에너지 사용에 따른 산업별 온실가스 배출 특성 분석

- 에너지산업연관분석을 통하여 -

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An Estimation of GHG Emission Intensities from Energy Use

- Energy Input-output Approach -

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Abstract

In Korea, LCA is mainly performed by using a process LCA method which belongs to a bottom-up approach. The reason for applying the process method is that LCA approach associated with an input-output method is based on a top-down approach, which has its own limitations. It is well known that there are potential limitations of the input-output LCA method.

In this study, an energy input-output analysis is conducted on the basis of the input-output table of 2000 issued by the Bank of Korea in 2003. Furthermore, according to economic sectors, emission of the Greenhouse Gases relative to the energy use is characterized. The total amounts of GHG emission estimated in this study was 512 million tons of CO_2 equivalent, which is acceptable figure if it compared to national official data. Nevertheless, differently from other product and service sectors, it is in the energy sector possible for the input-output method is identified for yielding reliable results.

요약문

우리나라에서 LCA는 주로 상향식 접근법인 process LCA를 통해 이루어지고 있다. 이는 하향식 접근법의 대표 격인 산업연관 LCA 방식이 갖는 본원적 한계에 기인하였다. 산업연관표를 이용한 LCA 수행은 잘 알려진 한계가 잠재되어 있음은 이미 주지된 사실이다.

본 연구는 한국은행이 2003년 발간한 2000년 산업연관표를 기반으로 에너지산업연관표를 작성하였고, 이를 통해 한국의 경제구성 부문별로 에너지 사용에 따른 온실가스 배출 특성을 분석하였다. 분석 결과 2000년 우리나라 GHG 배출량은 512백만 CO_2 등가 톤으로, 비교 가능한 국가 통계에 비할 때 신뢰할 만한 결과를 만들고 있는 것으로 판단되었다. 이 분석을 통해 에너지 분야의 LCA 분석은 에너지산업연관분석도 만족할 만한 신뢰도의 결과를 갖는 것으로 나타났다.

주제어 : LCA, 산업연관표, 에너지산업연관표, 혼합단위모형, 온실가스, 배출특성, 배출계수

1. Introduction

As seen in the climate change, the reason for it is that the global environment impacts, which comes from whole life cycle of a technology, is regarded as more urgent international issue than the local and regional environment impacts, which evaluates in the technology use stage.

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

For an candidate input-output table,

- price distortion in unit conversion,
- aggregation error in setting sector up, and
- missing error in sector candidated.

Despite that there are potential limitations in an input-output approach, the input-output analysis can be applied successfully in the energy sector such that the results of the analysis are satisfactorily reliable. The reasons for that are as follows:

- the types of prices and structures are simple,
- each energy sector has large volume,
- treatment of the large size of matrices gradually gets easier.

2. Composition of energy input-output table

2.1. Composition of energy input-output table with heterogeneous units

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

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

① calculate unit prices for each energy source from the BOK

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

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

④ calculate total energy used from the original transaction matrix

2.2. Sector re-arrangement

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

2.3. Accuracy check of composed energy input-output table

This approach is comparably accurate because it uses national average values of energy sources in a case that the sectorial price variation of energy sources is little.

Table 1. Sector Re-arrangement

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

Meanwhile, in a case that sectorial price variation of energy sources is high, it would be deteriorated.

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

This study groups similar energy sources to compensating this weakness. The analysis presented the actual error as acceptable. The aggregated results of differences between energy consumption data calculated by this study (E-IO) and data from census of national energy statistics (KEEI) as to primary energy consumption by KEEI (2006) are demonstrated (Table 2).

Table 2. Comparison in Primary Energy Consumption (2000)

(unit : K-TOE)

energy source	E-IO	KEEI	%
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.	-

First, they have a fundamental difference to aggregating accounts. For example, energy balance sheet of KEEI includes transformation, stock change, and exports, but excludes international bunkers. Take 2000 crude petroleum as an example, in the above table 2, total supply (demand) in E-IO is 121,901 K-TOE, which means it is overestimated 22% based on standard of KEEI. This results from additional accounts in 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 gets smaller 102,517 K-TOE, which means this error is reduced to 2%.

3. Energy input-output analysis

3.1. E-IO analysis

An analysis of emission of GHG using the E-IO table makes few difference, compared to one using the conventional input-output analysis. The whole procedures are as follows: 1) to complete an E-IO table on the basis of the conventional input-output table; and 2) according to the table, to analyze the relationship between energy and environment (Fig. 1).

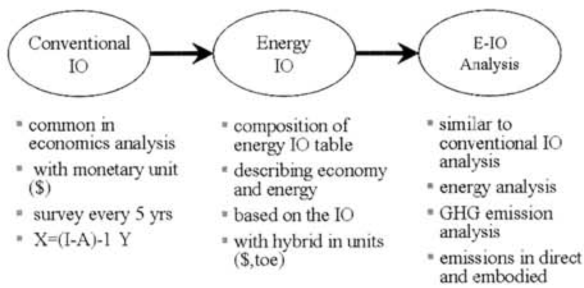

Fig. 1. E-IO Analysis Process

After these procedures, the relationship among economic activity, energy use, and GHG emission can be identified.

In E-IO analysis, it is often concerned with energy measured in physical units and non-energy flows in money.

The basic concepts of E-IO method introduced in detail by Miller & Blair (1985), and applied to 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 conventional input-output analysis, then convert these values to TOE by means of prices relating money outputs to energy outputs.

To obtain the energy and environmental intensities through E-IO table computation procedure can be summarized as follows. For more information on the E-IO analysis see chapter 6 in Miller & Blai (1985).

3.2. Estimation of GHG emissions

For the assessment of GHG emission caused by energy consumption, emission factors of IPCC Guidelines revised in 1996 was applied. This study, however, partly modified the factors based on IPCC (1996) considering the reality of Korea. The modification was performed according to the recommendations of IPCC (1996) in the two points. One is to consider fraction of carbon stored and fraction of carbon oxidised of each fuel to reflect the difference use pattern of 14 energy sources. The other is that since energy sources were combined into 14 sectors, emission factors were modified by weighted average as to component rate of included energy sources. The modification to CO_2 emission coefficient of fuel type is explained as follows.(Table 3)

In 2007, IPCC (2006) issued emission coefficient in "IPCC 2006 Guidelines for National Greenhouse Gas Inventories," which was not formally applied for 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 GHGs emission statistics of South Korea. Because of these reasons, this study will use emission coefficients of IPCC Guidelines (1996).

In the GHG emission intensity estimates of economic activities, there is an additional fourth group, the final demand group, which includes private and government sector.

In this section, we confine our focus onto CO_2, CH_4, and N_2O only, mainly because they are the direct causal components of global warming listed in IPCC (1996).

Also, GHG direct and total emissions intensity *EvI* of the intermediate transaction and final demand sectors according to energy source is shown in eq (1) and (2), respectively.

Table 3. Modified GHG Emission Factors by Energy Source (t-CO_2/TOE)

sector name	emission factor	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	

EvI_δ and EvI_α, matrices of the (k×n), designates GHG emissions intensity caused by direct energy use and total energy use. The unit is t-GHG/KRW.

$$EvI_\delta = e_m I_a A + e_m \qquad (1)$$

$$EvI_\alpha = e_m I_a (I-A)^{-1} + e_m \qquad (2)$$

Where e_m is the matrix of the (k×n) dimension, which designates the emission factors of a specific GHG (e.g. CO_2, CH_4, N_2O) among GHG emitted by fuel of k type energy in industry and final demand sectors. The unit means the amount of emissions of pollutants to the amount of energy use. I_a is a diagonal artificial matrix of the (n×n) dimension. The value of its diagonal elements is 1 for the energy industry and 0 for other industries. This matrix is an artificial matrix for a convenience of a calculation. And I and A are the same as a conventional IO analysis.

4. Estimation results

4.1. GHG emission intensity analysis

The total amount of GHG emission from each group shows that CO_2 takes up 61.1% in direct emission, 63.7% in total emission in energy group; 22.4% in direct emission, 28.5% in total emission in energy intensive group; 0.5% in direct emission, 1.9% in total emission in energy less intensive group; finally in the final demand group, CO_2 takes up 16.1% in direct emission, and 6.0% in total emission.

As for CH_4, it takes up 16.0% in direct emission, 32.7% in total emission in energy group; 39.8% in direct emission and 45.8% in total emission in energy intensive group; 0.7% in direct emission and 3.0% in total emission in energy less intensive group; and finally 43.6% and 18.5% in final demand group.

Lastly, the emission of N_2O patterns a lot like that of CO_2; 62.0% in direct emission and 61.1% in the total emission in energy group; 28.7% in direct emission and 33.2% in total emission in energy intensive group; 0.3% in direct emission and 1.9% of total emission in energy less intensive group; and finally 8.9% in direct emission and 3.7% in total emission in final demand group (Table 4).

Table 4. Contribution of Groups by GHG

(%)			CO_2	CH_4	N_2O
energy G.		direct	61.1	16.0	62.0
		total	63.7	32.7	61.1
non-energy	energy intensive G.	direct	22.4	39.8	28.7
		total	28.5	45.8	33.2
	energy less intensive G.	direct	0.5	0.7	0.3
		total	1.9	3.0	1.9
	final demand G.	direct	16.1	43.6	8.9
		total	6.0	18.5	3.7
sum		direct	100	100	100
		total	100	100	100

4.2. GHG emission factor by sector

In recent years, as the global warming is getting more and more distinctive, high energy consuming and bad energy intensity countries like Korea GHS emission factor should be taken into account for the establishment of its national economic policy.

This study derive the industrial emission factors based on the E-IO analysis and 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.

$$EF_j = \frac{\sum_{i=1}^{14}(IPCC_{i,j} \times Energy_{i,j})}{\sum_{i=1}^{14} Energy_{i,j}}, \quad (3)$$

for $j = 1, 2, 3, \cdots, 96$

The results of the analysis shows that the sector #−10 (3.407), #−13 (0.116), and #−10 (0.047) are the highest in CO_2, CH_4, and N_2O respectively in the energy group. Next, in the energy intensive group, the sector #−34 and the sector #−32 are high in CO_2 emission factor, as 3.722 and 3.047, respectively. #−43 (0.410) and #−24 (0.895) show the lowest CO_2 emission factors in this group. #−41 (0.471) and #−15 (0.416) are the highest, and #−35 (0.052) and #−43 (0.054) are the lowest in CH_4 emission factor. #−34 (0.053) and #−32 (0.044) are highest in N_2O emission factor, whereas #−43 and #−35 mark the lowest as 0.003 and 0.014, respectively. Finally, in energy less intensive group, #−46 and #−59 show the highest in CO_2 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 CH_4 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 the high values in N_2O emission factor and #−90 with 0.005 marks the lowest of all (Fig. 2).

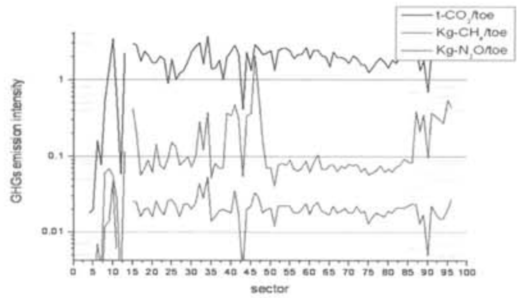

Fig. 2. GHG Emission factors of 96 Sectors

4.3. Total GHG emission in 2000

On the basis of the amount of GHG emission estimated by the model used in this study, the total amount of GHG produced by the energy consumption in Korea, year 2000, belongs to two categories, the direct emission amounts to 511,556 million ton (Mill−t) and the total emission is 1,378,352 Mill−t.(Table 5)

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%.

Table 5. Estimation of GHG Emission in 2000

GHG	CO_2		CH_4		N_2O	
emission type	direct	total	direct	total	direct	total
unit per year	Mill-t-CO_2		K-t-CH_4		K-t-N_2O	
energy group	311	873	6	27	4	10
non-energy groups	116	416	14	41	2	6
final demand group	82	82	15	15	0.6	0.6
total	509	1,372	35	84	7	16

The magnitudes of total emission to 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%.

Note that the total emission is calculated on the GHG including CO_2, CH_4, and N_2O only from the record of IPCC(1996). For the equivalent coefficient of CO_2, i.e, GWP (global warming potential), CH_4 (21) and N_2O (310) are applied.

5. Political recommendations

The amounts of GHG emission estimated in this study is compared with them of KEEI (2003) for the energy use sector regarded as an official national communication report (Table 6). According to the results of the present study, CO_2 and N_2O are overestimated by 16% and 137% respectively, while CH_4 is approximately underestimated by 19%.

From the beginning, since 1999, the national LCI DB amount to 321 until 2007 in Korea. Absolutely, it is not enough to perform the proper LCA. Moreover, the recent shortened technical life cycle leads to old-fashioned DB among them. It will be a same situation for Korean energy industries. Until now Korea has established no more than seven LCI DB focusing on the final energy since it has been developed in 2000. This is due to the limitations of input resources.

In oder to overcome these actual constraints and limitations, it is worthy to introduce a top-down method which complements a process LCA method, which is known as one of bottom-up approach.

This, if used in combination with the bottom-up approach which is prevalent in Korea, can provide useful policy effects. It can support other national projects performing microscopic analysis, e.g. construction of the inventory DB (parameter) for the Life Cycle Assessment (LCA) through a survey or process analysis of individual companies on pollution source emissions.

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Table 6. Comparison of Estimation with National Communication Report for 2000

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

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