of the amount of GHG emissions estimated by the model used in this study, the total amount of GHG produced by the energy consumption in Korea, for2000, belongs to two categories, the direct emission amounts to 512 million ton of CO2 equivalents(M-t-CO2 eq.) and the embodied emission is 1,378 M-t-CO2 eq.(Table 4)

In table 4, there is an additional group, the final demand group, which includes the private and government sectors and is independent of the other intermediate sectors in IO.

Note that the total emission is calculated for the GHG including CO2, CH4, and N2O only from the record of IPCC(1996). For the equivalent coefficient of CO2, i.e, global warming potential(GWP), CH4(21) and N2O(310) are applied.

〈Table 4〉 Estimation of GHG Emissions in 2000

GHG Compound		CO_2		CH_4		N_2O		GHG emission	
emission type		direct	embodied	direct	embodied	direct	embodied	direct	embodied
unit per year		Kt-CO_2		t-CH_4		t-N_2O		Kt-CO_2-eq.	
energy group		310,749	873,316	5,681	27,296	4,238	9,898	312,182	876,958
non-energy groups	energy intensive group	113,736	390,315	14,119	38,281	1,964	5,382	114,641	392,787
	energy less-intensive group	2,382	26,119	233	2,522	23	315	2,394	26,270
final demand group		81,826	81,826	15,465	15,465	606	606	82,339	82,339
total		508,692	1,371,575	35,499	83,565	6,832	16,201	511,555	1,378,352

With respect to the total emission, emission proportions of each group are as follows: energy group is 61.0%, energy intensive group is 22.4%, and energy less-intensive group is 0.5%, and the final demand group is 16.1%.

The magnitudes of an embodied emission to a direct emission are as follows: energy group is 280.9%, energy intensive group is 342.6%, and energy less-intensive group is 1,097.1%, and the final demand group is 100%.

V. Recommendation

The amounts of GHG emissions estimated in this study are compared with there of KEEI(2003) for the energy use sector which is an official national communication report(〈Table 5〉).

Since these results have different units, the same GWP coefficients are used for comparing two kinds of emission amounts.

According to the results of the present study, CO2 and N2O are overestimated by 16% and 137% respectively, while CH4 is underestimated by 19%.

〈Table 5〉 Comparison of the Estimation with the National Report for 2000

		CO_2	CH_4	N_2O
E-IO	unit	M-t CO_2	t-CH_4/year	t-N_2O/year
	direct (a)	509	35,499	6,832
	total	1,372	83,565	16,201
Energy sector in KEEI(2003)	unit	M-t CO_2	Kt-CO_2	Kt-CO_2
	actual (b)	439	918	894
(a/b)		116 %	81 %	237 %

However, according to the LCA concept, emission of the GHG in accordance with the energy use has to include not only the direct emission in the usage phase, but also the total emission resulting from associated emission.

The reason for it is that if a pollutant emission caused by user's economic activities is concerned of a global environment impact substance, the LCA must be performed in the whole life cycles that occur from other places in the earth as well as in the consumption phase.

In this respect, the amount of embodied emission obtained from this study can be strongly recommended, as the quantity of an environmental pollutants emission is evaluated according to international treaties on climate change, such as the United Nations Framework Convention on Climate Change(UNFCCC).

In contrast to the national report that focuses on the total estimation amount of GHG generated from the emission origins, results of this study analyze a direct emission in detail with respect to an industry classification made by the IO table, which is the basis of economic policies, and then adds associated emissions due to a final consumption to estimate the total amount of GHG emission.

From the various results, the IO approach can be extended so that an additional effect appears. In other words, the so-called emission evasion effect from developed countries to an underdeveloped one can be estimated, since the final consumption in developed countries leads to a utilization of the production facilities and raw materials supplied from underdeveloped countries.

Without knowledge and consideration of interactions among economy, energy, and environment, establishing energy policy of climate change may be less efficient policy implementation such as an "aggregated policy" and it may sacrifice a national economy to save a global environment because of a negative economic feedback from a forceable implementation.

Therefore, to establish an efficient policy for diminishing GHG emissions, insights into a GHG emission, use of energy source, and economic interaction of diverse sectors in a national economy are needed to do it.

An E-IO analysis tool using hybrid-units is suitable to analyze an interrelationship between economic activities, energy uses, and environment impacts. By analyzing in detail the characteristics of a GHG emissions for each industry sector, the method can provide us with significant clues to monitor and manage GHG emission in Korea.

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

Emission coefficients of pollutants should be developed that reflect the domestic economic conditions. The Tier-1 method in IPCC(1996) was used in this study but domestic data should be developed to which Tier-2 or Tier-3 can be applied. Like Japan's emission coefficient for the transportation sector, advanced countries have a well developed data base of emission coefficients by industry sectors.

The nation's statistics system for an analysis needs to be unified. In order to fabricate in a highly reliable E-IO table through the collection and verification of national energy statistics, GHG emission statistics, and economic statistics that are required for the analysis in this study, the listed values need to be consistent and the differences between the sector classification standard and the data accounting standard should be harmonized.

An E-IO table needs to be developed, such as BOK(2003)'s large sized IO table with a basic classification into 404 sectors. A more detailed sector classification is required to establish a more sophisticated and useful energy-environment policy by using analysis results.

Analysis of GHG emissions from the non-combustion pathways of energy sources is required. In this study, only an energy combustion was considered. Although the level of GHG emissions is low, analysis of the GHG emissions from feed stocks like naphtha or asphalt or from coke burning in the metal refining sectors should be performed.

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정환삼

KAIST에서 경영과학을 공부하고 현재 한국원자력연구원 정책연구부에 재직 중이다. 관심분야는 에너지 분야의 기술경영과 환경영향 평가이다.

東野達

Kyoto 대학에서 1989년 환경위생학 박사학위를 취득하였으며, 현재 대학원 과정 에너지-사회과학 전공 교수로 재직 중이다. 주요 연구 분야는 에너지-환경학이며, 특히 대기환경 분야에 관심을 기울이고 있다.

심상렬

경제학 박사를 취득하고, 현재 에너지경제연구원의 에너지정책연구본부 본부장으로 재직 중이다. 주요 연구 분야는 에너지 분야 거시경제 분야이다.