# An e-SAM Approach to the Analysis of Energy Consumption and $CO_2$ Emissions in Korean Industry

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# 환경사회계정행렬(e-SAM)을 이용한 산업활동의 환경 파급효과 분석

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## 국문요약

산업연관표와 국민 계정을 연결시켜 작성하는 기존의 사회계정행렬(SAM: Social Accounting Matrix)에다 우리나라 산업별 화석에너지 소비량과 이산화탄소 배출량 등 환경지표를 추가로 연결한 환경 사회계정행렬(environmental SAM)을 국내 최초로 작성하고, 이 결과를 이용하여 우리나라 산업별 생산 활동이 화석에너지 소비와 이산화탄소 배출에 미치는 영향을 추정하였다. 본 논문에서는 특히 화석에너지 소비와 이산화탄소 배출 변화의 요인 분해(decomposition)시 기존의 직, 간접 효과는 물론 산업연관분석에서는 찾아내기 어려운 환류 효과(induced effect)까지 세분하여 추정하였다. 추정 결과 우리나라에서 화석에너지 소비가 가장 많은 발전 산업(electricity industry)은 직접 효과가 큰 반면 간접 효과는 매우 작은 것으로 나타났다. 두 번째로 화석에너지 소비량이 많은 제철 등 제1차 금속 산업의 경우에는 직접 효과뿐만 아니라 간접 효과도 큰 것으로 나타났다. 무엇보다도 각 산업 활동별로 상당히 큰 값의 환류 효과가 존재함을 확인할 수 있었다. 특히 서비스 산업은 환류 효과가 직, 간접 효과보다 더 큰 비중을 차지하였다. 본 논문은 향후 에너지 소비량 감축과 같은 정책의 시행이나 산업 활동의 변화가 각 산업별로 화석에너지 소비와 이산화탄소 배출에 미칠 영향을 여러 가지 요인별로 세분하여 파악할 수 있게 하였다는 점에서 산업 활동의 영향 평가는 물론 정책 영향 평가에서도 활용가치가 높다고 본다.

**주제어** 환경사회계정행렬, 화석에너지소비, 이산화탄소배출, 산업활동의 파급효과

## Abstract

This research aims to find out the existence of considerable induced effect that the conventional I-O model cannot. First, we construct an environmental Social Accounting Matrix for Korea by combining statistics on the Korean GDP and I-O with physical data on the fossil energy consumption and $CO_2$

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emissions. The impacts of productive activities on fossil energy consumption and $CO_2$ emissions are evaluated by calculating the e-SAM multipliers. By applying decomposition technique further, we get direct, indirect, and induced effects of production activities by industry. The result of decomposing the e-SAM shows that while the direct effect of the electricity industry is large, its indirect effect is very small. In the case of the primary metal industry, both the direct and the indirect influence of this industry were very large. On the contrary, in case of the service industry, the induced effect of fossil energy consumption was as high as 50% of the gross effect. These results suggest that different energy policies should be established for different industries. Also, the findings show the e-SAM model is better than I-O model in analyzing implications of policies on energy use in the economy.

**❙ Keywords ❙** e−SAM, Fossil Energy Consumption, $CO_2$ Emissions, Impact of Industrial Activity
JEL Codes: C67, D57, Q40, Q51

## Ⅰ. Introduction

Social Accounting Matrices (SAMs) have been widely used in an attempt to understand national economies. SAMs refer to data in matrix form that integrate and adjust the input output (I-O) table and statistics on national income. SAMs are typically used to maintain consistency in national accounts and economic policy simulations.

SAMs were subsequently incorporated into the System of National Accounts (SNAs). Stuvel (1965) calculated a SAM composed of production, income and accumulation accounts using data from UK national accounts. Over time, more studies on the construction of SAMs emerged. Pyatt (1988) explained the-SAM system and demonstrated its use in economic analysis modeling. Pang and Lim (2007) explained the data source and preparation method of the-SAM in detail, using the Australian economy as an example.

Due to the oil crisis and global warming, research interest on the relationship between energy consumption and economic activities has grown. To connect physical flows in energy consumption to monetary flows in the economy, the energy I-O table has been applied. However, the energy I-O has the limitation of being unable to measure the feedback effect of income, which promotes renewed production through consumption.

Accordingly, Environmental Social Accounting Matrix (e-SAM) can be used as a method of analyzing direct and indirect linkages between productive activities and energy consumption, including the feedback effect. The e-SAM combines quantity based energy indexes with money based national accounts. To construct an e-SAM, a SAM should first be established that connects the production account, consumption and outlay account, capital account, and trade account of the national accounts.

An e-SAM can then be constructed to connect data on energy consumption and $CO_2$ emissions by economic activities to the national account SAM. Xie (1996) developed an environmentally extended SAM by connecting environmental physical flows to a SAM. The e-SAM provides an integrated data system in which pollution related information regarding factors such as pollution abatement sectors, sectorial payments for pollution cleanup, pollution emission taxes, pollution control subsidies and environmental investments are accounted for separately. Likewise, Xie & Saltzman (2000) used this mechanism to compile an e-SAM and utilized it in a CGE Model. Manresa and Sancho (2004) estimated energy intensities by sector and $CO_2$ emissions from the Catalonian economy in Spain using an e-SAM. However, their results do not distinguish the within industry energy consumption of transforming industries, such as electricity and oil refineries, from the energy consumed by other industries. Rodríguez et al. (2007) analyzed the efficiency of the economy and environment by preparing an environmental SAM through a combination of physical environment data with the existing framework of SAM and analysis of the multiplier effect

In this study, we construct an e-SAM for Korea by combining GDP and I-O with physical data, such as fossil energy consumption and $CO_2$ emissions. An e-SAM has not yet been compiled in Korea because of huge data requirements and difficulties in maintaining consistency among the national accounts. We use an e-SAM to analyze the impacts of productive activities on fossil energy consumption and $CO_2$ emissions in Korea. In the analysis, we estimate the aggregate impacts of economic activities on energy consumption and $CO_2$ emissions and decompose them into direct, indirect, and induced effects.

This study proceeds as follows. In Section 2, we construct an e-SAM using data that include GDP, fossil energy consumption, and $CO_2$ emissions with an I-O table in Korea. In Section 3, we analyze the effect of productive activities in Korea on energy consumption using the constructed e-SAM. We discuss the results of this analysis in Section 4.

# Ⅱ. The e-SAM with energy consumption, and $CO_2$ emissions in Korea.

## 1. The structure of e-SAM

The-SAM was developed to capture a country’s economic activities by consistently connecting diverse information from the System of National Accounts. The central piece of the-SAM is the I-O table, to which statistics representing the flow of national income are added to represent national transactions such as production, distribution, and consumption in matrix form.

One popular application of the-SAM is the e-SAM, which is constructed by adding energy consumption and $CO_2$ emission information by economic activities to the-SAM. The e-SAM is also called a hybrid SAM because a SAM with a monetary unit is mixed with physical data. In this study, we construct an e-SAM in Korea by adding fossil energy consumption and $CO_2$ emissions to a SAM as exogenous information.

Table 1 shows the structure of the e-SAM that captures energy consumption and $CO_2$ emissions by economic activity. The I-O statistics are used as the base of the e-SAM and the national statistics on income are added. Income distributed from the added value of each industry and income transfers among institutional sectors are estimated using national income statistics. We then adjust the number of rows to match the number of columns. The rows of the e-SAM represent the distribution structure and the columns represent the input structure of goods and services. In other words, the columns of the-SAM refer to spending and the rows indicate the receipts of the relevant economic agent or organization. In this study, the physical accounts are arranged in rows to connect them to production activities.

Unlike previous studies that used purchasers’ prices or producers’ prices in the transaction table, we use basic prices. The transaction table of purchasers’ prices becomes a table of basic prices when the distribution margin, product taxes, and subsidies are removed. The Bank of Korea first produced transaction tables with basic prices in 2003 in accordance with the ‘1993 System of National Accounts’ recommended by international organizations such as the UN. Therefore, we use transaction tables with basic prices for 2005. To account for international transactions, the import transaction table is used in addition to the domestic transaction table.

In classifying the industries, we follow the major classifications (28 industries) of the I-O table made by the Bank of Korea. We then reduce the number of service industries by merging industries that do not have large energy consumption, resulting in a total of 18 industries. To capture the energy industry with greater accuracy, we integrate 14 energy industries (Anthracitic Coal, Bituminous Coal, Crude Oil, LNG, Coal Briquettes, Other Coal Products, Naphtha, Gasoline, Jet Fuel, Kerosene, Diesel Oil, Heavy Oil, LPG, and Town Gas) from the fine classification (403 industries) into a single industry.

Table 1 Structure of the e-SAM

| | | Production | Income | Institutional sectors | | | Investment | Export | Total |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Household | Company | Government | | | |
| Production | | | | | | | | | |
| Income | | | | | | | | | |
| Institutional sectors | Household | | | | | | | | |
| | Company | | | | | | | | |
| | Government | | | | | | | | |
| Savings | | | | | | | | | |
| Import | | | | | | | | | |
| Total | | | | | | | | | |
| Energy | Fossil energy consumption | | | | | | | | |
| | $CO_2$ emissions | | | | | | | | |

## 2. Estimation of energy consumption and $CO_2$ emissions by economic activities in Korea

First, the energy inputs by industry in the I-O table, which are originally in monetary units, are converted into physical units. We obtain physical units by dividing the monetary units by the unit price of each energy source. In estimating the unit price of each energy source, we use the aggregated energy in both monetary and physical units. For this, we use the supplementary table of the I-O tables from the Bank of Korea and other data, including the Yearbook of Energy Statistics.

Next, energy consumption data are standardized to a common term, tons of oil equivalent (TOE). Table 2 shows the aggregate amount of fossil fuel consumed in Korea in 2005 in TOE. It shows fossil fuels used directly in the process of production or household consumption, except for primary energy used for transformation.

Of the total fossil fuel consumption in Korea, coal, oil, and town gas account for 27.5%, 62.6%, and 9.9%, respectively. Bituminous coal accounts for 14.3% of the total energy consumption because it is used for thermal power generation, which constitutes a significant part of Korean power generation. Coke and other coal products account for 10.6% due to the steel industry, one of the major industries in Korea.

When we classify fossil fuel sources into two categories (i.e., imported and domestic), more than half of coal is imported, whereas more than 90% of petroleum products are produced domestically. However, most of the crude oil used for the production of petroleum products is imported. Korea imports crude oil and refines it into gasoline, light, and heavy oils for final use. The supply of the Korean refineries is more than enough to meet the domestic demand, so a considerable amount is exported.

The chemical industry, which decomposes the naphtha generated in the process of oil refining, has been highly developed in Korea. The chemical industry provides the basis for the textile, electric and electronic equipment, and automobile industries in Korea. Town gas is made by blending natural gas and LPG from crude oil, both of which are imported. In sum, Korea's fossil fuel mostly depends on imported energy, such as crude oil and bituminous coal. Using the fossil fuel data in Table 2, we obtain the $CO_2$ emissions of industries in Korea by applying IPCC emissions factors (2006).[1]

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[1] more details Park, Chang-Gui. 2009. "An Analysis of $CO_2$ Emission Structure in Korean Industry Using Hybrid Input-Output table", Journal of Environmental Policy, 8(1), Korea Environment Institute, 49-72.

Table 2 Fossil fuel supply in Korea (final use only, 2005)

(1000 toe[1)])

| Fuels | Domestic | Imported | Total | |
|---|---|---|---|---|
| Anthracite | 378 | 2,923 | 3,301 | ( 2.0) |
| Bituminous coal | 0 | 23,865 | 23,865 | (14.3) |
| Coal briquettes | 925 | 0 | 925 | ( 0.6) |
| Coke and other coal products | 17,403 | 297 | 17,700 | (10.6) |
| Sub Total | 18,706 | 27,085 | 45,791 | (27.5) |
| Naphtha | 464 | 0 | 464 | ( 0.3) |
| Gasoline | 8,685 | 9 | 8,695 | ( 5.2) |
| Jet oil | 11,119 | 0 | 11,119 | ( 6.7) |
| Kerosene | 5,747 | 48 | 5,795 | ( 3.5) |
| Light oil | 31,029 | 257 | 31,286 | (18.8) |
| Heavy oil | 31,346 | 598 | 31,944 | (19.1) |
| Liquefied petroleum gas | 6,433 | 8,718 | 15,151 | ( 9.1) |
| Sub Total | 94,824 | 9,630 | 104,454 | (62.6) |
| Town gas | 16,516 | 48 | 16,565 | ( 9.9) |
| Total | 130,046 | 36,763 | 166,810 | (100.0) |

Note: 1) toe: ton of oil equivalent

2) The numbers in the parentheses are the shares (%) of each industry in the total amount

Source: Yearbook of Energy Statistics (2006).

2005 Input-Output Table of Korea (2009).

Korea Iron & Steel Association Bulletin (2006).

## 3. The analysis of e-SAM

The steps mentioned above allow us to construct the e-SAM shown in Table 3. To determine the relationship between productive activities and their impacts, we expand the production part of the-SAM and delete other sectors that do not have significant numbers, as shown in Table 4. The e-SAM tells us that to produce 1,991.2 trillion Korean Won of output, all industries spent 929.3 trillion Won (or 46.5% of the total output) on the intermediate input of domestic materials, 397.1 trillion Won (19.9%) on employee compensation and 252.5 trillion Won (12.6%) on operating surplus. Additionally, 258.8 trillion Won (13.0%) were spent on imports, and 110.9 trillion Won (5.6%) were spent on fixed capital. Korean industry consumed 111.9 million tons of fossil fuel and generated 99.5 million tons of carbon for an output production of 1,991.2 trillion Won in 2005. Households consumed 19.3 million tons of fossil fuel and emitted 14.0 million tons of carbon. Industries are responsible for 85.3% of fossil fuel consumption, and households are responsible for 14.7%. In the case of $CO_2$ emissions, industries emitted 87.7%, and households emitted the rest.

Table 3 Macro e-SAM in Korea (2005)

(billion Won)

| | | Productions | Income | | | Institutional sectors | | | Investment | Exports | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Employee compensation | Operating surplus | Net taxes | Household | Company | Government | | | |
| Productions | | 929,349 | - | - | - | 396,069 | - | 120,010 | 202,469 | 343,325 | 1,991,222 |
| Income | Employee compensation | 397,118 | - | - | - | - | - | - | - | 832 | 397,950 |
| | Operating surplus | 252,480 | - | - | - | - | - | - | - | - | 252,480 |
| | Net taxes | 42,583 | - | - | - | 39,346 | - | - | 26,765 | - | 108,694 |
| Institutional sectors | Household1) | - | 396,996 | 84,701 | - | 44,090 | 32,880 | 56,146 | - | 9,975 | 624,788 |
| | Company | - | - | 167,779 | - | | 98,718 | 7,823 | - | -31,202 | 243,118 |
| | Government | - | - | - | 108,694 | 90,281 | 32,239 | - | - | 6,982 | 238,196 |
| Savings | | 110,936 | - | - | - | 20,768 | 79,281 | 54,217 | - | -2,395 | 262,807 |
| Imports | | 258,756 | 954 | - | - | 34,234 | | | 33,573 | - | 327,517 |
| Total | | 1,991,222 | 397,950 | 252,480 | 108,694 | 624,788 | 243,118 | 238,196 | 262,807 | 327,517 | 4,446,772 |
| Fossil energy consumption | [1,000 toe] | 111,853 | | | | 19,322 | | | | | |
| $CO_2$ emissions | [1,000 ton] | 99,514 | | | | 14,012 | | | | | |

Note: 1) Includes non-profit institutions serving households.

When reviewed by industry type, the proportions of spending for agriculture/forestry/fishery and the service industries on intermediate inputs were low (38.7% and 35.0%, respectively), their value added was high. In contrast, although the share of spending by the manufacturing industry for intermediate inputs was high (54.9%), its value added was low. The manufacturing industry also showed a higher rate of spending (22.1%) on imports in comparison with other industries.

Table 4 e-SAM in Korea (2005)

(trillion Won)

| | Industry | | | | | Total | House-hold |
|---|---|---|---|---|---|---|---|
| | AFF1) | Manufact-uring | Electri-city | Service | Others | | |
| Intermediate input | 16.6<br>(38.7) 2) | 499.2<br>(54.9) | 10.2<br>(38.1) | 280.8<br>(35.0) | 122.6<br>(56.4) | 929.3<br>(46.5) | 396.1 |
| Employee compensation | 2.7<br>(6.3) | 100.0<br>(11.0) | 2.6<br>(9.8) | 245.6<br>(30.6) | 46.2<br>(21.3) | 397.1<br>(19.9) | |
| Operating surplus | 19.5<br>(45.6) | 57.6<br>(6.3) | 4.4<br>(16.5) | 155.2<br>(19.3) | 15.8<br>(7.3) | 252.5<br>(12.6) | |
| Product tax | 1.0<br>(2.3) | 10.4<br>(1.1) | 0.2<br>(0.7) | 22.6<br>(2.8) | 8.4<br>(3.9) | 42.6<br>(2.1) | 39.3 |
| Consumption of fixed capital (Savings) | 2.1<br>(4.8) | 41.0<br>(4.5) | 5.4<br>(20.4) | 62.9<br>(7.8) | 5.8<br>(2.7) | 117.2<br>(5.9) | 20.8 |
| Import | 1.0<br>(2.3) | 200.5<br>(22.1) | 3.9<br>(14.5) | 35.0<br>(4.4) | 18.4<br>(8.5) | 258.8<br>(13.0) | 34.2 |
| Total (Output amount) | 42.9<br>(100.0) | 908.7<br>(100.0) | 26.7<br>(100.0) | 802.0<br>(100.0) | 217.2<br>(100.0) | 1,997.5<br>(100.0) | 624.8 |
| Fossil energy consumption (1,000 toe) | 2,888 | 36,849 | 33,516 | 32,772 | 5,828 | 111,853 | 19,322 |
| $CO_2$ emissions (1,000 ton of Carbon) | 2,422 | 33,872 | 32,376 | 26,031 | 4,813 | 99,514 | 14,012 |

Note: 1) AFF - Agriculture, Forestry and Fishery
2) The numbers in the parentheses are the shares (%) of each industry in the total amount

In Table 5, the effects of industrial activities on energy consumption subdivided by industry type are calculated in accordance with the method explained in Chapter 2. Table 5 shows that the greatest proportion of fossil fuel was consumed by the electricity industry, reaching 30.0% of the total industry fossil fuel consumption. The second greatest proportion was the transportation industry at 17.5%, and the third greatest proportion was the primary metal industry at 15.0%.

However, in the case of $CO_2$ emissions, the order would change. The greatest proportion of $CO_2$ emissions was generated by the electricity industry. However, the industry with the second greatest proportion was the primary metal industry (including iron/steel manufacturing) at 17.1%, rather than the transportation industry. This is because thermal power generation consumed more coal. These three industries generated more than 2/3 of the total industry fossil energy consumption and $CO_2$ emissions in Korea.

Table 5 Proportion of total fossil energy consumption and $CO_2$ emissions by industry in Korea (2005)

(%)

| | AFF[1] | Petroleum and Coal Products | Chemical | Non-metal Minerals | Primary metal | Electric, Electronic | Electricity | Transportation, Storage | Others | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Fossil energy consumption | 2.6 | 2.6 | 3.6 | 4.4 | 15.0 | 1.3 | 30.0 | 17.5 | 23.0 | 100.0 |
| $CO_2$ emissions | 2.4 | 2.3 | 3.4 | 4.7 | 17.1 | 1.1 | 32.5 | 16.0 | 20.5 | 100.0 |

Note: 1) Agriculture, Forestry and Fishery

If we examine the average energy and $CO_2$ intensity of all industries, 56.2 tons of fossil fuel consumption and 50.0 tons of carbon emissions are needed for one billion Won of output. Table 6 shows the energy and carbon intensity of industries produced by the e .SAM. The largest energy consuming industry is the electricity industry due to thermal power generation. The second largest energy consuming industry is transportation. The third largest energy consuming industry is non metallic minerals, such as cement. The fourth largest energy consuming industry is primary metals, such as iron and steel. It is worth noting that these levels do not reflect the total impact of production activities on energy and the environment. By definition, they include only the direct effects of production activities.

Table 6 The intensities of fossil energy and $CO_2$ emissions by industry in Korea (2005)

| Industry | Fossil energy intensities (toe/billion Won) | $CO_2$ emissions intensities (ton of Carbon/ billion Won) |
|---|---|---|
| Food and beverage products | 16.6 ( 0.9) | 13.6 ( 0.9) |
| Textile and leather products | 25.0 ( 0.9) | 20.4 ( 0.8) |
| Wood and paper products | 61.0 ( 1.0) | 52.1 ( 1.0) |
| Printing, publication and reproduction | 15.6 ( 0.1) | 12.3 ( 0.1) |
| Petroleum and coal products | 48.6 ( 2.6) | 39.5 ( 2.3) |
| Chemicals | 29.5 ( 3.6) | 24.7 ( 3.4) |
| Non-metal mineral products | 209.0 ( 4.4) | 196.8 ( 4.7) |
| Primary metal products | 143.4 (15.0) | 145.6 (17.1) |
| Metal products | 34.8 ( 1.3) | 25.9 ( 1.1) |
| General machinery | 12.8 ( 0.8) | 10.0 ( 0.7) |
| Electric and electronic equipment | 7.7 ( 1.3) | 5.7 ( 1.1) |
| Precision equipment | 7.9 ( 0.1) | 6.0 ( 0.1) |
| Transportation equipment | 7.5 ( 0.9) | 5.8 ( 0.7) |
| Electricity | 1,256.9 (30.0) | 1,214.1 (32.5) |
| Transportation and storage | 245.2 (17.5) | 199.9 (16.0) |
| Other services | 18.3 (11.8) | 14.0 ( 10.1) |
| Total | 56.2 (100.0) | 50.0 (100.0) |

Note: The numbers in the parentheses are the shares (%) of each industry in the total amount.

# Ⅲ. Impact of industrial activity on energy consumption and $CO_2$ emissions

## 1. e-SAM multipliers

e-SAM multipliers can be obtained through a multi sectoral model under assumptions of linearity, fixed price, and equilibrium. To obtain the multiplier, various accounts should first be divided into endogenous variables and exogenous variables. In economic theory, production, value added, income, and other variables are generally treated as endogenous, whereas government spending, exports, investment, and similar variables are generally treated as exogenous. As with many previous SAMs, such as those by Khan and Thorbecke (1989) and Noh (2006), production and consumption are regarded as endogenous variables, and government spending, investment and international trade are regarded as exogenous variables in this study, as shown in Table 7.

Table 7 Endogenous and exogenous variables in the e-SAM[1)]

| | | SAM | | |
|---|---|---|---|---|
| | | Endogenous variables (*m*) | Exogenous variables (*k*) | Totals |
| SAM | Endogenous variables (*m*) | $Y_{mm}$ | $X_{mk}$ | $Y_m$ |
| | Exogenous variables (*k*) | $X_{km}$ | $X_{kk}$ | $X_k$ |
| | Totals | $Y_m$ | $X_k$ | |
| Energy consumption factors | Endogenous variables (*r*) | $R_{rm}$ | | $R_r$ |

The multiplier of a SAM can be estimated using the e-SAM. We begin with the following identity:

Total amount of transactions = Endogenous variable transaction amount + Exogenous variable transaction amount.

The above identity can be presented in equation (1) as

$$Y_m = Y_{mm}u_m + X_{mk}u_k, \tag{1}$$

where $Y_m$ is the aggregation by industry or sector, $Y_{mm}$ is the endogenous variable transaction amount, $X_{mk}$ is the exogenous variable transaction amount and $u_m$ and $u_k$ are the unit matrix column vector.

The average propensity ($A_{mm}$) to spend can be obtained in equation (2) by dividing the transaction amount of the endogenous sector ($Y_{mm}$) of each account by the aggregation of the-SAM of each industry or sector ($Y_m$). This is called the-SAM structural coefficient.

$$A_{mm} = Y_{mm}\hat{Y}_m^{-1}, \tag{2}$$

where is a diagonal matrix. Equation (2) can be rewritten as equation (3):

$$Y_{mm}u_m = A_{mm}Y_m, \tag{3}$$

which can further be expressed by substituting (3) for (1).

$$Y_m = A_{mm}Y_m + X_{mk}u_k, \tag{4}$$

where $u_k$ is the unit matrix column vector. We can obtain the following equation by solving (4) in relation to $Y_m$.

$$Y_m = (I - A_{mm})^{-1}X_{mk}u_k. \tag{5}$$

When we place $(I - A_{mm})^{-1} = M_{mm}$ and $X_{mk}u_k = Z_m$ into equation (5), we obtain equation (6).

$$Y_m = M_{mm}X_{mk}u_k = M_{mm}Z_m. \tag{6}$$

Here, we call $M_{mm}$ a SAM multiplier. Each element $m_{ij}$ of $M_{mm}$ represents the effect of a one unit change in the exogenous variable $Z_m$ on $Y_m$.

Furthermore, to estimate energy consumption or $CO_2$ emissions resulting from production, it is necessary to estimate technical coefficients that connect the physical energy flows accompanying the monetary transactions of the-SAM. Here, equations (7) and (8) represent the energy coefficients.

Fossil energy consumption coefficients ($\alpha_m$): Fossil energy consumption per unit of production or per sector m (household)

$$\alpha_m = \hat{F}_m \hat{Y}_m^{-1} u_m, \quad (7)$$

where $F_m$ is the fossil energy consumption, and $u_m$ is the unit matrix column vector.

$CO_2$ emissions coefficients ($\beta_m$): $CO_2$ emissions per unit of production or per sector m (household)

$$\beta_m = \hat{C}_m \hat{Y}_m^{-1} u_m, \quad (8)$$

where $C_m$ is the $CO_2$ emissions amount, and $u_m$ is the unit matrix column vector.

Fossil energy consumption ($F_m$) and $CO_2$ emissions ($C_m$) are obtained by multiplying the-SAM multipliers of fossil energy consumption and $CO_2$ emissions, $M_{mm}^f$, $M_{mm}^c$ by $Z_m$, as follows:

$$F_m = \hat{\alpha}_m (I - A_{mm})^{-1} Z_m = M_{mm}^f Z_m \quad (9)$$

$$C_m = \hat{\beta}_m (I - A_{mm})^{-1} Z_m = M_{mm}^c Z_m, \quad (10)$$

where $\hat{\alpha}_m (I - A_{mm})^{-1}$ is the fossil energy consumption SAM multiplier caused by a one unit increase in an exogenous variable, which is called $M_{mm}^f$. $\hat{\beta}_m (I - A_{mm})^{-1}$ is the $CO_2$ emissions SAM multiplier caused by a one unit increase in an exogenous variable, which is called $M_{mm}^c$.

The e-SAM multipliers by industry are shown in Table 8. e-SAM multipliers are conceptually similar to the I-O multiplier. e-SAM multipliers indicate the direct or indirect spillover effects when one unit increases in the exogenous sector, as do I-O multipliers. Because e-SAM multipliers are more inclusive than I-O multipliers, the values for e-SAM multipliers are larger than the values for I-O multipliers. This is because e-SAM multipliers capture income effects, and I-O multipliers do not.

The e-SAM multipliers of fossil fuel consumption and $CO_2$ emissions are shown in Table 8. The values differ significantly from industry to industry. In terms of the e-SAM multipliers of fossil fuel consumption, the electricity industry has the greatest value, 1.34, followed by non metallic mineral products, 0.39, and primary metals, 0.37. The electricity industry causes the economy to consume 1,340 tons of fossil fuel to produce 1 billion Won of output due to a high dependency on thermal power generation in the Korean electricity industry. In response to the surge of electricity demand from industry during rapid economic growth, Korea has significantly expanded thermal power. As a result, thermal power generation now accounts for more than 60% of the power generation industry in Korea. Similarly, in terms of the e-SAM multipliers of $CO_2$ emissions by industry, the electricity industry has the greatest value, 1.29, followed by primary metals, 0.37, and non metallic mineral products, 0.36. The multipliers of $CO_2$ emissions by industries are similar to those for fossil fuel consumption.

The electric and electronic equipment industry has the lowest e-SAM multipliers of fossil fuel consumption and $CO_2$ emissions, 0.10 and 0.09, respectively. The service industry consumes small amounts of fossil fuel with low $CO_2$ emissions. Simply put, an increase in the ratio of service industries or high tech industries, such as the electric and electronic equipment industry, will help to reduce energy consumption.

Table 8 The e-SAM multipliers by industry

(1,000 toe, 1,000 ton / billion Won)

|  | Textile, Leather | Wood, Paper | Chemical | Non-metal | Primary Metal | Electric, Electronic | Electricity | Transportation, Storage | Service |
|---|---|---|---|---|---|---|---|---|---|
| Fossil energy consumption | 0.16 | 0.22 | 0.15 | 0.39 | 0.37 | 0.10 | 1.34 | 0.32 | 0.12 |
| $CO_2$ emissions | 0.14 | 0.19 | 0.13 | 0.36 | 0.37 | 0.09 | 1.29 | 0.27 | 0.11 |

## 2. Decomposition of the e-SAM multipliers

In many cases, production and consumption activities are accompanied by fossil energy consumption and $CO_2$ emissions. Accordingly, conflicts occur between the economy and resources, so natural resources must be used efficiently. A strategy is needed to maximize economic activities while minimizing energy consumption. To create such a strategy, we must decompose the e-SAM multiplier. In this analysis, following Rodriguez et al. (2007), we decompose each e-SAM multiplier into four effects: a characteristic effect, a direct effect, an indirect effect and an induced effect.[2]

- Characteristic effect: the effect caused by the production of goods and services alone.
- Direct effect: the effects on production and the energy use of the consumption of raw/subsidiary materials that are inputs to the manufacturing process for the production of products or services.
- Indirect effect: the effects on production and the energy use of the consumption of other raw/subsidiary materials required for the production of raw/subsidiary materials that are inputs into the manufacturing process.
- Induced effect: the effect of inducing further production by the expenditure of income created in the manufacturing process. This is also called the feedback effect.

These effects are obtained in the following relationship. We obtain four decomposed equations of the effects by designating I as the unit matrix, A as intermediate inputs

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[2] It was referred to Rodríguez et al. (2007).

consumed by production activities, $M_T$ as the domestic production inducement effect (Leontief production inducement coefficient) of the square I-O table and $M_s$ as the e-SAM multiplier (gross effect).

$$M_s = \text{characteristic effect } (I) + \text{direct effect } (A) + \text{indirect effect } (M_T - I - A)$$
$$+ \text{ induced effect } (M_s - M_t). \quad (11)$$

Accordingly, we can decompose the fossil energy consumption multiplier and $CO_2$ emissions multiplier of equations (9) and (10), respectively, into the following:

$$M_S^f = \hat{\alpha}_m I + \hat{\alpha}_m A + \hat{\alpha}_m (M_T - I - A) + \hat{\alpha}_m (M_S - M_T) \quad (12)$$

$$M_S^C = \hat{\beta}_m I + \hat{\beta}_m A + \hat{\beta}_m (M_T - I - A) + \hat{\beta}_m (M_S - M_T). \quad (13)$$

Table 9 and Table 10 show the e-SAM multipliers and their decomposition into four effects: characteristic, direct, indirect and induced effects. The characteristic effect in the multiplier equals the intensities discussed previously. The I-O multiplier is decomposed to characteristic, direct, and indirect effects. There is secondary effect that creates an additional induced effect, such as the income generated from the consumption of production yields, which induces further production. This feedback is called the induced effect. The-SAM approach can capture this effect, whereas the conventional I-O model cannot. Thus, the e-SAM multipliers can be the most comprehensive indicator of the gross effect.

We consider the e-SAM multipliers and I-O multipliers of energy consumption by industry in Table 9. Most industries, with the exception of the electricity industry, have values between 0.10 and 0.39, which is at least 10% higher than the IO multiplier values of 0.7  0.34. This finding confirms the existence of a considerable induced effect in the economy.

The direct effect is higher than the indirect effect in the analysis of most industries. However, the indirect effect is higher than the direct effect in electronic industries, which are characterized as assembly industries. The indirect effect of electricity is very small, at 2.2% of the total effect, whereas that of primary metals is as high as 27.0% of the total effect.

When comparing the manufacturing industry and the service industry, the induced effect of the service industry is larger than that of the manufacturing industry, whereas the direct and indirect effects of the manufacturing industry are relatively larger. For example, the induced effect of fossil energy consumption by the service industry represents as much as 50% of the gross effect. In terms of the e-SAM multipliers of $CO_2$ emissions, most industries, with the exception of the electricity industry, have values between 0.09 and 0.37, which is at least 10% higher than the IO multiplier. The IO multiplier's value of 0.6 0.34 indicates a significant induced effect caused by consumption.

The e-SAM multipliers for energy consumption are larger than those for $CO_2$ emissions in most industries. This is simply because the $CO_2$ emissions coefficient is smaller than the energy consumption coefficient. However, in the primary metal industry, the $CO_2$ emissions coefficient is not smaller than the energy coefficient because the industry mainly uses bituminous coal. The $CO_2$ emissions coefficient for bituminous coal is far greater than that for oil. Accordingly, $CO_2$ emissions will differ in accordance with the composition of the energy sources for the-SAMe amount of energy consumption.

**Table 9 Decomposition of the e-SAM multipliers of fossil energy consumption by industry**

(1,000 toe / billion Won)

| | Textile, Leather | Wood, Paper | Chemical | Non-metal | Primary Metal | Electric, Electronic | Electricity | Transportation, Storage | Service |
|---|---|---|---|---|---|---|---|---|---|
| e-SAM Multiplier | 0.16 | 0.22 | 0.15 | 0.39 | 0.37 | 0.10 | 1.34 | 0.32 | 0.12 |
| I-O Multiplier | 0.11 | 0.18 | 0.11 | 0.34 | 0.34 | 0.07 | 0.31 | 0.29 | 0.07 |
| Char. Effect | 0.03 | 0.06 | 0.03 | 0.21 | 0.14 | 0.01 | 1.26 | 0.25 | 0.02 |
| Direct Effect | 0.04 | 0.07 | 0.04 | 0.09 | 0.10 | 0.03 | 0.03 | 0.02 | 0.03 |
| Indirect Effect | 0.04 | 0.05 | 0.04 | 0.05 | 0.10 | 0.04 | 0.03 | 0.02 | 0.02 |
| Induced Effect | 0.05 | 0.04 | 0.03 | 0.04 | 0.03 | 0.03 | 0.03 | 0.04 | 0.06 |

Table 10 Decomposition of the e–SAM multipliers of $CO_2$ emissions by industry

(1,000 ton / billion Won)

| | Textile, Leather | Wood, Paper | Chemical | Non-metal | Primary Metal | Electric, Electronic | Electricity | Transportation, Storage | Service |
|---|---|---|---|---|---|---|---|---|---|
| e-SAM Multiplier | 0.14 | 0.19 | 0.13 | 0.36 | 0.37 | 0.09 | 1.29 | 0.27 | 0.11 |
| IO Multiplier | 0.10 | 0.16 | 0.10 | 0.32 | 0.34 | 0.06 | 0.26 | 0.23 | 0.06 |
| Char. Effect | 0.02 | 0.05 | 0.02 | 0.20 | 0.15 | 0.01 | 1.21 | 0.20 | 0.01 |
| Direct Effect | 0.04 | 0.06 | 0.04 | 0.08 | 0.10 | 0.02 | 0.02 | 0.02 | 0.02 |
| Indirect Effect | 0.04 | 0.04 | 0.04 | 0.04 | 0.10 | 0.03 | 0.02 | 0.01 | 0.02 |
| Induced Effect | 0.04 | 0.03 | 0.03 | 0.04 | 0.02 | 0.03 | 0.03 | 0.03 | 0.05 |

Finally, the impacts by industry are estimated to standardize the relative size of the multiplier effect, as shown in Table 11. These impacts can be obtained by dividing the column sum of each industry's e-SAM multiplier by the average for the whole industry. A resulting coefficient larger than one indicates that the industry's relevance to other industries is higher than the industry average. The non metal and primary metal industries have above average impacts.

Table 11 Factors of impact of production, fossil energy consumption and $CO_2$ emissions by industry

| Industry | Factors of Impact | | |
|---|---|---|---|
| | Production | Fossil energy consumption | $CO_2$ emissions |
| Agriculture/forestry/fishery Products | 0.89 | 0.62 | 0.58 |
| Food and beverage products | 1.10 | 0.58 | 0.55 |
| Textile and leather products | 1.09 | 0.63 | 0.61 |
| Wood and paper products | 1.01 | 0.86 | 0.84 |
| Printing, publication and reproduction | 1.11 | 0.58 | 0.55 |
| Petroleum and coal products | 0.50 | 0.31 | 0.29 |
| Chemicals | 0.99 | 0.58 | 0.55 |
| Non-metal mineral products | 1.03 | 1.53 | 1.54 |
| Primary metal products | 1.03 | 1.48 | 1.59 |
| Metal products | 1.17 | 0.95 | 0.95 |
| General machinery | 1.17 | 0.68 | 0.68 |
| Electric and electronic equipment | 0.90 | 0.39 | 0.38 |
| Precision equipment | 1.05 | 0.47 | 0.46 |
| Transportation equipment | 1.21 | 0.58 | 0.58 |
| Electricity services | 0.85 | 5.32 | 5.58 |
| Transportation and storage | 0.82 | 1.28 | 1.16 |
| Service | 0.98 | 0.49 | 0.47 |
| Others | 1.11 | 0.66 | 0.64 |

## Ⅳ. Summary and Conclusions

We constructed an e-SAM in Korea that connects fossil fuel consumption and $CO_2$ emissions to the-SAM for the first time to determine the relationship between energy consumption, $CO_2$ emissions, and economic activity. Unlike previous studies that used purchasers' prices or producers' prices in the transaction table, we used basic prices that exclude the distribution margin, product taxes, and subsidies for better accuracy. We found that in 2005, Korean industries consumed 111.9 million tons of fossil fuel and generated 99.5 million tons of $CO_2$ to produce 1,991.2 trillion Korean Won of output. Industries are responsible for 85.3% of fossil fuel consumption, and households are responsible for 14.7%. In the case of $CO_2$ emissions, industries emitted 87.7%, and households emitted the rest

We estimated the e-SAM multipliers by using the e-SAM. e-SAM multipliers show direct and indirect spillover effects when the exogenous sector increases by 1 unit, as in the I-O multiplier. However, e-SAM multipliers are more inclusive than I-O multipliers. Therefore, their coefficient values are higher than the I-O multipliers because the e-SAM multipliers detect an income effect and the I-O multiplier does not.

The e-SAM multipliers for fossil fuel differ by industry. In Korea, the e-SAM multipliers of industries differ by more than 13 times, ranging from 0.1 to 1.34. The electricity industry has the highest e-SAM multipliers, at 1.34, indicating that 1 billion Won of output requires 1,340 tons of fossil energy consumption. This is due to the high dependency on thermal power generation within the electricity industry in Korea (over 60%). Accordingly, the electricity industry in Korea uses significant amounts of fossil fuel and emits large amounts of $CO_2$. Electric and electronic equipment use the lowest amounts of energy of all of the industries in Korea. An electric and electronic equipment output of 1 billion Won requires 100 tons of fossil fuel consumption and produces 90 tons of $CO_2$ emissions. This small amount of fossil fuel expenditure is understandable because semiconductor manufacturing to process wafer accounts for a large part of the electric and electronic equipment industry. The service industry uses 120 tons of fossil fuel and emits 110 tons of $CO_2$ for an output of 1 billion Won, indicating that this industry spends a small amount of fossil fuel with low $CO_2$ emissions.

Next, we decomposed e-SAM multipliers to measure the induced effect of income, which could not be done with the energy I-O analysis. The induced effect of income has significant implications for fossil fuel policy. In the case of the service industry, for example, the induced effect of fossil energy consumption was as high as 50% of the gross effect, suggesting that different energy policies should be established for different industries.

An interesting result was identified in the case of the electricity industry, which consumes the largest volume of fossil energy and emits the greatest quantity of $CO_2$. The decomposition of the e-SAM multipliers of the electricity industry showed that although the direct effect of the electricity industry is large, its indirect effect is very small, suggesting that a policy to gradually reduce the share of thermal power generation will be helpful for Korea to reduce $CO_2$ emissions with less impact..

In contrast, in the case of the primary metal industry, which is the second largest fossil energy consumer and $CO_2$ emitter, both the direct and indirect influences of the industry were very large. Therefore, a policy is needed to improve the manufacturing process or to diversify supply sources for the steel products required by industries.

Because the effects of basic industries, such as electricity and primary metals, on energy consumption in Korea are significant, structural improvements are necessary in these industries. Even if only the production process is improved in these two industries, this will significantly contribute to the management of fossil energy consumption and $CO_2$ emissions in the industry sector in Korea.

The study found out the existence of considerable feedback effect that the conventional I-O model cannot detect. Thus, we argue that the-SAM approach provides better view of the economy's flow while the e-SAM has better explanation than the I-O does in the presence of considerable feedback effects in the economy. By the-SAMe token, we can better understand how changes in the industrial activities will impact on energy use and $CO_2$ emissions in the economy as a whole if we employ the e-SAM rather than the I-O model. The e-SAM model will do better in analyzing implications of policies on energy use and $CO_2$ emissions in the economy as well.

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