Decomposition Analysis of Changes in Energy Intensity of the Thai Manufacturing Sector during 1991-2013

P. Boonkham and N. Leeprechanon

***Abstract*—This paper analyzes changes in energy intensity in the manufacturing sector in Thailand during 1991-2013, using the logarithmic mean Divisia index in multiplicative form. Results show that energy intensity in the manufacturing sector improved during this 22-year period, especially in the food & beverage, chemical, and unclassified sub-sectors; sub-sectors that did not show improvements were the fabricated metal, wood & furniture, textile, paper, non-metallic metal, and basic metal sub-sectors. Computational results show that energy consumption in the manufacturing sector increased significantly during 1991-2013 mainly on account of production effects, but that structural effects and intensity effects contributed only marginally to changes in energy consumption. The findings imply the need to balance restructuring policies within the manufacturing sector with efforts to reduce energy intensity, so as to attain sustainable economic development and improvements in energy efficiency, in accordance with Thailand's long-term energy efficiency goals.**

***Index Terms*—Energy intensity, decomposition analysis, logarithmic mean Divisia index.**

I. Introduction

The manufacturing industry in Thailand has played an important role in spurring the rapid development of the Thai economy, as well as contributing to rapid urbanization and industrial development. Thailand is a large exporter of industrial products, with the manufacturing industry accounting for 29% of total exports. Thai manufacturers play a major role in the Asian market; however, Thai manufacturing lacks a competitive edge in many areas, especially in the area of high-technology products. Thailand has also been a major importer of high-value-added products, including food and beverages, chemicals, and textiles.

The manufacturing industry accounts for ca. 36% of Thailand's total industrial energy consumption. Moreover, industrial energy efficiency, especially in the manufacturing sector, has greatly improved in Thailand since early 1991. To analyze and understand historical changes in energy consumption and related economic and environmental factors, it is useful to separately identify the elements behind these changes. Index decomposition analysis (IDA) is a technique that has been developed to identify the factors causing changes at the sector level. Methodologically, the underlying technique is linked to the index number problem in economics and statistics. However, it has been widely used to analyze changes in energy consumption and energy-related carbon emissions. Ang and Choi [1] reviewed two well-known index decomposition analysis techniques: the Laspeyres index and the Divisia index. Some studies based on Laspeyres decomposition analysis have analyzed energy consumption and energy intensity [2], [3] others have used Divisia decomposition analysis to analyze changes in energy consumption and carbon emissions in terms of explanatory factors [4]-[6]. In this paper, we focus on analyzing changes at the manufacturing sector level. Many countries have studied effects of changes in energy consumption and energy intensity on the manufacturing sector, as the energy use by this sector is large. For example, studies of the manufacturing industry have been conducted in Korea by Choi and Oh [7]. In Holland by Groot and Mulder [8]. In China by Hasanbeigi [9]. In Japan by Ke [10]. In California by Stephane [11]. In Jordon by Al-Ghandoor [12]. In Portugal by Margarita and Victor [13]. In Taiwan by Shrestha *et al*. [14]. , and in India by Reddy and Ray [15]. After reviewing the literature, we found that research on changes in energy consumption and energy intensity in the manufacturing sector have most often been based on decomposition analysis techniques. However, there is no consensus among researchers as to which decomposition method is best. Ang [16] compared various IDA methods, and concluded that the multiplicative form of the logarithmic mean Divisia index (LMDI) is the preferred method of IDA, on account of its strong theoretical foundation, adaptability, ease of use, perfect decomposition capacity, and high efficiency.

In Thailand, several studies have analyzed changes in energy intensity in the manufacturing industry. Both Bhattacharyya and Ussanarassamee [17] and Chontanawat [18] used the LMDI in multiplicative form method to analyze how changes in energy intensity have been influenced by structural and intensity effects, during 1981-2000 and 1991-2011, respectively. However, these studies did not take production effects into account. In this paper, we seek to fill this gap by applying the LMDI in multiplicative form to examine the roles and impacts of structural, intensity, and production effects on the Thai manufacturing sector. The manufacturing sector in Thailand was selected to test the proposed method, using data from the years 1991-2013. An outline of the approach, which includes the decomposition analysis method and data processing techniques, is discussed. Next section gives a numerical example of the method, and the results of the decomposition analysis are presented from that. The final section summarizes the main conclusions of the paper.

II. Method and Data Processing

Two main categories and eight methods of IDA have been

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developed in the literature, as shown in Fig. 1. Ang [16] who provided a comprehensive summary of each method showing their advantages and disadvantages, concluded that the LMDI in multiplicative form is the preferred method, on account of its strong theoretical foundations, adaptability, ease of use, perfect decomposition capacities, and high efficiency. Therefore, we adopted this method to decompose changes in energy intensity in the Thai manufacturing sector in terms of effects related to production, structure, and intensity [10]. The production effect is a measure of change in the total manufacturing production output; the structural effect is a measure of the production share of each manufacturing sub-sector; and the intensity effect is an indication of the amount of energy used per value added in each manufacturing sub-sector.

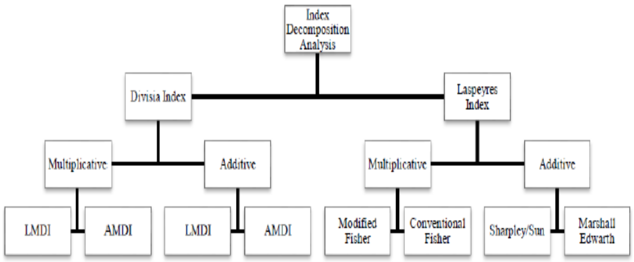

Fig. 1. Methods of energy decomposition analysis proposed by Ang [16].

When Decomposition analysis method. Decomposition analysis separates the influence of key factors on energy consumption over time. Ang [19] provides practical guidelines for using the LMDI in multiplicative form to decompose energy consumption into activity, structure, and intensity effects, as shown below. To present the methodology used in this study, we define the following terms:

E_t = total manufacturing energy consumption in year t (ktoe)

E_i = energy consumption in manufacturing sub-sector i in year t (ktoe)

Q_t = total manufacturing production in year t (billion baht, 1988 constant prices)

Q_i = total manufacturing production in manufacturing sub-sector i in year t (billion baht, 1988 constant prices)

S_i = production share of sector i (= Q_i/Q_t)

I_i = energy intensity of sector i (= E_i/Q_i), (ktoe/billion baht)

The total manufacturing energy consumption can be expressed as follows:

$$E_t = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum_i Q S_i I_i \tag{1}$$

The change in total energy consumption between the base year, denoted as year 0, and a target year, denoted as year t, can be decomposed according to the following expressions: The total effect on energy consumption is

$$\frac{E_t}{E_0} = D_{tot} = D_{act} \times D_{str} \times D_{int} \tag{2}$$

The manufacturing production effect is

$$D_{act} = \exp\left(\sum_i w_i \ln\left(\frac{Q^t}{Q^0}\right)\right) \tag{3}$$

The manufacturing structural effect is

$$D_{str} = \exp\left(\sum_i w_i \ln\left(\frac{S^t}{S^0}\right)\right) \tag{4}$$

The energy intensity effect is

$$D_{int} = \exp\left(\sum_i w_i \ln\left(\frac{I^t}{I^0}\right)\right) \tag{5}$$

The weighted function adjustment is

$$W_i = \frac{(E_i^t - E_i^0)/(\ln E_i^t - \ln E_t^0)}{(E^t - E^0)/(\ln E^t - \ln E^0)} \tag{6}$$

Data Processing

We collected the raw data on value added to the manufacturing sector from the National Economic and Social Development Board of Thailand (NESDB) [20] and from the Department of Alternative Energy Development and Efficiency (DEDE) for the energy consumption of each manufacturing sub-sector from 1991 to 2013 [21]. The Thailand manufacturing industry was classified into nine sub-sectors: non-metallic, basic metal, wood & furniture, paper, food & beverage, fabricated metal, chemical, textile, and unclassified. The unit of energy consumption is in thousands of tons standard coal equivalents (ktoe) and the value-added data are in billion baht at constant 1988 prices [22].

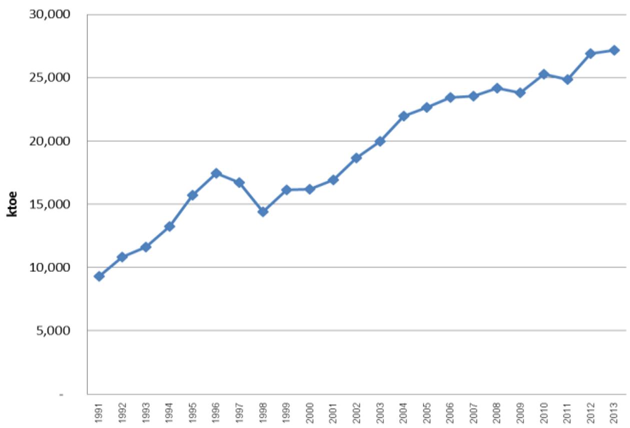

Fig. 2. Energy consumption of the manufacturing sector in Thailand, 1991-2013.

Fig. 2 shows energy consumption in the manufacturing sector in Thailand from 1991 to 2013, based on energy consumption data from the DEDE (units, ktoe). Three periods can be identified: 1) during 1991-1996, energy consumption of the manufacturing sector increased continuously, from 9300 to 17,469 ktoe, an increase of 88%. 2) During 1996–1998, energy consumption of the manufacturing sector decreased from 17,469 to 14,388 ktoe, a decrease of 18%. 3) During 1998-2013, energy consumption of the manufacturing sector increased steadily until the flooding events in Thailand in 2011. The flooding events caused energy consumption to decrease due to the suspension of production processes at this time, especially in central areas such as Nakornsawan, Ayutthaya, and Pathumthani provinces and the Bangkok capital area; however, overall, energy consumption increased during this period from 14,388 to 27,193 ktoe, an increase of 89%.

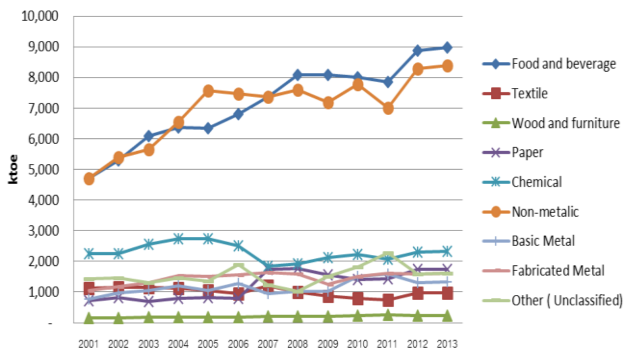

Fig. 3. Energy consumption of manufacturing sub-sectors in Thailand, 1991-2013.

Fig. 3 which shows the energy consumption of manufacturing sub-sectors in Thailand during 1991-2013, indicates that two sub-sectors (food & beverage and non-metallic) accounted for 72% of the total energy consumption, with the remaining sub-sectors (textile, wood & furniture, paper, chemical, basic metal, fabricated metal, and unclassified) accounting for 28% of the total energy consumption.

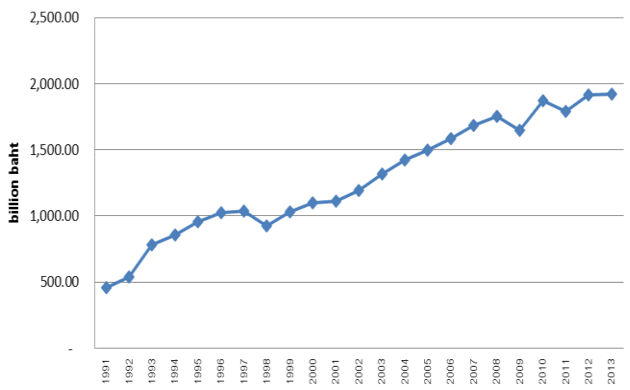

Fig. 4. Value added by the Thai manufacturing sector during 1991-2013 at constant 1988 prices.

Fig. 4 shows the value added by the Thai manufacturing sector during 1991-2013 at constant 1988 prices. The value added increased every year except for 1998, 2009, and 2011, which were years of economic crisis or flooding events. However, overall, the value added by the manufacturing sector showed an increase of 1460 billion baht during 1991-2013, or a 318% increase over 22 years.

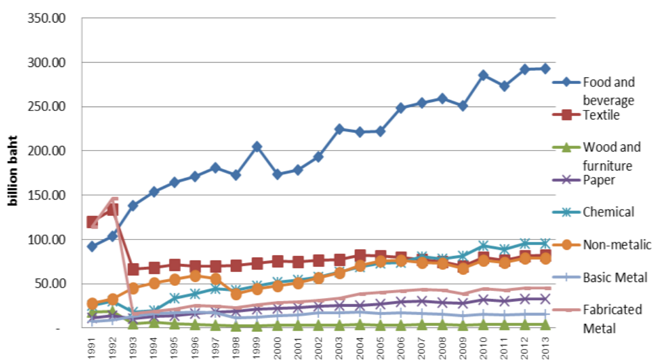

Fig. 5. Value added by Thai manufacturing sub-sectors during 1991-2013 at constant 1988 prices.

Fig. 5 shows the value added by Thai manufacturing sub-sectors during 1991-2013 at constant 1988 prices. The food & beverage sub-sector accounted for 293 billion baht (15% of the total value added), the chemical sub-sector for 95 billion baht (5%), the textile sub-sector for 82 billion baht (4.3%), the non-metallic sub-sector for 79 billion baht (4.1%), the fabricated metal sub-sector for 45 billion baht (2.4%), the paper sub-sector for 33 billion baht (1.7%), the basic metal sub-sector for 16 billion baht (0.8%), the wood & furniture sub-sector for 4 billion baht (0.2%), and the unclassified sub-sector for 1273 billion baht (66%).

III. Numerical Example

This section describes the computational process of the proposed LMDI in multiplicative form.

Assuming that D is an aggregate composed of n factors ($x_1 \dots x_n$), $D = \Sigma$, and $D_i = X_1, i, X_2, i \dots X_{n,i}$, and further assuming that from time 0 to time T the aggregate changes from D_0 to D_T, the objective is to derive the contributions of the n factors to the change in the aggregate, which can be expressed according to Eq. (1)-Eq. (6).

TABLE I: Data for the Illustrative Example

Manufacturing sub-sector	Base year,1991				Target year,2013			
	E	Q	S	I	E	Q	S	I
	ktoe	Billion Baht		ktoe/ billion baht	ktoe	Billion Baht		ktoe/ billion baht
Food & beverage	3685	92	0.20	39.86	8979	293	0.15	30.65
Textile	842	120	0.26	7.01	891	82	0.04	10.87
Wood&furniture	85	18	0.04	4.63	231	4	0.00	57.75
Paper	390	12	0.03	33.35	1751	33	0.02	53.06
Chemical	802	26	0.06	31.31	2322	95	0.05	24.44
Non Metalic	2258	28	0.06	82.03	8383	79	0.04	106.11
Basic Metal	363	7	0.02	49.75	1320	16	0.01	82.50
Fabricated Metal	293	115	0.25	2.55	1612	45	0.02	35.82
Others	582	41	0.09	14.26	1613	1272	0.66	1.27
Total	9300	459	1	20.26	27192	1919	1.00	14.17

Sources: E_0 and E_T are from [21], Q_0 and Q_t are from [20], and S_0, S_t, I_0, and I_t are derived by calculation.

A brief summary of the computational flow of the proposed LMDI technique is as follows:

Step 1: Collect data including energy consumption values (E_0, E_T) obtained for 22 years (1991-2013) from Thailand Energy Situation Annual Reports, prepared by the DEDE, and value-added data of manufacturing sub-sectors (Q_0, Q_T), obtained from the NESDB.

Step 2: Set the base year (0) and the target year *(T)*.

Step 3: Find values of S_0 and S_T from the value added by manufacturing sub-sector *i*, divided by the sum of the total value in the base year and the target year.

Step 4: Find I_0 and I_T from E_0/Q_0 and E_T/Q_T (base year and target year, respectively).

Step 5: Calculate the weighting function using Equation (6).

Step 6: Calculate the production effect using Equation (3).

Step 7: Calculate the structural effect using Equation (4).

Step 8: Calculate the intensity effect using Equation (5).

Step 9: Calculate the changes in total energy consumption between the base year and the target year using Equation (2).

Step 10: Perform an aggregate analysis to determine the influence of production, structure, and intensity effects on energy consumption.

IV. RESULTS AND DISCUSSION

Table II shows changes in the energy intensity of Thai manufacturing sub-sectors during 1991–2013. Overall, energy intensity decreased from 20.28 ktoe per billion baht in 1991 to 14.17 ktoe per billion baht in 2013, a decrease of 30%. Thus, the energy efficiency of the manufacturing sector has improved overall during the last 22 years, especially in the food & beverage (decrease of 23%), chemical (decrease of 22%), and unclassified (decrease of 91%) sub-sectors. However, no improvements were noted in the textile (increase of 71%), wood & furniture (increase of 1109%), paper (increase of 61%), non-metallic (increase of 30%), basic metal (increase of 68%), and fabricated metal (increase of 1290%) sub-sectors.

TABLE II: CHANGE IN ENERGY INTENSITY OF THAI MANUFACTURING SUB-SECTORS

Manufacturing sub-sector	Base year		Target year		Change	%
	1991	%	2013	%		
Food & beverage	39.86	15.06%	30.67	7.60%	9.19	7.46%
Textile	7.01	2.65%	11.98	2.97%	-4.97	-0.32%
Wood & furniture	4.63	1.75%	56.02	13.88%	-51.39	-12.13%
Paper	33.35	12.60%	53.79	13.33%	-20.44	-0.73%
Chemical	31.31	11.83%	24.35	6.03%	6.96	5.79%
Non Metalic	82.03	30.98%	106.51	26.39%	-24.48	4.60%
Basic Metal	49.75	18.79%	83.57	20.70%	-33.82	-1.91%
Fabricated Metal	2.55	0.96%	35.51	8.80%	-32.96	-7.83%
Others	14.26	5.39%	1.27	0.31%	12.99	5.07%
Total	20.28	100.00%	14.17	100.00%	6.11	-30.00%

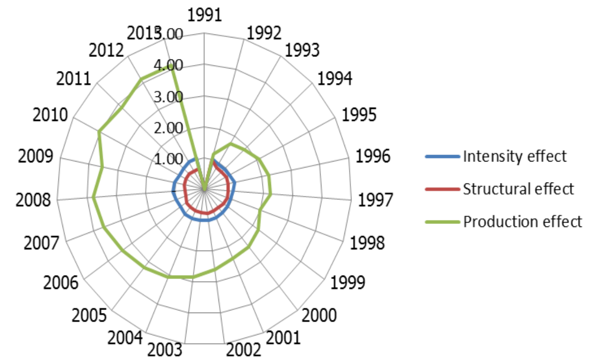

Fig. 6. Influence of production, structural, and intensity effects on the Thai manufacturing industry during 1991-2013.

Using Eq. (2), we decomposed the factors affecting the energy intensity of the Thai manufacturing sub-sectors, based on data for total energy consumption, manufacturing output, manufacturing structure, and energy intensity effects. The results, presented in Fig. 6, show that the activity effect, which is related to the dependence of manufacturing output on the energy intensity of the manufacturing sector, increased substantially during 1991-2013 on account of changes from labor-intensive to automated production systems, increased energy conservation, and other incentives promoted by the government, such as tax incentives and the formation of the Energy Service Company (ESCO) to enforce energy conservation laws. Structural effects on the manufacturing sector, which are related to the dependence of energy efficiency on energy intensity, were nearly constantly during 1991-2013, on account of stability in the structure of energy production and consumption patterns during this time.

V. CONCLUSION

We decomposed changes in the aggregate energy intensity of the Thai manufacturing sector during the period 1991-2013. The contribution of manufacturing sub-sectors to percent changes in real energy intensity was also monitored. By applying the LMDI in the multiplicative form method, energy consumption patterns were decomposed into manufacturing production effects, structural effects, and energy intensity effects. The results show that the energy intensity of the manufacturing sector decreased from 20.28 ktoe per billion baht in 1991 to 14.17 ktoe per billion baht in 2013, which was largely accounted for by decreases in the food & beverage, chemical, and unclassified sub-sectors. However, sub-sectors showing no improvement were the textile, wood & furniture, paper, non-metallic, basic metal, and fabricated metal sub-sectors. The decomposition analysis showed that a key driver for the decrease in energy consumed by the Thai manufacturing industry was the manufacturing production effect. Structural and energy intensity effects, on the other hand, showed no substantive influence on the changes. The results suggest that the LMDI technique can also be successfully applied to the analysis of energy consumption and contributory effects in the transportation and residential sectors in the future.

This study has provided an in-depth understanding of energy development patterns in the Thai manufacturing sector during the period 1991-2013, thus providing policy makers and analysts with data on how energy demand and required capacity may change in the future according to Thailand's energy efficiency goals, which are to accomplish a 25% improvement in energy intensity by 2030 under its energy efficiency master plan. The present study can be used as a roadmap for improving and restructuring the Thai manufacturing sector in the near future, for purposes of reducing overall energy consumption of the manufacturing industry.

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