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에너지산업연관분석을 이용한 산업별 에너지 사용 pattern 분석

정환삼[†] · 東野 達* · 심상렬**
한국원자력연구원, *교토대학교, **에너지경제연구원
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Analysis of Sectoral Energy Use Pattern with Energy Input-Output Approach

Whan-Sam Chung[†], Susumu Tohno* and Sang Yul Shim**
Korea Atomic Energy Research Institute
**Graduate School of Energy & Social Science, Kyoto University*
***Korean Energy Economics Institute*
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요 약

에너지가격의 인상과 고갈의 시대에 들면서, 사회적으로 에너지 정책에 대한 정부의 개입요구가 더욱 높아지고 있다. 에너지 정책 시행은 양면의 상반된 효과를 유발할 수 있다. 우선 긍정적인 면에서 에너지 수입의 감소를 통해 불필요한 외화유출을 방지할 수 있어 재원의 적절한 배분을 가능케 하고, 비싼 에너지 사용의 절약을 통해 가격 경쟁력을 제고할 수 있을 것이다. 이에 반해 무분별한 에너지 절약 정책의 경우, 투입재를 에너지에서 설비로 비합리적으로 대체하여 정책실적만 기록할 뿐이고 오히려 경제에서는 생산성을 저해하는 예기치 못한 부정적인 효과를 초래할 수도 있다. 에너지 정책에서 정책효과를 높이기 위해서는 경제를 구성하는 각 산업 부문별로 에너지 사용 형태를 분석하고 그 결과를 이해하는 노력이 선행되어야 한다. 이 점에서 본 연구는 거시적 접근법의 대표적 방법인 에너지 산업연관분석을 이용해 한국의 산업 부문별 에너지 소비행태를 분석하였다. 이를 통해 에너지 사용 집약도와 에너지원별 소비행태의 변화에 대한 계량적 분석을 수행하였다.

주요어 : 에너지, 산업연관분석, 에너지원, 소비행태, 집약도, 거시적 분석법

Abstract — Approaching to the era of high energy price and energy sources scarcity, the demand for governmental intervention to mitigate the short-term shocks is highly increasing. When any energy policy is implemented, double-side effects would be derived. To begin with positive aspect, by decreasing energy import, unnecessary currency outflow can be prevented and the resultant saved money will be appropriately allocated. Furthermore, industrial competitiveness will be assured by reducing use of expensive energy. On the contrary, inappropriate energy saving policy may lead to unexpected negative effects that would hinder improvement in productivity due to indiscreet replacing energy by equipments. In order to enhance effectiveness of energy policy, efforts should be made in advance to understand the energy use pattern of each industry sector which composes the economy. Therefore, in this study, an energy input-output method, one of the macroscopic approaches, is applied to analyze energy use patterns of each industry sector in Korea. Using this method, a quantitative assessment is performed to obtain the energy use intensity and the amount of energy uses with

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[†]To whom correspondence should be addressed
Korea Atomic Energy Research Institute, Dukjin-dong
Yusung Daejon, 305-606
Tel : 042-868-2146
E-mail : wschung@kaeri.re.kr

respect to energy types.

Key words : Energy, Input-output analysis, Energy source, Use pattern, Energy intensity, Macroscopic approach

1. Energy consumption in Korea

1-1. Energy use at a glance

Despite the Asian financial crisis in 1997-1998 which hit severely Korean economy in particular, Korea's primary energy consumption more than quadrupled during the past 20 years, from 56.3 million TOE in 1985 to 233.4 million TOE in 2006. Energy consumption increased a 7.0% increase per annum on average, while gross domestic product increased a 6.5% per annum during the corresponding period. With regard to the structural change of fuel source, the share of the high carbonic coal and petroleum decreased from 39.1% and 48.2% in 1985 to 24.3% and 43.6% in 2006, respectively of the total primary energy consumption. In contrast, low carbonic gas, nuclear and renewables, except for hydro power, increased from 0.0%, 7.4% and 3.6% in 1985 to 13.7 %, 15.9% and 1.9% in 2006.

Korea's rapid industrialization over the past two decades has resulted in substantial increase in energy consumption in industrial sector by more than 480%, from 20.0 million TOE in 1985 to 97.2 million TOE in 2006. Consequently, Energy consumption is one of the key factors to economic growth in Korea (Fig. 1).

In 2006, the share of Korea's energy imports is equivalent to 28% in the total import bills, and 97% of the domestic energy consumption are dependent on imported sources. Thus, Korea is the 10th largest energy consuming as well as the 7th largest oil consuming country in the world. And also the 4th largest oil importer and the 2nd largest coal and liquified natural gas (LNG) importer in the world. Moreover, 83% of the total greenhouse gases (GHGs) emissions are from energy related activities in 2004. Thus, more correct and reliable energy analysis is required for improving effectiveness of the economic and environmental policies in Korea, particularly with emphasis on energy and carbon dioxide (CO2) intensity in industrial sector.

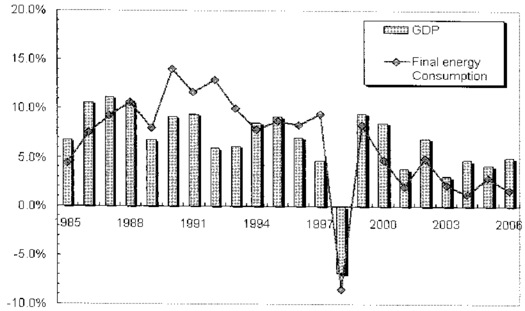

Fig. 1. GDP and final energy consumption growth rate (1985~2006).

1-2. Energy policy issue

According to the statistics of the IEA (2006) on energy consumption of the OECD countries, Korea maintained relatively well the energy intensity to gross domestic product (DDP) at least up until the 1980s comparing with that of USA and Germany. However, since the 1990s, the energy intensity has been deteriorated substantially, resulting the highest among the OECD countries and 3 times as that of Japan. Such a serious situation is well contrasted with the drastic improvement in energy intensity of China, which is a non-OECD country (see Table 1). China seems to be transferred from low price production to higher price one gradually in her manufactured products and services. On the other hand, Korea's GHGs emission intensity has been slightly below the average of OECD countries since 1990.

Without reliable knowledge and due consideration of interactions between economy and energy, formulation of energy policy and its implementation may be not only less efficient but also it may rather harmful to national economy in coping with the turbulent global energy situation. Therefore, insights into the energy sources and economic interaction of diverse sectors in national economy are necessary to establish efficient policy for enhancing national sustainability.

Hence this study analyzed interactions of each economic sector and energy source through energy input -output (E-IO) tables, having heterogeneous units, based

Table 1. energy intensity of OECD countries and China (M-toe/B-2000 US$).

	France	Germany	Italy	Japan	Korea	UK	USA	OECD average	China
1975	0.232	0.302	0.209	0.137	0.273	0.253	0.388	0.296	2.945
1980	0.231	0.293	0.180	0.124	0.337	0.231	0.353	0.278	2.516
1985	0.223	0.277	0.164	0.112	0.226	0.211	0.296	0.249	1.850
1990	0.211	0.231	0.161	0.108	0.327	0.188	0.273	0.228	1.593
1995	0.209	0.199	0.165	0.113	0.358	0.182	0.262	0.223	1.143
2000	0.194	0.181	0.161	0.111	0.373	0.161	0.236	0.207	0.834
2001	0.197	0.184	0.159	0.11	0.365	0.159	0.23	0.204	0.776
2002	0.194	0.179	0.158	0.11	0.355	0.152	0.229	0.203	0.775
2003	0.196	0.181	0.165	0.108	0.352	0.151	0.222	0.201	0.807
2004	0.195	0.178	0.166	0.108	0.348	0.147	0.217	0.199	0.854

on input-output (IO) tables published by the Bank of Korea in 2003.

2. IO approach to evaluate energy intensity

Energy intensity can be estimated from simple calculations of energy use data divided by total production of the corresponding sector. In spite the figure is easy to get, however it is hard to use in planning for the future energy and GHG policy. Because it is only a footprint of past period and insufficient in describing attributes of sectors. While the IO analysis that this study deals with provides a useful framework to analyze the relations among economic activities and energy use. For example, when energy analysis is performed by using IO analysis, this analysis supports to analyze not only energy used for unit production of a final product but also indirect consumptions that are invested in resource and component supply sectors of upstream. In addition this method can provide decision makers with useful fundamental messages in energy and environment.

This study applied the E-IO tables which mixed with monetary unit and energy unit.

2-1. Methodology

The methodologies for analyzing the relations between economic activities and energy use can be classified into microscopic approach and macroscopic approach. The former analysis, known as a bottom-up approach, analyzes the amounts of energy uses through a field survey on the individual industry sector. The latter, known as a top-down approach, estimates the amounts of the national energy use employing IO tables that presents economic transactions among the composing entities or sectors.

2-2. Literature review

There are plenty of references on energy analysis conducted by employing the technique of IO analysis. The following are some of the examples:

- Studies of Wright (1974) and Herendeen (1975) which analysed the US IO tables to analyze the primary energy requirements of all sectors.
- Peet *et al.* (1985) performed an energy analysis of direct and indirect consumption of households in New Zealand for the period of 1974 to 1980.
- Lenzen (1998) reported the intensities of primary energy consumption and five components of GHG emissions by using Australia's 1992/93 IO tables.
- Miller and Blair (1985) published a well-organized textbook on energy IO analysis.
- Pachauri and Spreng (2002) identified indirect energy requirements of India's households based on the private expenditures for final energy consumption analyzing India's IO tables of the years of 1983/84, 1989/90 and 1993/94.
- Park and Heo (2007) employed process analysis technique for energy intensive products and applied IO analysis to other energy consuming products by referring to the study of Lenzen (1998) using the IO

Table 2. Cases of energy analysis by using IO tables

terms / time span	monetary only	physical also
cross section	Wright (1974) Herendeen (1975)	Miller and Blair (1985)
time series	Syrquin (1976) Peet et al. (1985)	Pachauri and Spreng (2002) Park and Heo (2007)

tables for the period of 1980 to 2000.

Among the above cases, most of them conducted cross sectional analysis using conventional IO tables that expressed in monetary terms except for the cases of Syrquin (1976) and Peet et al. (1985). Meanwhile, Pachauri and Spreng (2002) and Park and Heo (2007) conducted time series analysis of the E-IO tables in monetary an d physical energy terms, simultaneously (Table 2).

2-3. Process of physical IO analysis

In this study for the IO approach, mixed units were employed to analyze energy intensities in economy sectors. In E-IO analysis, it is often concerned with energy measured in physical terms - for example, ton of oil equivalent (TOE) or some other conventional energy units and non-energy flows in monetary terms. The basic concept of E-IO method was introduced in detail by Miller & Blair (1985), and applied to energy system by Pachauri and Spreng (2002).

One way to obtain the quantity of energy input in physical terms is to first compute the total energy requirements expressed in monetary terms in the conventional IO tables, and then convert these values into physical terms, *i.e.*, TOE.

The computation procedure for obtaining energy intensities from the E-IO tables can be summarized as follows (for more information on an E-IO analysis see chapter 6 in Miller & Blair (1985).

$$\delta = F^*(\widehat{X^*})^{-1}A^* \quad (1)$$

$$\alpha = F^*(\widehat{X^*})^{-1}(I-A^*)^{-1} \quad (2)$$

2-4. Composition of energy IO table

2-4-1. Data sources

Sectoral Energy Data: Intermediate transaction values in monetary terms (Korean Won, KRW) were replaced by the energy consumption survey data for corresponding energy sectors. However, since the code of South Korea's energy survey data is different from that of IO tables, it is impossible to apply the energy survey data for this study. Due to this real restrictions, quantity data applied to divided predetermined 14 energy sectors were replaced with values calculated by annual average price data for each energy source.

Fundamental IO tables: The energy IO tables were constructed by using sectorial supplementary tables on supply published by the BOK (2003). The reason that year 2000 IO tables were used is that it is the most recent one available in Korea. Year 2005 IO tables will be published in the late 2008.

Sector Reorganization: Industries were classified into total 96 sectors that consist of 14 energy sources (code 1~14) and 82 non-energy sectors. Especially, the economy sector which is a non-energy sector is aggregated into two groups in consideration of energy use characteristics of each sector after excluding energy sectors from the 404 BOK basic sector classification. As to expenditures for energy, there are one group composed of 31 energy intensive sectors (code 15~45) with comparably higher expenditures and another group of 51 less energy intensive sectors (code 46~96) with lower expenditures (Table 3).

2-4-2. Verification of productivity

The E-IO tables used in this study were recognized to satisfy the following two conditions.

- In terms of energy balance, the total primary energy intensity of a product should be equal to the total secondary energy intensity of the product plus the amount of energy lost in energy conversion. This means it meets energy conservation principle.
- In terms of linear algebra, conditions ensuring the non-negativity of total output computed in the Leontief

Table 3. Sector grouping and classification.

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	
	less energy 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	

inverse matrix, and in terms of economics, it must satisfy producibility. This means it must meet Hawkins-Simon (H-S) conditions.

Among these, energy conservation principle can usually be compensated by Exergy concept of thermodynamics. Since power generation sector considers 40% of thermal efficiency in a case of thermal & self power generation and 30% of thermal efficiency in a case of atomic power generation, energy loss can be artificially corrected in E-IO tables. However, this study did not correct it because the computation of energy IO quantity is based on IO tables of BOK (2003).

Next, Miller and Blair (1985) introduced the H-S conditions to ensure a non-negative solution in a Leontief model, so that a non-negative output will result from a given non-negative final demand. This condition was checked in this study as following step:

- For (I-A) coefficients matrix to satisfy H-S conditions, it can be checked with following two steps. First, all diagonal elements of the matrix must be positive and all non-diagonal elements of matrix must meet a pre-condition, which is non-positive. E-IO tables from 1985 to 2000 used in this study satisfies all these pre-conditions.
- Next, results of calculation of determinants values for all leading principal sub-matrices of the coefficients matrix of each year (I-A) showed that all minors were positive, which means all (I-A) matrices constructed in this study satisfy the H-S conditions.
- Therefore, Leontief inverse matrix, $(I\text{-}A)^{-1}$ was regarded as to satisfy H-S conditions, as well.

3. Results : energy intensity by economic sector

To analyze results of 96 sectors, energy and industrial sectors are aggregated into energy group, energy intensive group and less energy intensive group.

The reasons for grouping are that first, it can explain analysis results systematically, and second, characteristics of values between energy group of energy sectors and 2 groups of non-energy sectors are different. Their denominator units are physical terms (in TOE) and monetary terms, respectively, which their estimated values have different characteristics.

In the energy group, dimension of values is TOE/TOE, which means energy IO ratio among 14 energy sources that consist of this group. Meanwhile, in a non-energy group, dimension of value is TOE/million Korean Won (KRW), which means energy intensity is obtained by dividing the unit amount of energy used by the total output in monetary units. Considering this difference, the analysis results are as follows: for the sake of convenience, each sector was replaced by sector numbers in X-axis and the energy IO ratio for energy group and energy intensity for non-energy group are regarded as energy intensity.

① Energy intensity by industrial sector

Energy intensity is divided into two categories, namely direct energy intensity calculated in input coefficients matrix and total or embodied energy intensity through inverse matrix coefficients. And indirect energy intensity of each sector can be acquired by subtracting direct energy intensity from total energy intensity. With this concept the characteristics of each group are as follows:

The average value of direct and total energy intensity is shown as 0.132 and 0.640, respectively. Among the direct energy intensity of sectors, the highest is #-10 (thermal & self power generation, 2.440), and the lowest includes the sector #-2 and 3 (crude petroleum and natural gas, 0.000). Likewise, a similar pattern has been found in the total energy intensity: the sectors #-17 (metallic materials, 0.004) record the low, whereas the highest value turns up in the sector #-10 (4.571). Compared with the total energy intensity, the sectors including #-2 and 3 (0.0%) show the lowest in direct energy intensity. On the other hand, the sector #-10 (53.4%) and the sector #-33 (other nonmetallic mineral products, 51.9%) are the high ones in direct energy intensity. This means that energy which is directly input is bigger than an amount of total energy input needed for the output of each sector (Fig. 2).

② Energy intensity by energy source

In each group, the proportion of energy sources in terms of direct and total energy used are the following: This comparison is useful to recognize the consumer patterns of each energy source when it comes to the GDP in each economic sector.

In terms of energy sources, the results are as follows: First, in energy group, #-1 (coal, 34.8%) and #-2 (27.3%) are the highest in direct energy use; #-1 (18.4%), #-2 (17.0%), and #-3 (11.7%) are higher in total energy use. Next, in the energy intensive group, direct energy use is 54.0% by adding #-7 (fuel oil, 37.5%) and #-5 (naphtha, 16.5%); hence total energy use in #-2 (24.6%) and #-7 (18.3%) takes up 43%. Lastly, in the energy less intensive group, direct energy use of #-7 (55.0%) and #-10 (12.5%) is 67.4%. Total energy use of #-2 (28.0%) and #-7 (20.0%) is 48.1% (Fig. 3).

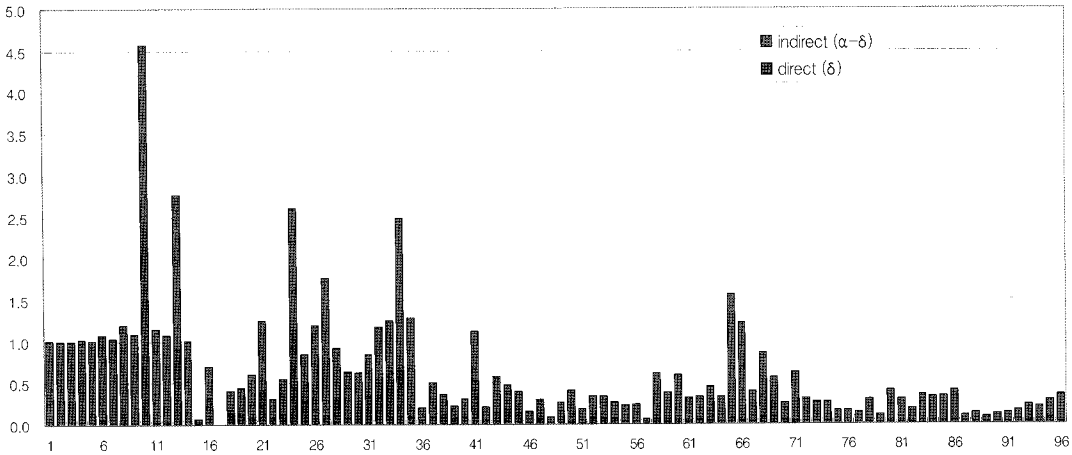

Fig. 2. Energy intensity by sector (1~96).

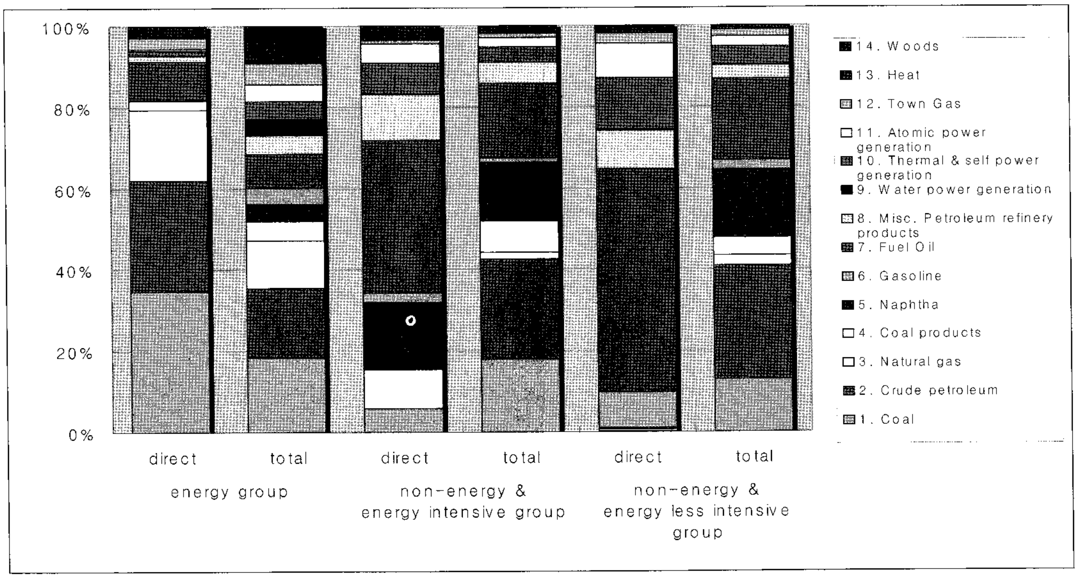

Fig. 3. Proportion of energy use by energy source.

4. Recommendations for the national energy policy

In 2006, the share of energy in Korea amounts to 28% in the total imports, 97% in the overseas dependence in primary energy, and 83% of the national GHG emissions derived from the energy sector in 2004. Thus, in the aspects of economic and environmental policies, the energy analysis is very important to not only in solving domestic dilemma but also in smooth adapting international paradigm.

Recently, the depletion of energy resources and the conflicts evoked are observed in reality. In order to establish more effective national energy policy, capability of IO analysis on energy and environment is required urgently at the national level.

When such analysis method is adopted, it will be more effective to establish the policy measures for climate change agreement, to set up the priority of the policies, and to quantitatively measure the implementation effects of policies. For example, this method will make possible the analysis of energy consumption and pollutant emission.

The IO analysis used in this study can be recommended to meet these requirements. This analysis has additional advantages as follows.

- It is useful for establishment of a national climate change agreement policy, definition of policy priorities and quantitative assessment of its implementation effects. This method can provide basis for analysis of energy consumption and pollutant emission by sector, analysis of energy consumption per added value and environmental pollution emissions, analysis of employment effects, analysis of linkage effects, etc.
- This can provide a tool, like Geological Atlas, which allows to explore the organic relationship between economy, energy and environment. Based on tables describing economic activities, this has great advantage in analysis of the relationship between economy and energy. This is also expected to provide reliable results if supplemented with the results obtained by international organizations like IPCC. More useful information can be obtained through time series analysis.
- This facilitates the expansion of assessment when additional analysis is required. For example, it allows to additionally assess global and/or regional environmental factors like acidification potential or ozone layer depletion potential and minimize the additional work required for analysis of the effects of environmental pollution on trading activities.

In order to improve the accuracy of the energy IO analysis model applied in this study the followings are required for further studies.

- In this study, an average price was used for each energy source when constructing energy IO table. However, in reality the same energy source is priced differently from sector to sector. For instance, electricity tariffs vary across consumers and a differential pricing system is being implemented in consideration of industrial and social policies.
- Energy IO tables need to expand, like the BOK (2003)'s large sized IO tables with the basic classification of 404 sectors. A more detailed sector classification is required to establish a more sophisticated so that more effective energy-environment policy could be formulated using the analysis results.
- Energy sources need to be classified more specifically according to the final energy type. In this study, energy sources were grouped into 14 types through verification of the energy balance sheets constructed by the KEEI (2006). However, a more detailed sector classification is required in order to support more effectively for the formulation of the nation's energy policy. For instance, in order to more effective analysis to climate change in the transportation sector, fuels like gasoline, diesel, kerosene, bunkers, LPG, LNG etc. should be set as an independent sector.

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