Energy Input-Output Table based on Life Cycle Approach: Construction and Application

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Abstract

In this paper, we construct and apply the energy input-output table for analyzing the life cycle energy consumption and GHG emission of Korea transportation economy for year 2005. Rail and road transport are the main work of study. The analysis of input-output connecting physical and monetary unit model provides us to investigate the importance of the transport economy in the energy and GHG perspective. The results indicate that life cycle energy of the rail and road transports are 2.34 and 37.69 million ton of oil equivalent (mil.TOE) respectively. Consequently, 3.94 and 86.59 Million ton of CO_2 equivalent (Mt CO_2) of each are generated. From the results obtained, we can highlight the significant role of the rail supply chain activity of which 50% of energy is consumed and GHG emission is generated. By decomposing the forthcoming policy target to GHG reduction, we showed that not only the modal shift from road to rail transport has been the predominant driver of the minimizing in GHG emission, but also energy production technology and energy selected to run transport activity.

Keywords: Korea transport, Input-output, GHG reduction

1. Introduction

Corresponding to the crucial work of climate change prevention in the area of transportation, it is necessary for policy makers to consider the energy consumption and GHGs emissions throughout the life cycle. In fact, it is an extremely useful if a comprehensive life cycle assessment (LCA) is conducted, but this tends to be time consuming and costly. As a result, most studies and models evaluate only the use stage. In 2005, 228.6 million tons of oil equivalents (mil.TOE) were directly consumed in the South Korean economy. The energy supply sector accounted for 25% (57.7 mil.TOE) respect to the national consumption while the transport consume for 16 % or 35.56 mil.TOE. The main contributor with respect to total transportation energy consumption was road transport, accounting for 79% (28.14 mil.TOE). Marine and aviation modes of transport consumed 12% (4.1 mil.TOE) and 8% (2.82 mil.-TOE), respectively, while the rail transport accounted for only 1% (0.5 mil.TOE). Hendrickson, 2006, Although, rail tends to have lower environmental impact than road, the environmental effects of infrastructure and supply chain to accommodate such shift are substantial if capacity expansion is required In this paper, attention is paid to the relationship among transport sector, energy supply sector and industrial production sector in the energy supply-demand perspective. This is implemented within the life cycle framework when transport activity is considered as the operation stage, industrial production is the stage of raw material extraction, material preparation, manufacturing and infrastructure, and energy supply sector is the energy production stage. Input-output analysis is the only one method and database available now for calculating life cycle energy and GHG emission of transportation in a consistent and integrated way. Road and rail mode are the main work of this study because they are expected as the source and solution of the numerous problems.

The objective of this paper is to investigate (a) the energy and GHG emission of rail and road transportation activities for year 2005, (b) the effects of such changes in term of fuel mix in power generation, energy consumption by rail transport, and passenger travel pattern. For these proposes, this study first constructed energy I-O table and connecting physical and monetary unit approach is then introduced.

2. Methodology

2.1Goal and scope of study

The goal of this study is to evaluate the energy and GHG emission of Korea's rail and road transportation economic activities. The scope includes the energy production, supply chain activity and transportation activity. The economic activities of rail and road transportation of year 2005 are set as the functional unit of energy and GHG calculation.

2.2 Data source

Two primary sources are data from the energy balance of 2005 surveyed by the KEEI (Korea Energy Economics Institute) and the conventional I-O table of 2005 prepared by the BOK (Bank of Korea) in 2008.

2.3 Energy I-O table construction

In a recent section, in which the direct and indirect energy and GHG emission are computed, energy supply sector appears as a key sector. So, it is worth to separate the energy supply sector from the industrial sector forming I-O table. Therefore, two characteristics of energy I-O table are constructed. The first presents the transaction energy between the rows and columns of the energy supply sector. The column illustrates type of energy that produced by combustible fuel from the row. The second shows the transaction energy consumed by 16 sub-industries. These sixteen industries are considered as the supply chain activities delivered to satisfy a final demand of Korea's transportation economic activities. Given the importance of life cycle framework, 16 sub-industries are categorized into raw material extraction, material preparation, manufacturing and infrastructure.

2.4 Physical and monetary connecting unit model

In the framework of analysis, we developed our methodological approach from a monetary and physical data shown in table 1 and 2. The monetary data generally expressed as in table 1 derived from the conventional I-O table while the physical data come from the energy I-O table of aforementioned section.

Table 1 Monetary unit (Million KRW)

	Supply chain activity(j)	Final demand of Transportation	Total output
Supply chain activity (i)	Z	F	x
Total input	x'		

Table 2 Physical unit (Energy and fuel flow; 1000 TOE)

	Energy	Consumed by Supply chain activity	Consumed by Final demand of transportation	Total
Secondary/ Tertiary energy	E_{st}	E_a	E_T	x_{st}
Primary fuel/energy	E_p			x_p

From table 1., the term 'x' indicates the total supply chain activity 'i' required throughout the economy to execute a certain sector of transportation; 'F' corresponds to the Korean won (KRW) purchased from the economic supply chain activity 'i' consumed directly by the functional unit of the transportation; Z refers to the KRW purchased from economic supply chain activity from row consumed by the supply chain activity of column.

According to Table 2, E_{st} illustrates the amount of secondary/tertiary energy from 'i' consumed to produce energy 'j', E_a refers to the amount of energy 'i' consumed by supply chain activities 'k', E_T is the amount of energy 'i' consumed by transportation activity, E_p is the primary energy/ fuel 'i' burned to produce energy 'j', x_{st} represents the total consumption of secondary/ tertiary energy type 'i', and x_p shows the total consumption of primary energy type 'i'.

Indeed, the data given in Table 1 and 2 cannot be regarded as a causal relationship between them because of the provision of unit used. We applied a hybrid unit to connect them. In this way, we can improve and complement the view of the energy consumption and GHG emission behavior of the transportation economy throughout its life cycle.

We start our approach including the hybrid unit by forming the Leontief model in the matrix mathematically expressed in the following way:

$$\begin{pmatrix} F \\ E_T \\ 0 \end{pmatrix} = \begin{pmatrix} I - A^* & 0 & 0 \\ -C_{Ea} & I - C_{st} & 0 \\ 0 & -C_p & I \end{pmatrix} \begin{pmatrix} x \\ x_{st} \\ x_p \end{pmatrix} \quad (1)$$

Where E_T represents the transportation activity measured in energy used per year; C_{st} indicate the coefficient of the energy supply term which describes the secondary/tertiary energy input from sector i demanded by sector j per total energy output; C_p means the amount of primary energy input required to produces secondary/tertiary energy per total output secondary/tertiary energy; C_{Ea} refers to the energy intensity, which reflects the relation between the direct energy consumption per total KRW output of the supply chain activity in the economy.

The output of the economy is identical to the main model of the Leontief shown in Equation (2).

$$x = (I - A^*)^{-1} \quad (2)$$

The output of the primary energy and secondary/ tertiary energy are given by

$$x_{st} = (I - C_{st})^{-1} C_{Ea} (I - A^*)^{-1} F + (I - C_{st})^{-1} E_T \quad (3)$$

$$x_p = C_p (I - C_{st})^{-1} C_{Ea} (I - A^*)^{-1} F + C_p (I - C_{st})^{-1} E_T \quad (4)$$

Where $C_{Ea}(I\text{-}A^*)^{-1}F$ is the amount of energy consumed by supply chain activity; $C_p(I\text{-}C_{st})^{-1}$ is the energy production activity delivered to E_T and $C_{Ea}(I\text{-}A^*)^{-1}F$. Note here that this E_T term can refer to the multiplication of volume activity and energy intensity which are the factor used to decompose CO_2 emission in transportation sector mentioned by OCED. In order to have a clear understanding, below equation shows their relationship.

$$E_T = AI \quad (5)$$

When A is the volume of transportation indicted in passenger-kilometer travel (PKT) or tone-kilometer travel; and I define as the energy intensity presents in energy use per PKT or tkm.
Referring our model, analyzing changes in transport energy consumption can be decomposed into the changes of final demand termed transport activity, as well as the coefficient technology changes in term of energy production activity and supply chain activity.
By evaluating the GHG emission effect from the above equation, the formula for total transport GHG emission is easily explained in matrix as follow:

GHG emission = CB (6)

Here, B refers to the matrix of x_{st} and x_p, and C is the matrix of CO_2 emission factor of fuel used. The factor used for calculation mainly come from the IPCC report, exception of CO_2 factor for nuclear and renewable energy in which comes from the Ministry of Knowledge Economy, 2009.

3. Application and Results

3.1 Energy and GHG analysis

Using the energy I-O table couple with the proposed model, the life cycle energy consumption and GHG emission or rail and road transport are calculated and shown in Table 3.

Table 3 Energy direct and indirect consumption of rail and road transport

Life cycle stage		Unit	Rail transport		Road transport	
			Energy direct consumption	Energy indirect consumption	Energy direct consumption	Energy indirect consumption
Raw material extraction		1000 TOE	0.79	1.59	4.06	8.18
Material preparation	Petrochemical product		120.17	30.17	778.06	195.35
	Non-metallic metal		49.82	29.67	244.63	145.70
	Basic metal		48.32	23.27	248.13	119.70
	Textile, wood and pulp		89.30	139.58	475.03	742.37
	Fabricated metal		49.01	122.01	244.96	609.77
Manufacturing			85.13	19.40	437.24	99.64
Infrastructure			248.70	34.29	1,134.31	156.37
Operation			505	741.99	28,129.74	3,917.07
Total		1000 TOE	1,196.25	1,141.96	31,696.17	5,994.15
			2,338.21 (1,833.21*)		37,690.32	
Total CO_2 emission		Mt CO_2 equiv.	3.94		86.59	

* this number subtracted from the direct electricity used.

As the energy consumption of the rail transport activity (operation stage) is 0.5 million TOE, the energy consumption of supply chain activity and energy production activity are 0.65 and 1.08 million TOE, respectively. This result clearly shows that there is significant amount of energy consumption from the rail transport's supply chain and energy production activity. Base on the evaluation, GHG emissions of the whole life cycle rail transport is 3.94 million ton CO_2 equivalents (Mt CO_2). By looking into each stage of life cycle, the energy analysis shows that infrastructure in which accommodates rail transport activity has the highest contribution. For the road transport, the energy consumption of road transport activity is 28.13 million TOE. The energy consumption of road's supply chain activity and energy production activity are 3.57 and 5.99 million TOE, respectively. Of the total energy use by the road transport, the operation stage contributes approximately 75% of total energy used, and 25% comes from the supply chain activity and energy production activity. The GHG emission from the whole life cycle of road transport is 86.59 Mt CO_2. These results reveal that the evaluation of the life cycle is better than consideration of only the operation stage. Moreover, the indirect energy obtained from the energy supply sector activity also plays a critical role.

3.2 Greenhouse gas reduction scenario

To estimate changes in transport energy and GHG emission in Korea economy, this paper decomposed the changes into the forthcoming directions target to GHG reduction by Korea policy. This paper also evaluated the effect of energy and GHG based without failing to serve demand for transportation service in a base year evaluation. A shift toward to less energy consumption and GHG emissions of transportation economy can be made by three levels which are government level, industrial level and society level. The definition and condition of each is explained in the sequent section of model shift application. The introduction of shift can then be evaluated. To do so, the effected coefficient or final demand term of the physical and monetary input-output table are adapted and further calculated using the connecting unit model.

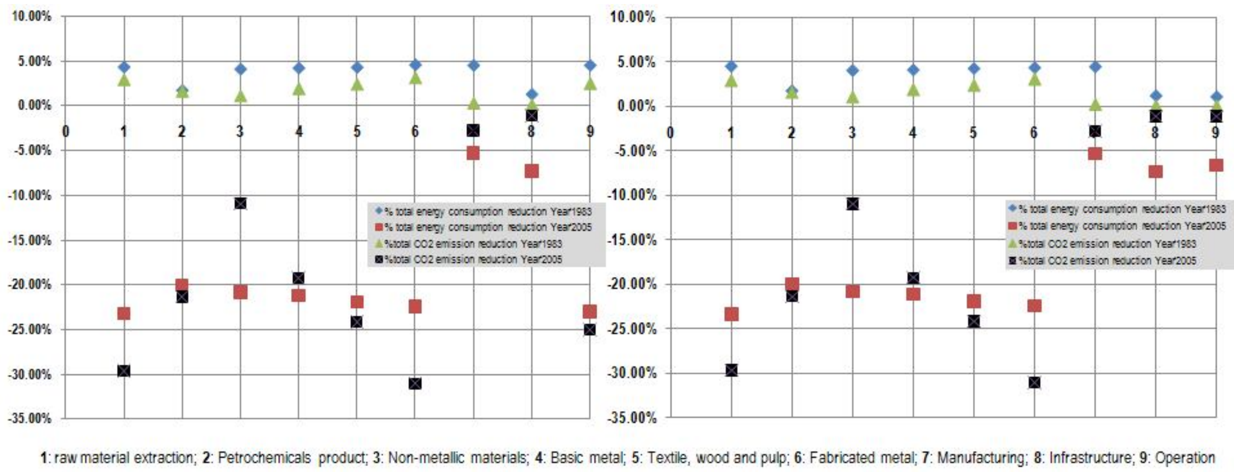
Scenario 1*:* Energy production's technology change

The first scenario is classified as the Korean government policy level focusing on supply-oriented policy by adapting the use of non-fossil fuel to power generation. These changes effects to both coefficients C_p and C_{st} in the model. Furthermore, these changes in fuel mix results in a decrease in embodied carbon per generated electricity in the energy supply sector. To explain the effect of this scenario, the amount of energy demand of supply chain activity and transport activity maintained the same as in 2005. The data used for the energy and GHG calculation are presented in Table 4. This data come from the KEEI report published year 2008. 1983, 1990 and 2005 are selected for the calculation because it provides a clear picture of fuel change to power generation. To reflect of changes, 1990 is set for the base year of comparison. Within the framework of analysis, the comparative results are shown in Figure 1.

Table 4 Fuel mix to power generation

Fuel consumption		1983		1990		2005	
		% Ratio		% Ratio		% Ratio	
Fossil fuel	Coal	9.6	74.7	17.7	43.2	35.6	53.9
	Petroleum (Fuel oil)	65.1		16.9		4.8	
	LNG	-		8.6		13.5	
	City gas	-		-		~0	
Non-fossil fuel	Nuclear	19.4	25.3	50.7	56.8	44.5	46.1
	Renewable energy	5.9		6.1		1.6	
	Total	100	100	100		100	100

Reference: KEEI, 2008



(a) Rail transport (b) Road transport

Fig.1. Reduction of energy and GHG effects from fuel mix

From Fig.1, several findings are found. By looking into 2005 relative to 1990, material preparation stage that is the preparation of petroleum product, non-metallic materials, basic metal, including textile and pulp, of both rail and road transport meet a 20-25 percent reduction in total energy used. Likewise, the GHG emission appears a 30 percent reduction for raw material extraction and preparation of fabricated metal stage. The changes of fuel mix to power generation give a great effect to rail operation. It has been shown that 25 percent approximately of energy consumption and GHG emission reduced. A fuel mix gives few effects to road operation because the main energy used is petroleum oil product.

Scenario 2: Transportation activity shift on rail mode (Industry level)

In order to reduce amount of GHG from rail transportation, one of the possible policies reducing GHG is that changes type of energy consumption from high CO_2 embodied to low CO_2 embodied. The rail transport classifies into passenger service and freight service. Each of them is again categorized by type of fuel used. The location of service is both in city and inter-urban area. These part deals with inter urban railway because the policy target to GHG reduction subject to this area. Diesel locomotive, diesel rail car, electric locomotive and electric rail car are four subcategories differentiated by fuel type and power source. The policy projected that passenger and freight service by diesel locomotive and diesel rail car should be replaced by electric locomotive and electric rail car. There policy aims to be 30% and 80% reduction of diesel locomotive car and diesel rail car by 2014 compare to 2005. Meantime, the increment of electric locomotive and electric rail car are 70%. The Energy I-O table developed in this work is used to estimate the amount of energy required target to this plan of rail industry. This calculation is made base on one unit of railway that operates for one year. The results are compared and shown in Table 5.

The study presented that a shift in energy consumption from diesel to electricity provide change the total energy used in rail transport. As a result, the total reduction of GHG emission is 184.53 ton CO_2-equivlaent per train-year.

Table 5 Direct and indirect energy consumed by diesel oil and electricity

Energy type	Diesel consumption (TOE)			Electricity consumption (TOE)		
	Direct	Indirect	Total	Direct	Indirect	Total
Coal	0.00	5.03	5.034	0.00	232.09	232.09
Crude petroleum	0.00	33.56	33.56	0.00	2.34	2.34
Natural gas	0.00	1.72	1.72	0.00	79.70	79.70
Nuclear	0.00	5.65	5.65	0.00	262.24	262.24
Renewable	0.00	0.21	0.211	0.00	9.73	9.73
Coal product (coke oven coke)	0.00	0.00	0.00	0.00	0.00	0.00
Fuel oil	441.58	0.88	442.46	0.00	30.70	30.70
Other petroleum product(LPG)	0.00	0.88	0.88	0.00	0.06	0.06
Non-Fuel oil (Naphtha)	0.00	9.71	9.71	0.00	0.67	0.67
Gas	0.00	0.00	0.01	0.00	1.98	1.98
Heat	0.00	0.00	0	0.00	0.00	0.00
Electricity	0.00	4.86	4.86	204.00	19.95	223.95
Total	441.58	62.52	504.10	204.00	639.48	639.48*
CO_2 generation (t-CO_2 equiv.)		1,366.3			1,151.77	
CO_2 reduction per train-year (t-CO_2 equiv.)				184.53		

* For double count prevention, this number subtracted from the direct electricity used.

Scenario 3*:* Passenger travel style shifts from road public to rail public (Society level)

As stated by OECD/ITF, modal shift from road to rail, maritime transport has been adopted in several national reports as one way to reduce GHG emission caused by transport. This scenario analyses the energy and GHG emission effects of shift of passenger accuracy rate carried by road transport to rail transport. In base year 2005, road transport delivered 83,217 million passengers-kilometers, and 73,546 million passengers-kilometers were carried by railway (KEEI, 2005). 10 and 20 percent rate of occupancy representing in passenger kilometer travel are the shift scenarios. This implies that 8,321 and 16,643 million passengers-kilometers will be moved by railway. To estimate the energy and GHG effects of shifting, average fuel consumption per passenger kilometer travel including occupancy rate of urban bus and electric rail car of train are applied. This amount of shift required for 820 and 1,639 of additional rail vehicles. Compare to base year, 11.31 and 22.63% increase of final demand for the rail transport has extend to the expansion of supply chain and energy production activity. Using the energy I-O table and connecting energy-economic model, the energy consumption and GHG emission of transport activity, supply chain activity and energy supply production are recalculated and presented in Table 6.

Table 6 GHG emissions for the passenger shift scenarios

Scope of evaluation			GHG emission reduction	
Energy supply production	Supply chain activity	Transport activity	10% shift scenario	20% shift scenario
√		√	-7.15%	-12.60%
√	√	√	-5.51%	-11.27%

From Table 6, the reduction of GHG emission results from 10% and 20% shift scenarios is reported. The results indicated that the use of different scope of evaluation will yield different contribution of percent reduction. The effects of 10% and 20% shift scenarios are 7.15% and 12.60% approximately without considering the GHG emission by the supply chain activity. The reduction of GHG of each scenario is 5.51% and 11.27% approximately when supply chain activity is included.

4. Conclusion and discussion

Within the framework of construction and development, energy I-O table and input-output connecting unit model provide the predominant findings. First, energy and GHG from the energy production and supply chain activity has been a major driver of the total consumption and generation in transportation economy. Second, the framework allows the analysis of energy and GHG changes due to structural coefficient and final activity changes emerge from the forthcoming policy target to GHG reduction. The important findings reveal that promoting the shift toward less CO_2 embodied for power generation directly effect to rail transport as well as other industrial production in the economy. In addition to the shift toward less CO_2 embodied of fuel used, the rail transport is well promoted to consider implementing this new system of using electricity. The evaluation of passenger travel shift from road to rail transport should calculate the total energy consumption and GHG emission since the supply chain and energy production activity of transport system plays a significant role regarded as being the important for transport system expansion.

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