Evidence of energy efficiency improvements in Thailand's manufacturing and transport sectors using structural decomposition analysis

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Abstract

The economy of Thailand has been growing rapidly since the 1980s. Consequent to the fast growth of the economy was a remarkable increase in energy consumption to the extent that domestic energy production was insufficient to cope with the energy demand. Therefore, Thailand's energy supply has relied on fossil fuel imports, which means greater insecurity for future economic development. The government has, thus, enforced energy conservation policies for designated manufacturing industries and large buildings since 1995. These policies aim to encourage these designated groups to use energy more efficiently and reduce their energy consumption. Therefore, the effectiveness of the energy efficiency policies is evaluated by implementing an input–output approach. The results reveal that there is evidence of energy efficiency improvement in the Thai economy during the 1995 to 2010 period. The energy intensity of the transport sector was higher than that of manufacturing in both of our selected

years. In contrast, the manufacturing sector actually consumed more total energy. The structural decomposition analysis revealed that the factors stimulating increases in energy consumption were the gross domestic product and population growth. Conversely, energy efficiency improvements and economic structural changes were the factors offsetting the increases in energy consumption. To sum up, the implementation of energy conservation policies has achieved an effective outcome.

1. Introduction

Thailand has transformed its economy from agricultural production to an agro-industrial and industrial orientation since the 1980s. The encouragement and support to the development of industrial sector policy aimed at increasing the country's gross domestic product (GDP) and alleviating poverty. This tactic rapidly boosted the growth in manufacturing to the extent that Thailand became a hub of manufacturing production in the 1990s. Thus, Thailand has become one of the fastest-growing economies in Southeast Asia, with an average annual GDP growth rate of 9.5% between 1987 and 1996 (Asian Development Bank, 2015; AIT, 2010; Ishizuka et al., 1995). Consequently, the problem arising from industrial growth was higher energy demand. During the 1986 to 1995 period, the primary commercial energy consumption and final energy consumption in Thailand increased by three times at an average annual rate of 12% (EPPO, 2010).

In order to ensure that fossil fuels could be supplied around the clock to all industries, the country increased its domestic energy production, yet it found that the production was insufficient to satisfy its domestic needs. Therefore, the country imported more primary energy, especially crude oil, which accounted for 80% of the total primary energy imports. In the mid-1990s, imports accounted for half of the total primary energy supply, and Thailand became the second-largest net energy importing country in Southeast Asia (EPPO, 2013). High import dependency exacerbates energy supply insecurity and makes economic development more sensitive to fluctuations in global oil prices.

Consequently, the government enacted the Energy Conservation Promotion Act in 1992, which aimed at reducing the nation's energy consumption as well as encouraging industries to use energy more efficiently. Under the Act, the National Energy Conservation Programmes (ENCON programmes) were officially established in 1995 and then directed towards designated factories and large buildings. ENCON is a rolling five-year programme, which has continuously been evaluated and revised in order to ensure effective outcomes from its policies. The first phase of ENCON covered the 1995 to 1999 period, the second phase was conducted from 2000 to 2004, and the third phase included the 2005 to 2011 period. Currently, ENCON is in its fourth phase, which includes the period from 2012 to 2016. The prioritised targets of the ENCON programmes are to achieve energy efficiency improvements as well as promote renewable energy use in the manufacturing and commercial sectors.

Although the energy conservation policies were enforced, energy consumption continued to increase year by year (EPPO, 2013). However, the increase in energy consumption does not necessarily imply that the policies for improving energy efficiency failed. There could be other possible driving forces that have caused the increase, such as a greater number of energy-intensive industries as well as economic growth. Therefore, a decomposition analysis is a useful method to evaluate and isolate the hidden factors behind the increase in energy consumption.

Such an analysis could reveal the evidence of energy efficiency improvements after the policies were implemented.

Several studies have used the index decomposition technique to analyse the energy efficiency improvement that is evident in Thailand's manufacturing sector. Bhattacharyya and Ussanarassamee (2004), Boonkham and Leeprechanon (2015), Chontanawat et al. (2014) and Punyong et al. (2006) find that the country's energy intensity has fallen slightly since the 1990s. The energy savings came from changes in the industrial structure, not from improvements in energy efficiency. In the past two decades, the share of energy-intensive industries decreased, while that for the low energy-intensive industries has moved in the opposite direction. However, studies using the input-output (IO)–structural decomposition analysis (SDA) methodology to identify the hidden factors behind the increase in Thailand's energy consumption are rare.

2. Research methodology

2.1 Energy input–output analysis

The energy IO analysis methodology was applied in this study. The IO analysis theory was first introduced by Leontief in 1936, followed by Bullard and Herendeen, who extended the ordinary IO framework with energy use (Miller and Blair, 2009). The energy IO analysis provides two energy intensity (EI) indicators – direct EI and total EI – which have become the key energy economic indicators for energy policy worldwide.

Hence, if the economic structure consists of n sectors, the mathematical equation can be expressed as follows:

$$X_i = (Z_{ij}/X_i)X_i + F_{ik} = A_{ij}X_i + F_{ik} = (I\text{-}A)^{-1}F = LF \quad (1)$$

where X_i is an *n x 1* vector of the product outputs of sector i, which needs to satisfy the final consumption within an economy. Z_{ij} is an *n x n* matrix representing the inter-industry sales from sector i to sector j. A_{ij} is a technical coefficients matrix representing the ratio of inputs and outputs of each of the n industries in a square matrix *(n x n)*. Note that multiplying A and X is equal to Z_{ij}. F_{ik} has a dimension of *n x k*, where k is the number of final consumption categories. I is a unity matrix. Leontief's inverse matrix, $L = (I-A)^{-1}$, represents the production structure, sized *n x n*. All of these coefficients are in monetary units.

For calculating EI, the energy sectors were reconstructed and the units were changed from their original monetary units into energy physical units (e.g. joules or BTUs). We use 'c' as a subscript to denote the energy sector (c represents energy types) in Eq. (1). Thus, in Eq. (2), Z_{cj} represents the energy consumption in physical units for the production in the non-energy sectors. This is the so-called 'Energy IO table'. The energy physical units can be referenced from the national energy statistics reports.

The direct energy-intensity coefficient (δ_j), also called 'direct EI', can be computed by dividing the amount of energy type c consumed by sector j by its total output (X_i) and then summing all the energy types consumed by sector j, thus becoming δ_j:

$$\delta_j = \sum(Z_{cj} / X_i) \qquad (2)$$

Using this approach, the total energy consumption intensity coefficient (α_{cj}) or the total EI can be computed by multiplying the direct EI with Leontief's inverse matrix, as shown in Eq. (3). Note that the total EI combines both the direct and indirect energy consumption for the production of industry j. The direct energy is electricity, diesel, natural gas, etc. The indirect energy consumption is the embodied energy in intermediated inputs which produced by other industries.

$$\alpha_j = \delta_j L = \delta_j(I-A)^{-1} \quad (3)$$

where α_j is the total energy consumption intensity needed to produce a particular dollar amount of output X_i for industry j.

Then, according to Miller and Blair (2009), the total energy consumption or the actual energy equation can be expressed as Eq. (4). The actual energy accounts for all energy usage, both direct and indirect, in the economy.

$$E = \alpha_j F_{ik} \quad (4)$$

where E is the vector of actual energy use in the economy.

Because this study emphasises the manufacturing and transport sectors, the actual energy in Eq. (4) was disaggregated into the energy usage in the manufacturing and transport sectors, whereas the remaining economic sectors (e.g. agriculture and construction) were included in the 'others' category. Thus, the disaggregated energy use by economic sector can be derived and expressed in Eq. (5) as follows:

$$E = \alpha_{cj} \cdot (f_{Manu} + f_{Trans} + f_{oth})$$

$$E = E_{Manu} + E_{Trans} + E_{oth} \quad (5)$$

where E_{Manu} is the energy use in the manufacturing sector, E_{Trans} is the energy use in the transport sector and E_{oth} is the total energy use in the other sectors.

Moreover, the energy use in each sector was disaggregated into the individual final demand categories in line with the IO table.

2.2 Structural decomposition analysis

The foundation of the SDA method is input–output analysis. Energy consumption changes during the 2000 to 2010 period are disaggregated into five key components (effects). SDA is employed to measure the impact of each effect on the changes in energy consumption during this period. The subscripts t and t-1 are used to represent two sequential years (where t-1 is the year before t). The weighted average of changes is based on Miller and Blair (2009) in this study.

Firstly, the SDA methodology decomposes the energy consumption change (the change in gigajoules [GJ] required by the economy) into two components: the change in the total energy intensity coefficients ($\Delta\alpha$) and the change in final demand (Δf). This is expressed as Eqs. (7) and (8).

$$E_t - E_{t-1} = \alpha_t f_t - \alpha_{t-1} f_{t-1}; \quad (6)$$

$$\Delta E = (1/2)(\Delta\alpha)(f_{t-1} + f_t) + (1/2)(\alpha_{t-1} + \alpha_t)\Delta f. \quad (7)$$

Further levels of the decomposition of Δf and $\Delta\alpha$ can be applied using the following steps. The final demand can be further decomposed into three components: the ratio of the final consumption of each industry sector to the total consumption or consumption structure effect (β), to the GDP per capita (Y) and to the population (P); thus, the extension of the decomposition can be expressed as Eq. (11).

Given that $f = \beta \cdot Y \cdot P$:

$$\Delta f = (\beta \cdot Y \cdot P)_t - (\beta \cdot Y \cdot P)_{t-1}$$

$$= (1/2)\,(\Delta\beta Y)\,(P_{t-1} + P_t) + (1/2)(\beta Y_t + \beta Y_{t-1})\Delta P; \qquad (8)$$

$$\Delta\beta Y = (1/2)\,\Delta\beta\,(Y_{t-1} + Y_t) + (1/2)\,(\beta_{t-1} + \beta_t)(\Delta Y). \qquad (9)$$

Eq. (9) can be included in Eq. (8) and expressed as follows:

$$\Delta f = (1/4)\,\Delta\beta\,(Y_{t-1} + Y_t)\,(P_{t-1} + P_t) + (1/4)\,(\beta_{t-1} + \beta_t)(\Delta Y)\,(P_{t-1} + P_t)$$

$$+ (1/2)(\beta Y_t + \beta Y_{t-1})\Delta P. \qquad (10)$$

Besides the decomposition of Δf, the change effect in the total energy intensity coefficients ($\Delta\alpha$) can also be further disaggregated into the changes in direct energy intensity, called the energy efficiency change effect ($\Delta\delta$), and the production structure change effect or Leontief effect (ΔL), which refers to Eq. (3). Hence, this can be expressed in Eq. (11).

$$\Delta\alpha = \delta_t \cdot L_t - \delta_{t-1} \cdot L_{t-1}$$

$$= (1/2)\,\Delta\delta\,(L_{t-1} + L_t) + (1/2)(\delta_{t-1} + \delta_t)\Delta L \qquad (11)$$

Combining Eq. (10) and Eq. (11) into Eq. (7), the final equation can be expressed as follows:

$$\Delta E = (1/4)\,\Delta\delta\,(L_{t-1} + L_t)\,(f_{t-1} + f_t)$$

$$+ (1/4)\,(\delta_{t-1} + \delta_t)\Delta L(f_{t-1} + f_t)$$

$$+ (1/8)\,(\alpha_{t-1} + \alpha_t)\,\Delta\beta\,(Y_{t-1} + Y_t)\,(P_{t-1} + P_t)$$

$$+ (1/8)\,(\alpha_{t-1} + \alpha_t)\,(\beta_{t-1} + \beta_t)(\Delta Y)\,(P_{t-1} + P_t)$$

$$+ (1/4)\ (\alpha_{t-1} + \alpha_t)\ (\beta Y_t + \beta Y_{t-1})\ \Delta P \qquad (12)$$

Subsequently, the changes in energy use in the economy are decomposed into five key components on the right-hand side of Eq. (12), which is used to evaluate the hidden driving forces in the changes in energy consumption from 2000 to 2010. The first term is the effect caused by changes in energy efficiency. The second term is the effect caused by changes in the production structure. The third term is the effect of the final consumption structure changes. The fourth term is the effect of changes in GDP per capita. The final term is the effect caused by the changes in population.

3. Data sources

The 2000 IO table and the most recent published 2010 IO table compiled by the NESDB were used in this study. The two data sets for the IO tables were adjusted to provide constant prices in terms of the base year (2010) by using the Producer Price Index maintained by the Product Group from the Bureau of Trade and Economic Indices, Ministry of Commerce. The physical energy data were obtained from the Thailand Energy Situation Annual Report from the Department of Alternative Energy Development and Efficiency, Ministry of Energy.

In this study, the IO tables were reorganised into 22 sectors, comprising 18 non-energy sectors and four energy sectors (based on the availability of energy data), as represented in Table 1. Renewable energy and hydropower are not examined in this study because of difficulties in data allocation. Moreover, the population data for both years were obtained from the World Bank (2016).

Table 1 Recognised sectors

Sector	Name	I/O sector
1	Agriculture	1-29
2	Mining	32-41
3	Food &beverages	42-66
4	Textiles	67-74
5	Wood and furniture	78-80
6	Paper and paper products	81-83
7	Chemical products	84-92
8	Non-metallic	95-104
9	Metallic	105-107
10	Fabricated metals	108-111
11	Other manufacturing	75-77, 112-134
12	Construction	136-144
13	Commercial	145-148, 158-178
14	Rail	149
15	Road	150-152, 157
16	Water way	153-155
17	Air	156
18	Others	180
19	Coal and lignite	30
20	Crude petroleum and natural gas	31
21	Petroleum refineries	93-94
22	Electricity	135

4. Results

Figure 1 illustrates that the direct EI (δ) in 2010 was lower than in 2000 for most industries, except rail transport and agriculture. This implies that to generate a thousand baht of GDP, most industries consumed less direct energy in 2010 than 2000. This means that they used energy more efficiently. Overall, the direct EI in the transport sector was dramatically higher than that in the manufacturing sector. The average direct EI in 2000 and 2010 were 0.2764 and 0.2083 GJ/1000 baht, respectively. The results reveal that the direct EI of the four kinds of transport were higher than the average direct EI in both years. The highest energy-intensive transport sectors were roads, followed by air. Meanwhile, the manufacturing sectors that had higher direct

EI values than the direct EI average were considered to be energy-intensive industries. Thus, the energy-intensive industries include the non-metallic, metallic, fabricated metals and chemical products sectors. However, the transport sectors (except rail) and the energy-intensive industries have shown that their direct EI has improved during the study period.

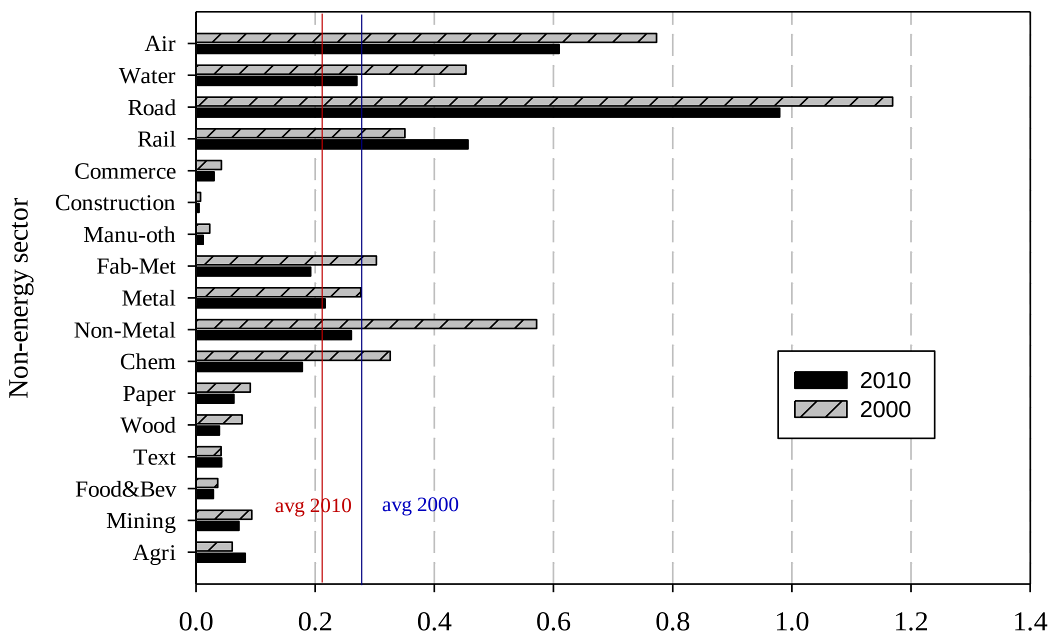

Figure 1 Direct energy intensity of non-energy industries (GJ/1000 baht)

Likewise, the total EI (α) in Figure 2 is a combination of the direct energy consumption and indirect energy usage, which is the amount of energy accumulated in the assembly of inputs that are produced by other industries. The average values of total EI were 1.29 and 1.03 GJ/1000 baht in 2000 and 2010, respectively. The proportion of direct EI to the total EI was approximately 20% in both years. This implies that, in order to generate a thousand baht's worth of GDP, Thailand's economic sectors require indirect energy consumption of 80% and direct energy consumption of only 20%. Thus, Thailand is not a manufacturing-dominated economy, but sevice-dominated economy (Zhang et al., 2014). Nevertheless, the average total EI value has decreased 20% from 2000 to 2010.

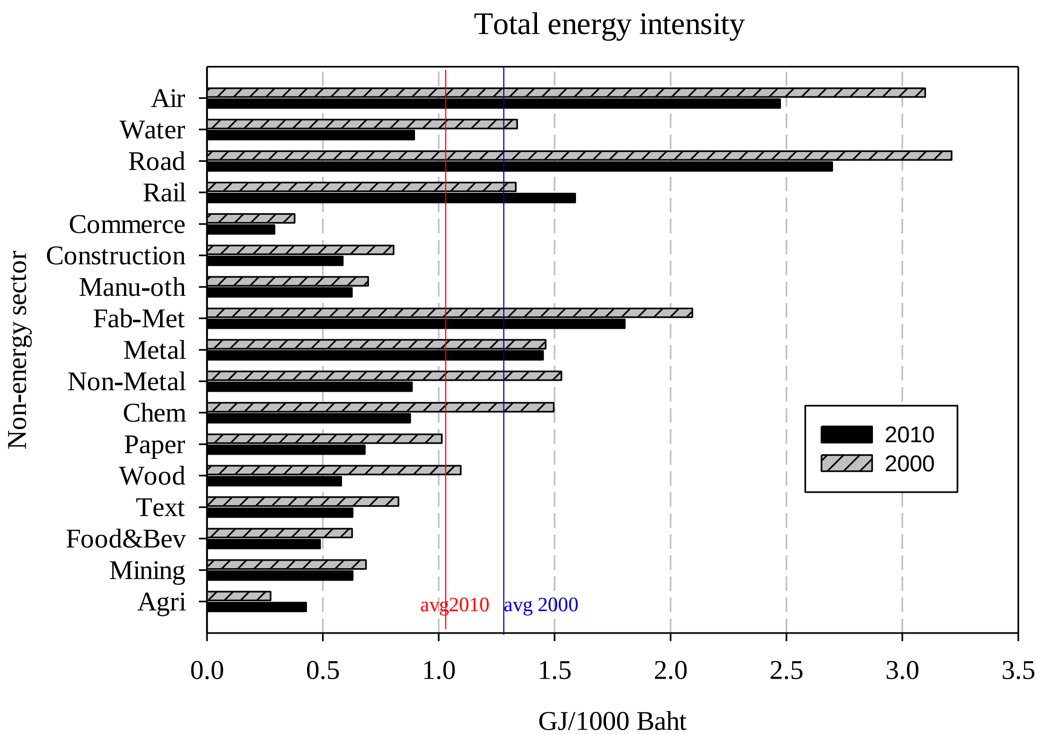

Figure 2 Total energy intensity of non-energy industries (GJ/1000baht)

A comprehensive energy analysis is the total amount of energy consumed within the economy, which is the sum of the direct and indirect amounts. Moreover, this type of analysis can identify which groups of consumers have stimulated the increase in energy consumption.

Figure 3 illustrates that the total energy consumption of Thailand's economy slightly increased from 2000 to 2010, by approximately 3%, even though most industries had improved their direct and total EI, as stated previously. The energy consumed by the manufacturing sector was more than that by the transport sector in both years.

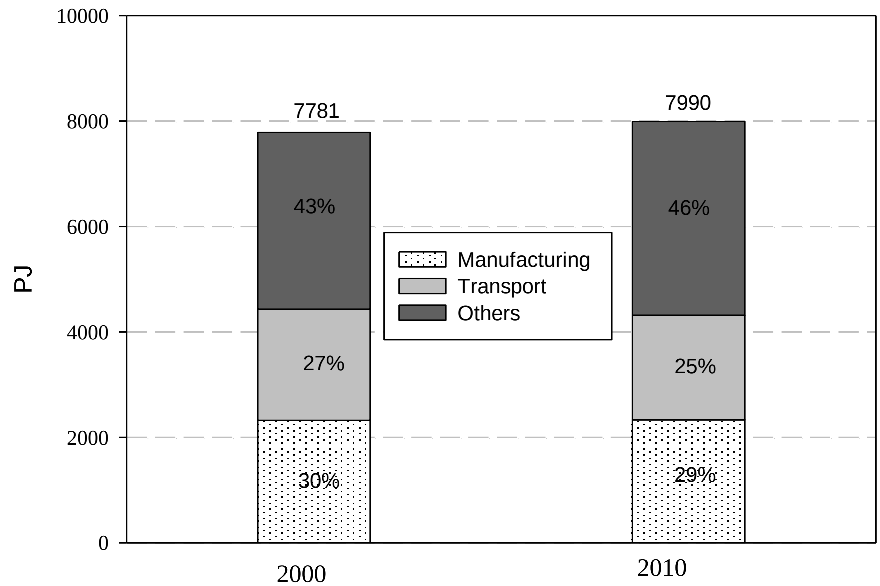

Figure 3 Total energy consumption, 2000 and 2010 (petajoules)

The results in Table 2 can be interpreted to mean that the manufacturing sector consumed energy to produce product outputs whose main purpose was for export. The second purpose was to produce products that would satisfy domestic consumption. The total energy consumption in exports was 129.3 PJ in 2000, then increased to 160.4 PJ in 2010, approximately 24% increase. The products' exports are considered as indirect energy exports. Nevertheless, the manufacturing sector also includes imports, which could account for some energy savings for Thailand because products manufactured outside the country require energy from other countries. Subsequently, the energy associated with net exports has a negative value. This implies that Thailand's manufacturing sector relied on a relatively greater proportion of imported parts in its assembly processes in terms of generating outputs. In addition, these manufacturing outputs were greatly affected by capital formation (such as fixed-asset investments and public infrastructure developments) of households and private enterprises.

Likewise, the total energy use of the transport sector was affected by households and exports. This is because Thailand's transport sector is based on private cars and freight transport.

Table 2 Disaggregated energy use by final consumption categories (petajoules)

Year	Economic sector	Private consumption expenditures	Exports	Gross fixed capital formation	Others	Imports
2000	Manufacturing	61.4	129.3	31.1	7.7	-129.5
	Transport	49.6	42.4	5.7	2.3	0.0
2010	Manufacturing	56.7	160.4	44.1	12.3	-173.5
	Transport	53.6	40.5	2.7	3.2	0.0

The structural decomposition analysis results in Table 3 reveal that the main factors stimulating the increase in energy consumption were the expansion of GDP and the growth of population. The energy efficiency effects were the offsetting factors for the increase in energy consumption in both the manufacturing and transport sectors, in particular the manufacturing sector, in which the improvement in energy efficiency was the strongest factor in reducing energy consumption.

Table 3 Structural decomposition of the factors affecting energy consumption, 2000 and 2010

Increase embodied energy	PJ	Energy efficiency effect ($\Delta\delta$)	Production structure change effect (ΔL)	Final consumption share change effects ($\Delta\beta$)	GDP per capita change effect (Δy)	Population change effect (Δp)
ΔE_Manufacturing	10.68	-366.79	-271.64	-293.48	795.38	147.21
	(%)	***-3433.46***	***-2542.71***	***-2747.16***	***7445.32***	***1378.02***
ΔE_Transport sector	-124.14	-190.21	-218.11	-111.75	268.44	127.49
	(%)	***-153.22***	***-175.69***	***-90.02***	***216.24***	***102.70***

Furthermore, the production and consumption structural change effects were also crucial factors in reducing energy demand between 2000 and 2010. The manufacturing structure transitioned from a high proportion of energy-intensive industries to more low energy-intensive industries during the study period.

5. Conclusion

The direct EI and total EI values of the transport sectors were higher than those of the manufacturing sectors during the study period. Moreover, they were higher than the average of both EI values. The highest energy-intensive transport sectors were road transport, followed by air transport; as for the manufacturing sectors, the main energy-intensive industries were the non-metallic, metallic, fabricated metals and chemical products sectors. These industries had direct EI and total EI values above the average. However, there were positive signs of energy intensity improvement in most of the non-energy sectors. This implies that most industries in Thailand used energy more efficiently during the 2000 to 2010 period.

The embodied energy analysis reveals that the manufacturing sectors consumed more total energy than the transport sectors even though they had lower EI values. The energy consumed by manufacturing was used to produce outputs for export, followed by domestic consumption. However, manufacturing also imported its assembly parts; thus, its total net exports had negative values. Meanwhile, energy consumption in the transport sector was mainly due to domestic consumption (private cars) and freight transport.

The GDP and population growth were the driving forces behind the increase in energy consumption during the study period. However, there is evidence of energy efficiency improvements in both the manufacturing and transport sectors. Thus, this implies that the energy conservation policies and programmes in Thailand have been effective in mitigating energy consumption.

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