Total Energy Content and Total Greenhouse Gas Emission Factors: The Updated Thailand Input-Output Table

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Abstract

Any decision making on minimum energy content and minimum GHG emissions among different commodities is required to be made under a full energy chain terms. The total energy content and total greenhouse gas (GHG) emission factor evaluated from the energy Input-Output Analysis (IOA) approach would be useful to fill the gap of limitation on boundary as normally found in the Process Chain Analysis (PCA) approach. This study presents factors of the total values of embedded energy and embedded greenhouse gas (GHG) that required and emitted from utilization of any commodities produced by 180 Thai economic sectors. The argument on disadvantage of outdated IOA data was improved by updating sectoral energy consumption elements in the power sector which is found significant to all other sectors in the economy. The most up-to-date data, i.e. the 2000 Input-Output (I-O) table was used to represent the economic structure, and the 1998 sectoral energy consumption was used to represent individual energy consumption. Thai electric power report was referred for updating the 1998 fuel mix in the power sector to represent the 2000 and the 2005 ones. Influence of fuel mix change in the power sector is found significant to the total energy content and total GHG emission factors. The total energy content and the GHG emission factors under the 2005 electricity-fuel mix are presented.

Keywords: Input-Output Analysis, Life Cycle Analysis, Full Energy Chain Analysis, GHG Emission Factor, Energy Intensity

1. Introduction

Selecting among different products for a target of minimum energy content and minimum GHG emissions requires a full energy chain analysis (FENCH) or a life cycle analysis (LCA) that includes overall sub processes. [1] While LCA from an approach called a process chain analysis (PCA) generally confronts limitation on boundary scope, an Input-Output Analysis (IOA) gives an average values those basically evaluated from historical data.[2] The combined PCA and IOA approach could reduce boundary truncations, but disadvantages by the IOA approach in the outer boundary layer stills persist. To do the combined PCA and IOA, the factors of total energy content and total GHG emissions firstly evaluated by an energy IOA approach.

The drawback of average results could be reduced by analyzing the IOA under high disaggregated economic sector. This study presents factors of total values of embedded energy and embedded greenhouse gas (GHG) that required and emitted from utilization of any commodities produced by 180 Thai economic sectors by filling up the gap of PCA boundary by Energy IOA technique. The disadvantage of outdated IOA data was suggested to be improved by updating sectoral energy consumption elements in high energy consuming sectors in an economy.

Similar evaluation used to be presented in [3] but the results are now outdated since the economic structure and energy consumption structure are changed and the recent (year 2000) I-O table and energy I-O table (year 1998) have been issued. Another work was done by using the most recent I-O and energy I-O data [4], but the factors do not updated since the current fuel mix in Thai power sector in the year 2000 was different from 1998, and the fuel mix in year 2005 was substantially changed from the energy I-O year (1998). Updating energy consumption mix in the power sector is presented in this study due to its significance to other sectors in the economy.[3] Results from this study could be used as factors of energy intensity and GHG emissions in year 2000 and 2005.

2. Methodology

Sectoral energy consumption vector, f_{kj}, is an amount of energy type k directly consumed in sector j per total monetary output of sector j (TJ/million Baht);

$$f_{kj} = \frac{F_{kj}}{X_j} \tag{1}$$

where F_{kj} is the energy type k required as an input for sector j in a common energy unit, and X_j is the total output of sector j (in monetary unit).

When j is the power sector, fuel type k consumed by the power sector in year n;

$$F_{kj} = \frac{Electricity\ output}{\eta_{k,avg}}$$
$$F_{kj,n} = \frac{G_{k,n}.(CF)}{\eta_{k,avg,n}} \quad (2)$$

where $G_{k,n}$ is a portion of electricity generation by fuel type k (GWh), the conversion factor, CF, is aimed to convert the GWh into the common energy unit as defined in any $F_{kj,n}$, and $\eta_{k,avg,n}$ is the average country electricity generation efficiency by k fuel in year n (GWh);

$$G_{k,n} = SH_{k,n}.G_{total,n} \quad (3)$$

where $SH_{k,n}$ is the percentage of share of electricity generation by fuel type k per total electricity generation in year n, and $G_{total,n}$= Total electricity generation in year n (GWh). Substitution of eq.(3) in eq.(2) yields,

$$F_{kj,n} = \frac{SH_{k,n}.G_{total,n}.(CF)}{\eta_{k,avg,n}} \quad (4)$$

The total output of the power sector (million Baht) in year n;

$$X_{j,n} = S_n.P_n \quad (5)$$

where P_n is the electricity price in year n (Baht/kWh), and S_n is the total electricity sale in year n. By substitutions of eq.(4) and eq. (5) in eq.(1),

$$f_{kj,n} = \frac{SH_{k,n}.G_{total,n}.(CF)}{\eta_{k,avg,n}.S_n.P_n} \quad (6)$$

Since, total electricity sale in year n;

$$S_n = G_{total,n}.\eta_{gen,n}.(1-TD_{l,n}).(1-U_n)$$

where $\eta_{gen,n}$ is the total country electricity generation efficiency, $T\&D_{loss,n}$ is the percentage of electricity transmission and distribution loss, and U_n is the percentage of self-used electricity in the power sector in year n. Then

$$G_{total,n} = \frac{S_n}{\eta_{gen,n}.(1-TD_{l,n}).(1-U_n)} \quad (7)$$

By substitution of eq.(7) into eq.(6),

$$f_{kj,n} = \frac{SH_{k,n}.(CF)}{\eta_{k,avg,n}.P_n.\eta_{gen,n}.(1-TD_{l,n}).(1-U_n)} \quad (8)$$

Then the fuel mix updating factor ($M_{f,k}$) is

$$\frac{f_{kj,n}}{f_{kj,b}} = \frac{\dfrac{SH_{k,n}}{SH_{k,b}}}{\dfrac{\eta_{k,avg,n}}{\eta_{k.avg,b}}.\dfrac{P_n}{P_b}.\dfrac{\eta_{gen,n}}{\eta_{gen,b}}.\dfrac{1-TD_{l,n}}{1-TD_{l,b}}.\dfrac{1-U_n}{1-U_b}} \quad (9)$$

Each sectoral energy consumption elements of each type of fuel k consumed in the power sector in the base year (subscripted b) could now be updated to represent as the f_{kj} in year n by multiplying f_{kj} in the base year with the factor $M_{f,k}$. After updating each f_{kj} elements in the $\mathbf{F}$ matrix, computing the sectoral energy intensity matrix, $\mathbf{EI}$ and the sectoral GHG emission factors, $\mathbf{EF}$, (see ref.[4]) the results could now represent the factors of year n. The CO_2, CH_4, and N_2O were evaluated by following the method in [8], [9], and [10] and the GHG are evaluated by the GWP from [7].

3. Data and Assumptions

2000 Input-output table was used to represent the economic structure [4] and 1998 sectoral energy consumption was used to represent individual energy consumption [5]. 1998 Electric Power in Thailand [6] and 2005 Electric Power in Thailand [7] was referred for updating fuel mix in the power sector in section 4. The IPCC Third Assessment Report (2001) was applied for Global Warming Potential (GWP) where the GWP of CO_2, CH_4, and N_2O are 1, 23, and 296, respectively. [7] Updating the imported energy is not considered in this study.

Table 1 and Table 2 presents the factors required for eq.(9) based on the year 1998, the base year data and year 2000 are derived from the report of Electric Power in Thailand 2000 [6] and those of the year 2005 are derived from the report Electric Power in Thailand 2005 [7] .

Table 1. Electricity price, overall generation efficiency, T&D and self use factors

	P[4,5]	η_{gen}	1-TD_l[4,5]	1-U[4,5]
1998	2.178	37.16%	0.91	0.96
2000	2-270	37.76%	0.92	0.97
2005	2.716	39.47%	0.92	0.97

Table 2. Electricity generation shares and generation efficiency by fuel types

$\eta_{k,avg}$	SH$_k$					
Fuel type\year	1998	2000	2005	1998	2000	2005
hydro	5.96%	7.02%	4.89%	Na.	Na.	Na.
fuel oil	20.28%	11.45%	6.96%	37.35%	36.90%	37.39%
diesel oil	1.19%	0.14%	0.35%	32.59%	30.15%	49.31%
coal& lignite	18.97%	18.47%	15.47%	36.84%	38.62%	40.06%
natural gas	53.61%	62.92%	72.33%	37.32%	37.32%	39.52%
others	0.00%	0.00%	0.00%	Na.	Na.	Na.

Using the factors of electricity price, generation efficiency, transmission and distribution and own usage in the power sector (shown in Table 3.), share of electricity generation by fuel type, and generation efficiency, shown in Table 4. in eq.(9) the updating factors, the fuel mix updating factor (M_f) for the year 2000 and 2005 were found in the last column in Table 4.

Table 3. Updating factors of electricity price, generation efficiency, transmission and distribution and own usage in the power sector

$\frac{\eta_{gen,n}}{\eta_{gen,b}}$ From base year (1998) to	$\frac{P_n}{P_b}$		$\frac{1-TD_{ln}}{1-TD_{lb}}$	$\frac{1-U_n}{1-U_b}$
2000	1.04	1.02	1.01	1.00
2005	1.25	1.06	1.01	1.01

Table 4. Share of electricity generation by fuel type, generation efficiency,and updating factors Fuel mix updating factor (M_f)

Fuel type	$\frac{SH_{k,n}}{SH_{k,b}}$		$\frac{\eta_{k,avg,n}}{\eta_{k,avg,b}}$		M_f,k	
from base year (1998) to	2000	2005	2000	2005	2000	2005
hydro	1.18	0.82	1.00	1.00	***1.10***	***0.61***
fuel oil	0.56	0.34	0.99	1.00	***0.53***	***0.26***
diesel oil	0.12	0.29	0.93	1.51	***0.12***	***0.14***
Coal &lignite	0.97	0.82	1.05	1.09	***0.87***	***0.56***
natural gas	1.17	1.35	1.01	1.06	***1.08***	***0.95***
others	1.01	0.73	1.00	1.00	***0.94***	***0.55***

The updating factors of fuel share in the power sector in the Table 3 implies that the share of natural gas had been increasing, while the share of others fuels had been decreasing in the studied periods. From 1998 to 2000, fuel conversion efficiency of coal & lignite and natural gas had increased. Fuel conversion efficiencies from 1998 to 2005 of most fuel sources had been improved. The electricity price in 2005 had been increased by 25% from 1998. The factors of loss in transmission and distribution, self electricity usage are shown, more or less, better. The multiplying factors of most fuels are less than 1.00, except the one of natural gas in 2000.

Although the share of natural gas is higher, due to the higher increasing rate of electricity price made the multiplying factor of natural gas is not far from 1.00.

5. Results

After updating the fuel mix factors in the power sector, deviation in sectoral energy content and greenhouse gases emission factor of 2000 and 2005 from ones of the year 1998 are presented in Table 5. Updating the 1998 fuel mix in the power sector to the one of the year 2000 and the year 2005 reveals the averages of 1.82 %, and 5.84%, respectively, lower in energy intensity in the economic sectors. Averages of 5.12 % and 14.66 % lower in GHG emission factors are found in the year 2000 and 2005, respectively,

Energy intensity and GHG emission factors of some significant sectors in the year 2005 are shown in Figure1 and Figure 2 in terms of their direct and full energy chain values. The sectors those require the highest direct energy input are the pipeline sector, the electricity, and the petroleum refineries, respectively, which are significant energy sectors. They also contain the highest energy content in terms of their full energy chain analysis. Among these sectors, total GHG emissions in the electricity sector is highest, but in the others are not high. The reason is GHG emitted largely from the combustion process which is normally incurred directly in the electricity generation process. Although high energy content is embedded in the natural gas and petroleum product, there is no direct combustion activity in the pipeline and the petroleum refinery processes.

In selected significant energy consuming sectors, such as the tin ore, the ice, iron and steel, and wage & salary (household) sectors, the direct primary energy consumption is small, but large amount of indirect primary energy embedded in their inputs, particularly via the high energy content inputs.

The cement, railways, ocean transport, basic industrial chemicals, iron & steel, ice, tin ore, and household sectors are also the highest GHG emitting sectors. Some of them, such as the cement, transport, basic industrial chemical sectors, highly emit GHG directly in their combustion processes. Some others, such as iron & steel, ice, and household sectors indirectly largely emit GHG by consuming the high GHG content product in their processes.

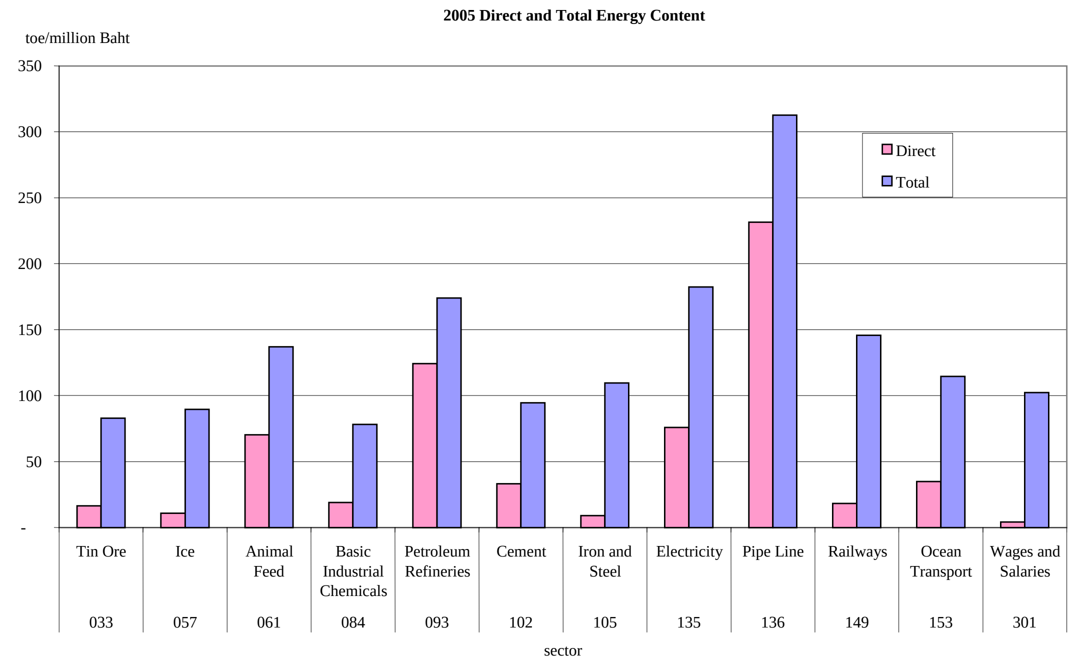

Figure 1. Energy intensity of some significant sectors in the year 2005

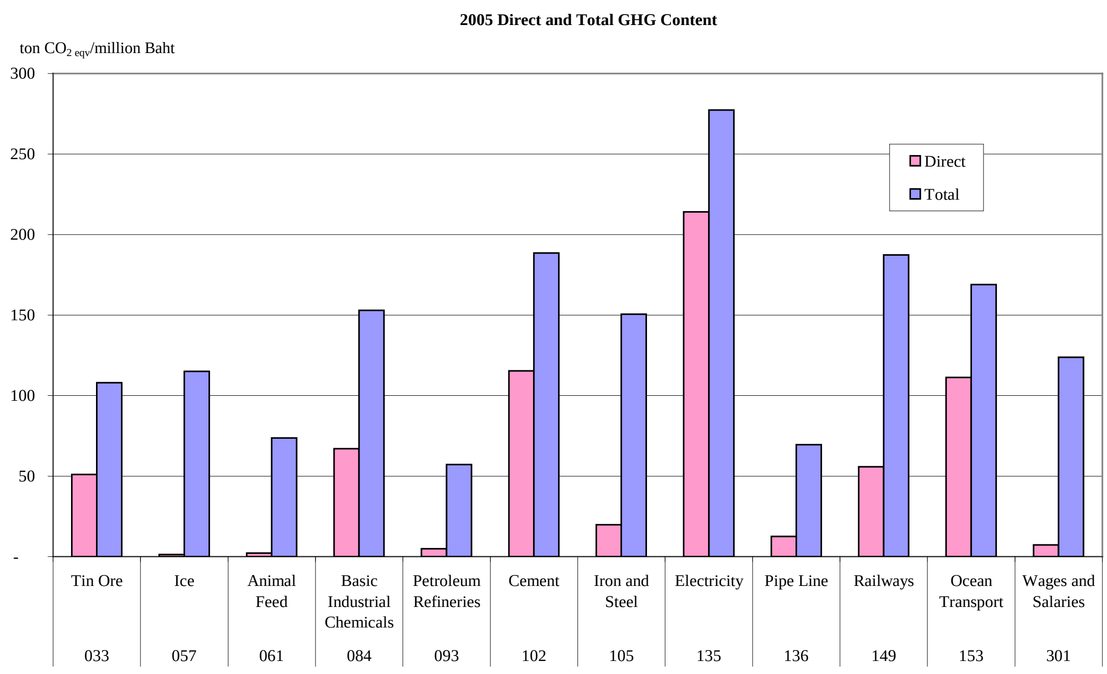

Figure 2. GHG emission factors of some significant sectors in the year 2005

In this study, there is only a direct change in fuel consumption mix in the electricity generation, and yield reduction in direct energy content by 32.5 toe/million Baht, direct CO_2 reduction by 115.85 ton/million Baht, CH_4 reduction by 0.0015 ton/million Baht, and N_2O reduction by 0.0005 ton/million Baht. The direct GHG emission could be reduced by 116.03 ton/million Baht. (shown in first row in Table 5)

In terms of full energy chain analysis, the change of fuel mix for electricity generation does not only impact the energy content and GHG emissions in the electricity product itself, but also indirectly impact to other sector those are producers of various product and services in the economy. In the electricity product itself, the total energy content of was reduced by 36.19 toe/million Baht, the total CO_2 reduced by 128.99 ton/million Baht, the total CH_4 reduced by 0.0033 ton/million Baht, the total N_2O

reduced by 0.0011 ton/million Baht, and the total GHG emission could be reduced by 129.83 ton/million Baht. (shown in the third row in Table 5)

Table 5. Changing EI and GHG emission factors
Unit: ton /million Baht *Unit: toe/million Baht

Increase values	EI*	CO_2	CH_4	N_2O	GHG
Direct					
Electricity	(32.50)	(115.85)	(0.0015)	(0.0005)	(116.03)
Other sectors	0	0	0	0	0
Total					
Electricity	(36.19)	(128.99)	(0.0033)	(0.0011)	(129.38)
Pipeline	(2.07)	(7.37)	(0.0001)	(0.0000)	(7.38)
Petroleum Refinery	(1.98)	(7.06)	(0.0001)	(0.0000)	(7.07)
Ice	(11.93)	(42.51)	(0.0005)	(0.0002)	(42.58)
Animal Feed	(3.28)	(11.68)	(0.0002)	(0.0000)	(11.69)
Household	(6.90)	(24.61)	(0.0003)	(0.0001)	(24.65)

Table 6. presents the percentage of change in the energy intensity (EI) and GHG's averagely, maximum, minimum, and in some significant sectors. Impact of fuel mix change in electricity generation as defined in this study causes 1.82 % reduction in EI, and 5.12 % reduction in GHG emission factor. Large different The maximum and the minimum values. The level of the indirect impact of change in the electricity generation to any other sector depends on the level of electricity demand within the production process of that sector. The level of the impact from a fuel structural change in a sector in the economy depends on the portion of electricity required as its input.

Table 6. Increasing in sectoral energy content and greenhouse gases emission factor by updating the 1998 fuel mix

	year 2000					Year 2005				
	EI *2000ud	CO_2	CH_4	N_2O	GHG2000ud	EI *2005ud	CO_2	CH_4	N_2O	GHG2005ud
average	-1.82%	-5.14%	3.90%	-1.46%	-5.12%	-5.84%	-14.71%	-7.61%	-4.79%	-14.66%
max	-0.21%	-1.89%	4.91%	-0.14%	-1.89%	-0.66%	-5.41%	-3.90%	-0.45%	-5.41%
min	-5.18%	-11.14%	2.00%	-9.24%	-11.10%	-16.56%	-31.86%	-9.58%	-30.40%	-31.81%
Tin Ore	-1.24%	-3.66%	3.55%	-0.14%	-3.56%	-3.98%	-10.46%	-6.94%	-0.45%	-10.19%
Ice	-3.68%	-9.46%	4.71%	-4.38%	-9.43%	-11.75%	-27.05%	-9.20%	-14.42%	-27.01%
Animal Feed	-0.73%	-4.80%	3.75%	-1.75%	-4.78%	-2.34%	-13.72%	-7.32%	-5.76%	-13.69%
Basic Industrial Chemicals	-1.39%	-2.73%	2.81%	-1.26%	-2.72%	-4.44%	-7.81%	-5.48%	-4.13%	-7.80%
Petroleum Refineries	-0.35%	-3.84%	3.80%	-1.94%	-3.84%	-1.13%	-11.00%	-7.42%	-6.37%	-10.99%
Cement	-1.94%	-3.71%	3.69%	-1.34%	-3.70%	-6.20%	-10.60%	-7.20%	-4.41%	-10.58%
Iron and Steel	-2.52%	-6.50%	3.63%	-1.22%	-6.47%	-8.05%	-18.60%	-7.09%	-4.03%	-18.51%
Electricity	-5.18%	-11.14%	4.91%	-9.24%	-11.10%	-16.56%	-31.86%	-9.58%	-30.40%	-31.81%
Pipe Line	-0.21%	-3.36%	2.00%	-1.84%	-3.35%	-0.66%	-9.61%	-3.90%	-6.07%	-9.60%
Railways	-1.47%	-4.21%	4.13%	-1.60%	-4.20%	-4.69%	-12.05%	-8.07%	-5.25%	-12.03%
Ocean Transport	-0.75%	-1.97%	4.08%	-1.52%	-1.96%	-2.40%	-5.62%	-7.96%	-5.00%	-5.62%
Wages&Salaries	-1.98%	-5.82%	4.22%	-1.82%	-5.80%	-6.32%	-16.64%	-8.24%	-5.97%	-16.60%

5. Conclusion

The sector that has the highest energy content and GHG emission factors is the electricity sector. Therefore, in some sectors that require a large amount of electricity as their input, they indirectly contains high energy content and high GHG emission factor. Consuming the petroleum products implies an intake of high energy content. Although these sectors are not the highest GHG emitters, but the other sectors consuming their products for combustion in their process will be embedded by high energy amount and GHG emissions. Products and services produced from Thai economy, some of them directly emit GHG in their combustion processes, the others indirectly emit GHG by consuming the high GHG content product or services. A sector that consumes a high GHG content product or a high energy content would consequently makes itself a rather high total energy content or high total GHG emission factor. Fuel structure in Thai power sector annually is changed, and significant to assessment of the total energy content and GHG emission factors.

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