Asian J. Energy Environ., Vol. 9, Issue 3 and 4, (2008), pp. 177-196

An Input–output Analysis of Total Requirements of Energy and Greenhouse Gases for all Industrial Sectors in Thailand

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Abstract: The aim of this study is to estimate the amount of CO_2—the most important greenhouse gas emission, for the Thailand economy. An input–output model based on energy and economic data is constructed in order to identify the sources of CO_2 emissions and to discuss the share of sectors in total emission. Thus, the empirical application is for Thailand, the energy and economic data are for the year 1998 and 2000 respectively. National balances of primary energy consumption are presented as well as the sectoral primary energy intensities and emission intensities in terms of TJ/M Baht and t-CO_2–e /Baht. Finally, the sectoral primary energy intensities and emission intensities are compared and sectors with the highest emissions identified. The results show that the highest energy intensive sectors are the Petroleum Refinery & Gas Separation Plant sector, the Road Freight Transport sector, the Electricity sector and the Cement sector; but the highest total GHG emitters are the

Electricity sector, Ocean Transport sector and the Cement sector respectively. It is observed that activities in these sectors depend primarily on fossil fuels which are combusted. The results of the study as well as the conclusions are used to formulate environmental policy recommendations such as the increased utilization of renewable energy technology, to achieve a reduction of the high sectoral energy as well as emissions intensities.

Keywords: Emissions, Energy Intensity, Input–output Analysis, Thailand.

1. INTRODUCTION

In a modern world, energy is an essential input to every production, transport, and communication process and is thus a driver for economic as well as social development [1]. Thailand is no different from other nations as her energy consumption has continued to grow steadily; with more than 60% of the energy consumed (in the form of electricity) being generated from fossil fuels. In 2001, the country's energy consumption was 2.90 quadrillion BTU (quads), nearly six times that of over 20 years ago when Thailand consumed barely over 0.5 quads. [2,3]. Thailand's energy intensity (the energy consumption per GDP) is increasing and projections indicate that at an economic growth rate of 5% per year, by 2017, it's energy consumption will increase from 0.78 trillion Baht to 2.1 trillion Baht with a corresponding increase in dependency on imported energy. This increasing consumption of energy is also expected to result in greater environmental burdens to the environment. It is therefore necessary to quantify the energy as well as emission intensities coming from the various economic sectors in order to identify sectors where significant energy savings can be made for the economy and also simultaneously achieve reductions in the environmental burdens. This study used an input–output model based on energy as well as economic data of Thailand to identify the sources of GHG emissions, estimate their amounts and also discuss their share of economic sectors in total emissions.

2. METHODOLOGY

2.1 Input-output analysis (IOA)

Input-output analysis was introduced by Wassily Leontief in 1973 and since then has become a powerful tool for economic planning. Input-output analysis is based on input-output tables which are useful tools for the projection of emissions, or analysis of emission structure, and economic planning [4]. Input-output tables present economic exchanges of goods and services among industrial sectors in matrix form. Most of the tables actually available are specified in monetary units. For example, energy and resource flows among industries can be analyzed on the assumption that goods are transferred in direct proportion to their monetary value. Methods for calculating the energy that is consumed to produce a final product, including indirect consumption by upstream industries such as the component and material industries, are known as energy analyses [5-8]. Input-output tables have been frequently applied to analyses of environmental issues. Liang et al. developed a multi-regional input–

output model for regional energy requirements and used it to estimate CO_2 emissions in China [9]. Another study assessed the "Life cycle GHG emission analysis of power generation systems in the Japanese context" [10]. The embodied carbon emissions from the material content have also been estimated using the Japanese Input-Output Table [11]. Researchers in other nations have also carried out similar studies for their national economies [12-19]. However, only one such similar study in which the "Embedded energy and total greenhouse gas emissions in final consumptions within Thailand" was assessed exists for Thailand [20]. The study only evaluated emission of CO_2, CH_4 and N_2O. This paper in addition to these also assesses CO emissions. In this study, Thailand's air pollutant emissions, energy consumption, and CO_2 emissions are estimated in detail by the approximately 180 sectors classified by the Thailand input-output tables (NESDB) (hereafter, the Input-Output Tables) [21], and the contribution of each sector to the total amount is analyzed. The causes of these environmental burdens as they relate to economic demand in Thailand were analyzed by using the Input-Output Tables (IOT) to calculate the total environmental burdens of each sector; in other words, the energy consumption and emissions induced by economic final demand of each sector.

The main limitation of the IOA is that all products are identified as an average product of the covering sector. A sector, however, contains many products for which the ratio price/energy-input is not necessarily the same. Another limitation is that the number of sectors is too limited. In the Thailand IOT, 180 sectors were included, however, these are not adequate enough to analyze certain materials as for some items it is not entirely clear which sector they belong to. Expansion of the number of relevant sectors would provide more accurate results. Unfortunately, the complexity of the problem would increase with an increasing number of sectors [22]. However, despite its limitations, with the aid of the input–output analysis method, it is possible to project output requirements that must be met by any sector of an economy given a change in output in the energy sector of the economy [4,5]. Additionally, the framework is appropriate to provide policy makers with information that enables the definition of policies aimed at changing the pattern of such impacts with the objectives of improving sustainability.

2.2 Framework of I-O analysis

The basic requirement of the input-output system is the ‘transactions table’, which is essentially an extended version of the ‘national accounts’, in which inter industry transactions (i.e., flows of goods and services between industries) are included, along with final demand transactions. The basic concepts of input-output analysis were discussed in detail by Miller et al. [4], and have been extended to incorporate pollution that results from economic activity since the late 1960s, and numerous studies have been conducted based on the different extensions [4-6,18]. In order to determine the emissions resulting from any economy, the energy input-output analysis method is utilized. Direct emissions are derived by the physical amount of each type of fossil energy that is directly combusted within the sector. The matrix of total energy content is

$$f = [F]\,[I - A]^{-1}, \qquad (2.1)$$

A is a square n x n matrix representing the inter-industrial transaction of n industries within the economy (transaction matrix). I is a unity matrix. The matrix F has a dimension of $k \times n$ where k is the number of fuel types. Each element of the sectoral energy consumption matrix ($F_{k\,I}$) is the direct consumption of fuel k in a physical unit by the monetary output of the economic sector i. The energy I-O model can be used for determining the fossil fuel or energy intensity for the production of goods and services based on a modified I-O model to account for Imports of goods and services [4] as shown in equation (2.2).

$$f^{*} = [F]\,[I - A^{d} - M]^{-1}, \qquad (2.2)$$

Equation (2.2) represents the total energy content including effect of import commodities to the economy. $(I - A^{d} - M)^{-1}$ represents the domestic purchase matrix. Imports of commodities, represented by the import matrix M, that are required by local industry, are introduced into the Eq. (2.1). Each element, M_{ij}, is the monetary amount of imports supplied from the foreign industry i to the domestic industry j per total monetary-domestic industry output of j. This modification is based on the assumption that the rest of the world would have the same total energy intensities for 'equivalent' commodities as the economy of the country being studied. This is because the fossil fuels consumed by the rest of the world is not known, and calculating it would require global I-O tables and fuel consumption data and it is better to make this assumption than to than assigning zero emissions release to imports [6]. The energy intensity (EI) is the multiplication of the transpose of the vector of conversion factor obtained from government agency [22] and the total energy content *f* i.e.

$$EI^T = [\text{ conversion factor }_{fx1}]^T \text{ x } [f_{f \times n}], \qquad (2.3)$$

Each element of the energy intensity EI_i (i = 1,…..,n) represents the energy intensity of sector i in the economy and the assumption is made that there is no disparity between different products from the same sector. The sectoral emissions were computed by applying the IPCC guidelines for emissions estimation. Thus, multiplying each element of F with the IPCC emission factors for estimation of CO_2 emission from combustion yields a matrix of sectoral CO_2 emission, C, with elements of

$$C_{ki} = F_{ki} \text{ x } CF_k \text{ x carbon emission factor}_k \text{ x fraction of carbon oxidized}_k \text{ x } (44/12), \qquad (2.4)$$

and, CF = conversion factor

Carbon and non-carbon emission factors for different fuel types (k) as well as activity type were obtained from government and international sources [22,23] and a vector of total sectoral CO_2 emission factors that includes infinite propagation of production chains of domestic or import commodities occurring in any economic sector computed with equation 2.5.

$$c = [C]\,[I- A- M]^{-1}, \qquad (2.5)$$

As emission factor for non-CO_2 emissions does not rely only on fuel type, but also activities, each economic sector is assumed to be equal in activities. Thus a matrix of sectoral non-emissions, C, has elements of

$$C_{ki} = F_{ki} \times CF_{ki} , \qquad (2.6)$$

Consequently, the total CO_2 and non-CO_2 emissions, from combustion activity are

$$c_{CO2} = d_{CO2} \, [I - A^d - M]^{-1}, \qquad (2.7)$$

$$c_{non\text{-}CO2} = d_{non\text{-}CO2} \, [I - A^d - M]^{-1}, \qquad (2.8)$$

Generally, fuel is combusted in a sector, but sometimes it is also used in some particular processes for feedstock beyond the combustion to produce other goods and services. Therefore to avoid over estimation of GHGs by using the matrix F, the matrix *e* in a vector, containing e_{ki} elements as 1 for any fuel that is used for combustion and as 0 for fuel used as feedstock in sector *i*, was introduced [7,19]. The overestimation of GHG emissions was minimized by introducing multiplier elements e_{ki} on every F_{ki} element such that,

$$F^*_{ki} = F_{ki} \cdot e_{ki} , \qquad (2.9)$$

The elements of matrix F were adjusted by Eq. (2.9), then each element of F_{ki} in Eq. (2.4) was substituted with F^*_{ki} .Direct GHG emissions from non-combustion activities were constructed as a vector i.e. d'. The amount of fugitive emissions from domestic fossil fuel productions of solid, liquid and gaseous fuels have been evaluated and since research on the locality of study was not available; therefore, estimation of fugitive emissions by the global average method was applied as suggested elsewhere [23] and GHG emissions from industrial process assumed equal to the same amount as reported in 'the industrial process sector'. Considering the propagation of non-combustion activities in all sub process chains, the total non-combustion emission of each GHG is $d'[I - A - M]^{-1}$. Consequently, the total CO_2 emission is

$$c_{CO2} = d_{CO2} [I - A^d - M]^{-1} + d'_{CO2}[I - A^d - M]^{-1}, \qquad (2.10)$$

Similarly, the total of non-CO_2 emissions are derived by

$$c_{non\text{-}CO2} = d_{non\text{-}CO2} [I - A^d - M]^{-1} + d'_{non\text{-}CO2} [I - A^d - M]^{-1}, \qquad (2.11)$$

Finally the sectoral amounts of carbon dioxide were computed by applying the Global Warming Potentials (GWPs) for all the GHGs considered as obtained from literature [22,23].

2.3 Data and data transformations

All the data utilized for this study were obtained from Thailand government databases [22-24] .The data were used to develop the Input–Output (I/O) structure of the Thai economy. Thailand I–O tables, available in four formats, i.e. 16 x 16, 26 x 26, 58 x 58, and 180 x 180 sectors, are published by the government. In order to assign each sector and represent an average commodity produced from its own sector most efficiently, the 180 x 180 I–O table was selected for this analysis. Both the economic input-output transactions matrices as well as energy input-output matrices for the years 2000 and 1998 respectively were utilized. Each element of the provided 'new purchasing price' of the 180 x 180 I–O table is the sum of the 'wholesale trade margin', the 'retail trade margin', the 'transportation' and the 'import'. Therefore the elements of the 'domestic purchase' were obtained by subtracting the 'wholesale trade margin' the 'retail trade margin', the 'transportation' and the 'import'. Additionally, the 'import' element was utilized to separately construct the 'import' structural matrix.

The energy input-output table obtained gave sectoral consumptions in various physical units according to fuel type. These were converted into Terajoules using the conversion factors for the different fuels obtained from the Department of Alternative Energy Development (DEDE) [22]. Energy and emission intensities are calculated using both the economic and energy input-output tables for the years 2000 and 1998 using the methodology outlined. However, because both tables were from different years (1998 and 2000 respectively), they had to be updated because since that period transformations both at the economic and energetic levels had occurred. Both the Gross Domestic Product (GDP) and the inflation have increased, also, it is expected that energetically, the efficiency of industry has improved. This means that for the year of reference of this paper (2000), less energy is required to produce the same output as in 1998. Consequently, both factors were considered by looking at the relative change in the energy-intensity (energy use/GDP) from 1998 to 2000.

3. RESULTS AND DISCUSSION

3.1 Energy intensities and GHG emission

The energy intensity has been defined as the energy consumption in Terajoules (TJ) per million Baht of output. Energy intensities for the leading ten sectors for final consumptions in 2000 are presented in Table 1.

Table 1. Top 10 sectors from total energy intensity.

No.	Sector Name	TJ/ M Baht	%
(1)	Petroleum Refinery & Gas Separation Plant	8.43	6.39
(2)	Road Freight Transport	3.10	2.35
(3)	Electricity	2.98	2.26
(4)	Cement	2.64	2.00
(5)	Ocean Transport	2.43	1.84
(6)	Coastal & Inland Water Transport	2.11	1.60
(7)	Route & Non route of Road Passenger Transport	2.05	1.55
(8)	Basic Chemicals	1.88	1.43
(9)	Agricultural Services	1.87	1.42
(10)	Iron and Steel	1.80	1.37

Examination of Table 1 shows that the Petroleum Refinery & Gas Separation Plant has highest total energy intensity as compared to the other economic sectors. This is because products from this sector are utilized not only in the power and electricity generation sector of Thailand but also in 156 industrial sectors of the economy. This trend is expected to continue with projections estimating most of Thailand’s economy to be driven by increased natural gas consumption as the percentage of Natural Gas utilized for electricity generation has increased from 57.6% in 1999 to 76% in 2006 [24]. Petroleum Refinery & Gas Separation Plant is followed by Road Freight Transport. The Road Freight Transport sector uses a combination of different fuel types namely, Pre-Gasoline, Reg-Gasoline, LPG, High Speed Diesel and Low Speed Diesel. These are combusted in engines to generate energy required for motion and traction. This explains such high energy intensity for Road Freight Transport. The Electricity sector comes next followed closely by the Cement sector. Electricity is generated mainly from the combustion of fuels like Natural gas, coal and lignite, fuel oil, diesel, and also biomass in power plants. Cement manufacturing process uses chalk and clay, mixed thoroughly and burnt to the point of fusion using huge amounts of diverse energy types ranging from charcoal, coal, lignite, gasoline, kerosene, diesel, natural gas as well as fuel oil. This explains the high energy intensity for cement. Next is the Ocean Transport, the Coastal & Inland Water Transport and the Route & Non route of Road Passenger Transport sectors. Imports into Thailand are mainly by sea and this has increased over the years [22,24]. These sectors also depend heavily on fossil fuels for their operations. The energy intensity of the Iron and Steel sector is also high and ranks amongst the top ten.

The characteristics of GHG emissions in terms the top ten sectors with the most environmental burdens are summarized in Table 2. Total GHG (CO_2) emissions in this study were estimated to be 5248 t-C eq /MBaht (see Table 2). Although this result by far exceeds that of similar studies, 1002 t- C eq /MBaht calculated by Hondo et al. and the 1077 t-C C eq /MBaht calculated by Asakura et al. and also

1029 t- C eq /MBaht calculated by Nansai et al. as stated in Nansai et al. [25], the results cannot be said to be comparable as they are for different economies and the dynamics (technologies, policies etc) which drive these economies are different. However, comparison of the total GHG (CO_2) emissions obtained from this study with those of a similar study on Thailand by Limmechokchai et al [20] revealed that the Total GHG emission intensities obtained in this study is much lower than obtained in the previous study (7713 t-C / MBaht). This could be attributed to changes in technologies and improvement in end-use efficiencies due to the energy conservation and energy efficiency programs of the government which might have occurred in the period between which these separate studies were conducted. Further examination of the results obtained in this study showed that the proportion of CO_2 emissions by sector was similar to that of energy consumption.

Table 2. Top 10 sectors from environmental burdens view point.

No.	Sector	t- CO_2-eq / MBaht	%
1	Electricity	386.831	7.37
2	Ocean Transport	305.822	5.83
3	Cement	283.087	5.39
4	Coastal & Inland Water Transport	224.140	4.27
5	Road Freight Transport	220.490	4.20
6	Fluorite Ore	186.996	3.56
7	Railways	171.224	3.26
8	Ocean And Coastal Fishing	167.636	3.19
9	Agricultural Services	163.762	3.12
10	Distilling & Blending of Spirit	156.004	2.97
Total		5248.254	100

The top ten sectors together, represent about 43% of the total GHG emissions obtained. It is interesting to note that the Electricity sector accounted for 7.4% of total CO_2 emissions, despite accounting for only 2.26% total energy consumption. These values and scenarios are similar to those obtained in a similar study by Nansai et al. [25] in which Electricity has the largest percentage of total CO_2 emissions and is also one of the most energy intensive sectors. Similar results were obtained from [20] where the Electricity sector accounted for 7.4% of total CO_2 emissions, despite accounting for only 2.26% total energy consumption. The electricity sector has the highest emissions of all sectors because about 76% of its energy requirement for electricity production is from Natural Gas. However, the high emissions intensity could be attributed also to its indirect energy requirements which are mostly fossil fuels, and these are usually combusted. The high emissions of the other top ten emitters can also be largely attributed to emissions from the type of fuels used in these sectors which are mostly a combination of fossil fuels usually combusted as well as the production processes. It was also observed that for most of the top ten energy intensive sectors, CO_2 contributed more than 95% of the total GHGs except for the Iron and Steel, and the Route & Non route of Road Passenger Transport sectors which had percentage CO_2 contributions of 70.5% and 81.7% respectively. Table 3 compares the results obtained with those of Limmechokchai et al. [20] according to the sectoral classification system defined by the National Economic and Social Development Board of Thailand (NESDB) as well as the Energy Information Agency (EIA) [22,24,26].

Table 3 indicates that whilst there has been an increase in energy intensities of all sectors, the total CO_2 sectoral emissions has reduced for only two sectors: the commercial and the industrial sectors. These sectoral emission changes indicate that there might have been some changes in energy consumption pattern of these sectors. Also other factors like lower capacity utilization, fuel switching, etc., might also have also affected the ranking as indicated in Table 3 which clearly shows that although there has been an increase in the energy intensities of different sectors, changes in technologies, fuels, and improvement in end-use efficiencies due to the energy conservation and energy efficiency programs of the government might have contributed to the reductions in the total amount of GHG emissions as observed.

Table 3. Comparison of energy and emission intensities (sectoral classification system).

	Energy intensity (TJ/ M Baht)		GHG emission Intensity (t- CO_2-eq / MBaht)	
Sector	a	b	a	b
Agriculture	13.08	10.27	549.65	518.01
Industry	78.39	76.81	2729.67	5405.23
Transportation	13.06	8.84	1147.34	636.83
Commercial sector	11.7988	10.88	289.67	676.97
Energy sector	15.4790	7.00	531.93	475.91
Total	131.81	113.80	5248.25	7712.95

Source: [a] This study; [b][20]

4. CONCLUSION

In this paper the energy and greenhouse gas flows in Thailand's economy were computed by using the 180 x 180 input-output transaction tables for the year 2000. As indicated by the results obtained, most of the greenhouse gases attributable to Thailand originate from the demand for electricity, generated from a combination of fossil fuels, by almost all sectors of the economy. These data can be utilized to choose key sectors for which policy measures and new technologies which should be introduced to reduce the environmental burdens. Also, these data indicate the amount of total emissions induced by unit production activity (10^6 Baht units); consequently, the embodied intensity *can* be used as inventory data in Life cycle Assessment (LCA), as it enables a clear definition of the system boundary of the life cycle. The embodied intensities obtained in this study will enable LCA to be carried from the viewpoint of both global warming potential and air pollution and are being applied to the LCA of commercial buildings in Thailand. The results of this work show that both the industrial and transportation sectors of Thailand's economy are still the most energy intensive sectors. The results of the comparison between this study and a similar one showed that the total energy intensity of the Thai economy has reduced. This is an important result and points to fact that the diverse energy efficiency programs both for designated factories and large commercial buildings introduced by the government of Thailand is achieving the desired effect. Emission inventories based on Input-Output Tables can not only demonstrate the structure of energy consumption and emissions, but also provide useful information for other environmental studies such as Life Cycle Assessment (LCA) which is commonly utilized to evaluate the environmental burdens of a product, or service. Therefore, it is possible to apply the embodied intensities which are calculated here for the structural analysis of the induced energy consumption and emissions to the life cycle inventory data in an LCA [27-31].

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