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CASE STUDY

Economy-wide energy efficiency using a comprehensive decomposition method

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ABSTRACT

This study compares the energy intensity performance in Indonesia to other South East Asia countries such as Vietnam, Thailand, Singapore, The Philippines and Malaysia for the period from 1971 to 2016. For this goal, this research employs a multiplicative Log Mean Divisia Index II method and Spatial-Temporal Index Decomposition Analysis. The manufacturing sector and commercial sector played a key role in the region's economic structures that accounted for around 60% to 80% of the total economic output from 1971 to 2016. The contribution of manufacturing sector increased quite significantly, from 8% in 1971 to a peak of around 31% in 2001, before it fell to 28% in 2016. On the other hand, the contribution of agriculture sector dropped from 49% in 1971 to approximately 17% in 2016. It is demonstrated in this research that the aggregate trend of the changes of energy intensity in these countries in the past forty-five years has been decreasing. For Indonesia, aggregate energy intensity rose steadily by an average of 3% per year from 1971 to 1999, more than doubling over this period, while from 1999 to 2001 energy intensity fell by 1% per annum on average, falling by 17% overall in 2016. Overall, in terms of structure and industry effects on aggregate energy intensity, all these countries showed a shift in industry value added to more energy-intensive industries which also offset by falling within-industry energy intensity. However, the analysis shows that both element of this trend was most pronounced in Indonesia.

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INTRODUCTION

The consumption of energy is necessary to drive the economy (Ozturk, 2010). Energy consumption in Asia Pacific countries has been rapidly increasing. According to the ADB (2013) projection, energy demand in the Asia Pacific region will rise by 2.1% per annum from 2010 to 2035, which is more than a 70% increase over this period. This growth rate is higher than the predicted world average growth rate of 1.5% (ADB, 2013). The ASEAN (Association of Southeast Asian Nations) countries, which is centred in the Asia Pacific region, is leading the global energy trend with a massive increase of 50% over the period from 2000 to 2013 due to its increased population and economic growth in the region. The economic growth within ASEAN countries has increased remarkably since 1999, from US$ 577 billion in 1999 to US$2.5 trillion in 2016, where in 2018, it has an averaging 5.3 per cent growth (OECD, 2019). ASEAN's increasing population is also been inherent to its economic growth. Based on *the World Economic Outlook* (IMF, 2017), ASEAN's working-age population has increased from an average of approximately 63% in 2000 to 67% in 2015. The population in ASEAN countries in 2013 reached more than 615 million people, or around 8.5 percent of the world's population, that used approximately 4.5% of the world's primary energy (ACE, 2015a). Energy demand in these countries has increased two and a half times more than it was in 1990 (IEA, 2015). This trend is predicted to rise even higher in the coming decades and forecast to increase by 80% from 2011 to 2035 (Shi, 2016). With ASEAN economies expanding steadily, energy demand is considered to surpass its supply unless a significant policy is enacted to manage energy demand. This situation necessarily creates challenges for sustainable development. Currently, ASEAN has a medium-term target to reduce its energy intensity by 20% by 2020 and a long-term target of 30% by 2025, compared to the base year 2005 (ACE, 2015b). Up to this time, the majority of ASEAN countries have developed some energy savings targets by enacting a variety of energy efficiency policies, with more than half having enacted a common standard of energy efficiency measures. Moreover, most of these countries have implemented energy labelling programs for all electric and gas appliances (IEA, 2013). Although some progress has been achieved by ASEAN in the last decade, the progress in energy efficiency is still relatively conservative compared to other groups of countries. From 1980 to 2011, the energy intensity of ASEAN only improved by 12%. This growth is still low compared to the improvement of the OECD (38%) or China (74%) (Shi, 2016). Based on the (IEA, 2013), the reason for the small improvement of energy intensity in ASEAN is due to the lack of energy efficiency regulations in buildings, mandatory regulations in appliances, and the absence of market-based energy prices in some countries. In addition, targets to reduce energy intensity in the ASEAN region are also hampered due to some countries not making a concrete policy about energy efficiency measures, specifically Myanmar, Laos and Cambodia, while other countries such as Malaysia, Thailand and Singapore have developed a variety of energy efficiency policies (Shi, 2016). The remarkable economic growth of ASEAN countries could lead to inefficient energy usage. The ASEAN's economy collectively has grown substantially by more than 125% since 2000, reaching US$7.4 trillion in 2016 (IMF, 2017). The ASEAN-6 countries have had substantial growth in their economy compared with the rest of the ASEAN members. Based on the recent World Bank (2019) data, the highest per capita income within ASEAN-6 in 2018 is Singapore at US$64,581, followed by Malaysia (US$11,239), Thailand (US$7,273), Indonesia (US$3,893), the Philippines (US$3,102) and Vietnam (US$2,563). According to IMF (2015), ASEAN countries have shown strong economic growth in the last decades, which almost doubled since 2000 (to around $6.1 trillion in 2013). The high growth of these six ASEAN countries evokes an intriguing question about the performance of energy consumption, since the growing per capita income may also lead to higher energy consumption, which may result in inefficient energy usage. Given the remarkable growth rate of these ASEAN-6 countries, examining the performance of these countries is essential. Energy efficiency improvements can be a result of more efficient technologies (intensity effect or changes within industry energy intensity) or changes in economic structure composition (structural effect/shifting to less energy-intensive sectors, for example, from the industrial sector to the services sector). This study employs Log Mean Divisia Index (LMDI) techniques to examine the trend of each of nine ASEAN countries' energy intensity to measure the contribution of within-sector efficiency improvements (intensity/technology effects) and structural changes (structural effects). By classifying the interaction amongst these two effects, this study attempts to explain the main driving force behind recent energy efficiency improvements of each ASEAN countries over time. In addition, this study also attempts to examine whether the decline in energy intensity in one country is similar within the same sector across other countries. This paper examines the energy intensity performance in Indonesia compared to other selected ASEAN countries from 1970 to 2016. Although decomposition analysis has been widely used in studies of energy-related issues in many countries, there is a lack of research into the decomposition of energy in Indonesia, particularly when comparing Indonesia to other countries. The selected ASEAN countries for analysis in this study are Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam while Brunei Darussalam, Cambodia, Myanmar, and Lao PDR have not been included due to lack of data. The aims of this study are essentially two. First, this paper aims at examining the development of energy efficiency and discovering energy intensity changes amongst selected ASEAN countries. Second, this study captures both temporal improvements within individual countries and spatial changes amongst selected countries employing the model developed by Ang *et al*. (2016). This study objective expects to provide a robust description of the overtime performance of the selected ASEAN country since it incorporates the abovementioned spatial and temporal approaches within a single analysis structure. The study investigates the driving forces affecting energy intensity performances of Indonesia to other south East Asia countries, including, Vietnam, Thailand, Singapore, The Philippines and Malaysia for the period from 1971 to 2016. This study has been carried out in Melbourne, Australia during 2018 – 2019.

MATERIALS AND METHODS

Many scholars employ the decomposition analysis to measure the driving forces of energy intensity (Hasanbeigi *et al*., 2013; Ke *et al*., 2012; Su and Ang, 2015; Wang *et al.,* 2018; Wood, 2009). This method is also an effective tool to observe factors that influence changes in carbon emissions, which also may provide analyses of the effects of related policy measures (Ang, 2004). Shrestha and Timilsina (1996) examined the carbon intensity of the power sector in 12 Asian countries and found that fuel changes were the main driver affecting changes in carbon intensity. Schleich *et al.* (2001) explored Germany's emission reductions in 1990 and argued that population growth, GDP and energy supply mix were the main drivers for the emission changes. Davis *et al.,* (2003) investigated carbon intensity in the USA from 1996 to 2000 and suggested that the declining carbon intensity was driven by the warming climate. Bhattacharyya and Ussanarassamee (2004) observed energy and carbon intensities in the manufacturing sector in Thailand from 1981 to 2000 and argued that energy intensity and industry structure were the main factors driving the changes in carbon intensity. By investigating 14 EU countries from 1990 to 2003, Diakoulaki and Mandaraka (2007) examined carbon emission changes and suggested five main factors: energy intensity, output, fuel mix, structure and utility mix. Besides LMDI method, other studies also attempt to measure the determinants of energy intensity by applying different methods, such as Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA). The DEA method has been employed in many studies to examine the relationship between energy efficiency and economic performance which formulates an index of Total-Factor Energy Efficiency (Honma and Hu, 2008, 2013, 2014; Hu and Kao, 2007; Hu and Wang, 2006; Xiaoli *et al.,* 2014). In terms of SFA, there are only a limited number of studies employing this method to examine the impact of energy efficiency policy measures to energy efficiency level (Adom *et al.,* 2018; Filippini and Hunt, 2011, 2012; Filippini *et al.,* 2014). In LMDI method, there are two effects that are conventionally measured in many energy intensities studies (Ang, 2004 and 2015), namely: 1) structural effect utilised to measure changes in energy consumption as a result of changes in the activity mix by sub-sectors. The structure effect of the productive sectors will be used to measure the changes in energy intensity that result from a transition of economic sectors such as from less energy-intensive to a more energy-intensive sector (for example, changes from agriculture sector to industry sector). This effect can determine changes in the energy intensity resulting from changes in the composition of economic sectors, and 2) intensity effect employed to measure changes in energy intensity caused by the improvement of technical efficiency in each sector of the economy. This effect is generally interpreted as changes in energy intensity resulting from efficiency improvements within sub-sectors of the economy. In order to determine changes in energy intensity trends, this study employs the LMDI-II Multiplicative. Following the LMDI-II Multiplicative, this study also uses a Spatial-Temporal Index Decomposition Analysis (ST-IDA) as Ang *et al.* (2016) recommends. According to Ang *et al.,* (2016), before conducting the ST-IDA study, the benchmark countries must be selected first. The decomposition method in this study provides an energy efficiency benchmark. However, this method doesn't make any assumptions related to the underlying economic and/ or production structure. This method provides a clear structure, by observing energy intensity changes as a result of the structure change. Following Ang *et al.* (2016), this study specifies the reference country by using a weighted average of all countries in all the years of specified study period in order to provide a neutral description of the country performance. To determine changes in energy intensity trends, the following approach is generally employed (Ang, 2015), and constructed as Eqs. 1, 2 and 3:

$$I_t = \frac{E_t}{Y_t} = \sum\nolimits_{k=1}^{n} \frac{Y_{kt}}{Y_t}\frac{E_{kt}}{Y_{kt}} = \sum\nolimits_{k=1}^{n} S_{kt} I_{kt} \qquad (1)$$

Where; I_t (aggregate energy intensity at time t), E_t (energy consumption in all sectors at time t), Y_t (economic activity of all sectors at time t), Y_{kt} (economic activity in sector k at time t), E_{kt} (energy consumption in sector k at time t), I_{kt} (energy intensity of sector k at time t), S_{kt} (share of sector k in economic value of all sectors at time t).

Using multiplicative decomposition, the relation of two time periods are described as Eq. 2.

$$D_{Tot,T} = \frac{T_T}{I_0} = D_{Int,T} \times D_{Str,T} \qquad (2)$$

Where; $D_{Str,T}$ is the structural effect at time T (an index that determines the effect of the structural shift), and $D_{Int,T}$ is the intensity effect at time T (an index that determines the changes in sectoral energy intensity effect), which are computed as Eqs. 3 and 4.

$$D_{Str} = exp\left\{ \sum\nolimits_{k=1}^{N} \frac{L\left(\frac{E_{k,T}}{E_T}\frac{E_{k,O}}{E_O}\right)}{\sum_k L\left(\frac{E_{k,T}}{E_T}\frac{E_{k,O}}{E_O}\right)} ln\left(\frac{S_{k,T}}{S_{k,O}}\right) \right\} \qquad (3)$$

And

$$D_{Int} = exp\left\{ \sum\nolimits_{k=1}^{N} ln\left(\frac{I_{k,T}}{I_{k,O}}\right) \right\} \qquad (4)$$

Changes in energy intensity are influenced by many factors. One way to isolate and explore these factors is decomposition analysis. Decomposition analysis measures the effect of various factors on energy consumption. Identifying the elements affecting energy consumption is important to define as it identifies which elements substantially reduce energy consumption and the areas that need to be prioritized for the development of energy efficiency policies. In other cases, the decomposition of energy consumption trends can be divided into three main elements: structural effect, intensity effect and activity effect (Ang, 2004 and 2015; IEA, 2018). However, as this study focused on the progress of energy efficiency development, it is important to only isolate the parameters on the structural effect and intensity effect as discussed in Ang and Liu (2001) and Ang *et al.* (2003). Since this study, having no preference in selecting the study period and country reference, following Ang *et al.* (2016), this study specifies the reference country by using a weighted average of all countries in all the years of specified study period in order to provide a neutral description of the country performance. As the performance analysis involves n countries (C1 to Cn) and will be evaluated for year 0 and year T, with assumptions of k sectors. Cu will be taken as the benchmark region (Cu is the benchmark country). The ratio changes in energy intensity between two countries (Country 1 and Country 2/ C1 and C2) in year 0, is indirectly constructed as Eqs. 5, 6 and 7.

$$\frac{I^{C1,0}}{I^{C2,0}} = \frac{I^{C1,0} / I^{Cu}}{I^{C2,0} / I^{Cu}} \qquad (5)$$

The structure and intensity effects are computed as Eq. 6 and 7.

$$D_{Str}^{C1,0-C2,0} = \frac{D_{Str}^{C1,0-Cu}}{D_{Str}^{C2,0-Cu}} = \frac{exp\left(\sum_k w_k^{C1,0-Cu} ln \frac{S_k^{C1,0}}{S_k^{Cu}}\right)}{exp\left(\sum_k w_k^{C2,0-Cu} ln \frac{S_k^{C2,0}}{S_k^{Cu}}\right)} \quad (6)$$

$$D_{Int}^{C1,0-C2,0} = \frac{D_{Int}^{C1,0-Cu}}{D_{Int}^{C2,0-Cu}} = \frac{exp\left(\sum_k w_k^{C1,0-Cu} ln \frac{I_k^{C1,0}}{I_k^{Cu}}\right)}{exp\left(\sum_k w_k^{C2,0-Cu} ln \frac{I_k^{C2,0}}{I_k^{Cu}}\right)} \quad (7)$$

Where, $w_k^{C1,0-Cu} = \frac{L\left(\frac{E_k^{C1,0}}{E^{C1,0}}, \frac{E_k^{Cu}}{E^{Cu}}\right)}{\sum_k L\left(\frac{E_k^{C1,0}}{E^{C1,0}}, \frac{E_k^{Cu}}{E^{Cu}}\right)}$ and $w_k^{C2,0-Cu} = \frac{L\left(\frac{E_k^{C2,0}}{E^{C2,0}}, \frac{E_k^{Cu}}{E^{Cu}}\right)}{\sum_k L\left(\frac{E_k^{C2,0}}{E^{C2,0}}, \frac{E_k^{Cu}}{E^{Cu}}\right)}$

For the ratio difference of a country's energy intensity (C1) between two time periods (year 0 and year T), is formulated as Eqs. 8, 9 and 10.

$$\frac{I^{C1,T}}{I^{C1,0}} = \frac{I^{C1,T} / I^{Cu}}{I^{C1,0} / I^{Cu}} \quad (8)$$

And

$$D^{C1,T-C1,0} = \frac{D_{Str}^{C1,T-Cu}}{D_{Str}^{C1,0-Cu}} = \frac{exp\left(\sum_k w_k^{C1,T-Cu} ln \frac{S_k^{C1,T}}{S_k^{Cu}}\right)}{exp\left(\sum_k w_k^{C1,0-Cu} ln \frac{S_k^{C1,0}}{S_k^{Cu}}\right)} \quad (9)$$

$$D_{Int}^{C1,T-C1,0} = \frac{D_{Int}^{C1,T-Cu}}{D_{Int}^{C1,0-Cu}} = \frac{exp\left(\sum_k w_k^{C1,T-Cu} ln \frac{I_k^{C1,T}}{I_k^{Cu}}\right)}{exp\left(\sum_k w_k^{C1,0-Cu} ln \frac{I_k^{C1,0}}{I_k^{Cu}}\right)} \quad (10)$$

Where, $w_k^{C1,T-Cu} = \frac{L\left(\frac{E_k^{C1,T}}{E^{C1,T}}, \frac{E_k^{Cu}}{E^{Cu}}\right)}{\sum_k L\left(\frac{E_k^{C1,T}}{E^{C1,T}}, \frac{E_k^{Cu}}{E^{Cu}}\right)}$ and $w_k^{C1,0-Cu} = \frac{L\left(\frac{E_k^{C1,0}}{E^{C1,0}}, \frac{E_k^{Cu}}{E^{Cu}}\right)}{\sum_k L\left(\frac{E_k^{C1,0}}{E^{C1,0}}, \frac{E_k^{Cu}}{E^{Cu}}\right)}$

Changes to energy intensity are defined by many driving factors including selection of production process, price of energy, technology advancement and innovation, fuel mix and government policy measures (Sun, 1998). Shifting within energy-intensive sectors or changes in the economic structure can also generate changes in energy intensity. At the lowest of sectoral disaggregation or individual process, energy intensity can simply be measured as the change in energy consumed per unit of output. Nevertheless, this measurement might not adequately explain the energy intensity at the aggregate level as there are other driving forces, such as structural shifts, that can lead to economic changes in energy intensity (Shahiduzzaman and Alam, 2013). For instance, when the structure of the economy shifts over a period of time from the less energy-intensive agriculture sector to the more energy-intensive manufacturing sector, then energy intensity may increase without any decline in energy efficiency. These indicators of energy efficiency have been developed and utilized for measuring, observing and evaluating energy performance across countries. Energy efficiency is usually estimated with either physical or monetary indicators. One of the monetary based indicators that are mostly used to estimate energy efficiency is energy intensity, where in this term the energy efficiency is measured by how much energy is required or needed per unit of output (in the economic context, it is measured by dividing the total energy consumption with total GDP). Overall, the International Energy Agency (IEA) defines energy efficiency as an effort to control energy consumption and to attain economic growth. Data in this study is gathered from two databases: The United Nations Statistics Division (UNSD) datasets and International Energy Agency (IEA). The UNSD supports databases in international industrial statistics. Although this database provides a substantial coverage of statistics across industries, it only comprises output/activity data and does not incorporate energy use data. Both output and energy consumption data are essential for this research to observe the level of energy efficiency development across the selected countries. Therefore, this study employed energy use data sourcing from the IEA that includes energy balance and energy consumption data across each sector of the economy. The GDP data in this study include the four main sectors of the economy for the six ASEAN countries: manufacturing, transportation, commercial and agriculture. The total energy consumption data is obtained from the energy balances of OECD and non-OECD economies data sets. As with many other cross-country studies measuring GDP, this study utilises the Value Added by Economic Activity, at constant 2010 prices in US dollars.

RESULTS AND DISCUSSION

Comparative analysis of the energy-intensity amongst ASEAN countries

Fig. 1 shows the energy-intensity changes in the six ASEAN countries from 1971 to 2016. Overall, in ASEAN countries, the Total Final Energy Consumption (TFC) per GDP or defined as Energy Intensity, fluctuated during the period of this study. Indonesia's energy intensity was average compared to the other ASEAN countries, where it started increasing moderately and peaked in 1999, followed by a decreasing trend of aggregate energy intensity for the rest of the period.

Economic Structure (sectoral share to GDP, 1971–2016)

Indonesia's industry has grown significantly over the past forty-five years. The total value of industrial output increased from US$61.6 billion in 1971 to US$801.9 billion in 2016 at 2010 prices, with an overall annual average growth rate of 8.95%. In the 1970s to the beginning of 1990s, industrial growth averaged approximately 7% per year. This phenomenal period of growth was followed by a short period during the economic crisis from 1997 to 1998, where industrial growth dropped sharply by negative 1% from 1997 to 2001. The commercial sector suffered a severe drop of negative 2% growth annually from 1997 to 2001. However, after the 2000s, industrial growth started to increase, although, the growth rate was slower compared to the early 1990s. All economic activity in the key end-use sectors of the ASEAN-6 economy increased at an annual average rate of greater than 4% from 2011 to 2016 (Table 1). The manufacturing, transport and commercial sectors contributed the most to growth in the total industrial value-added. While economic activity increased over the period of study in all sectors, rates of economic growth varied across the sectors. Annual growth in activity in the manufacturing, transport and commercial sectors was considerably greater than the rate of growth in the agriculture sector. The decline in the share of total economic activity of the agriculture sector and the increasing shares of the manufacturing, transport and commerce sectors indicate a change in the structure of ASEAN-6 economies over the period of study.

Table 1 summarises ASEAN countries' value-added shares and annual growth rate of value-added from 1971 to 2016.

Indonesia shifted from a predominately agricultural economy to a predominately manufacturing economy in quite short time period (Jacob, 2005). Since the 1990s, the domination of manufacturing sector has exceeded the contribution of the agriculture sector. The contribution of manufacturing sector increased quite significantly, from 8% in 1971 to a peak of

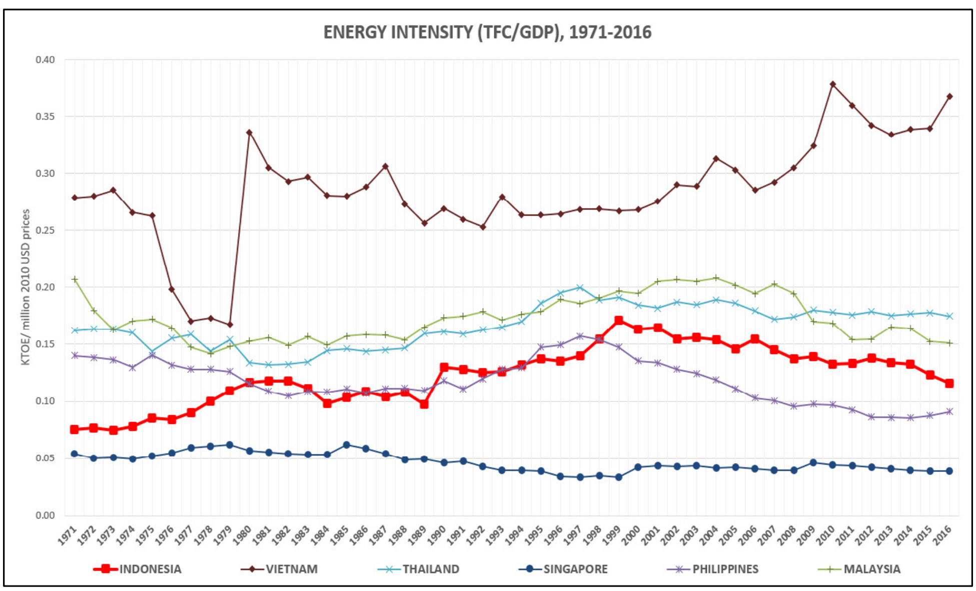

Fig. 1: Energy Intensity Comparison for six ASEAN countries, 1971-2016

Table 1: Gross value-added shares and annual growth rate of ASEAN-6

Country	Sectors	Annual growth rate value added (%)						Share of total (%)						
		71-81	81-91	91-97	97-01	01-11	11-16	71	81	91	97	01	11	16
Indonesia	Manufacturing	14	12	10	0	5	5	8	15	25	30	31	29	28
	Transportation	13	7	8	0	13	9	3	4	5	5	5	10	11
	Commercial	9	7	7	-2	6	5	40	45	45	45	42	44	44
	Agriculture	4	3	3	1	4	4	49	36	25	20	22	18	17
	AGGREGATE	7	7	7	-1	6	5							
Vietnam	Manufacturing	4	4	12	10	8	9	13	13	11	14	17	20	23
	Transportation	4	5	8	6	8	6	4	4	4	4	4	6	6
	Commercial	4	6	10	5	6	7	41	41	45	49	48	48	49
	Agriculture	4	5	5	4	4	3	41	41	40	32	31	26	22
	AGGREGATE	4	5	8	5	5	6							
Thailand	Manufacturing	10	10	7	2	5	3	17	22	28	31	30	32	31
	Transportation	6	10	8	6	5	5	5	4	5	6	7	8	9
	Commercial	7	7	6	1	4	5	49	52	51	50	48	48	51
	Agriculture	4	4	3	4	3	–1	29	22	15	13	14	12	10
	AGGREGATE	7	7	6	2	4	3							
Singapore	Manufacturing	10	7	7	4	8	1	20	25	22	21	21	23	20
	Transportation	14	8	9	6	5	4	7	13	13	14	15	13	13
	Commercial	6	8	9	3	7	4	71	62	64	65	64	64	67
	Agriculture	2	-6	-2	-7	-1	1	2	1	0	0	0	0	0
	AGGREGATE	8	8	8	3	7	3							
Philippines	Manufacturing	6	1	3	2	4	7	29	31	27	27	26	24	25
	Transportation	5	3	5	7	6	7	4	5	5	5	6	7	7
	Commercial	5	3	4	3	6	7	44	44	49	50	51	55	57
	Agriculture	4	1	2	3	3	1	22	21	18	17	17	14	10
	AGGREGATE	5	2	4	3	5	6							
Malaysia	Manufacturing	11	10	12	3	5	5	14	18	26	32	31	28	28
	Transportation	13	8	11	5	6	8	4	7	8	9	10	10	11
	Commercial	9	6	10	3	7	6	39	41	41	43	44	49	51
	Agriculture	5	3	1	1	4	0	44	34	25	16	15	12	10
	AGGREGATE	8	6	9	3	6	5							

around 31% in 2001, before it fell to 28% in 2016. On the other hand, the contribution of agriculture sector dropped from 49% in 1971 to approximately 17% in 2016. The greatest contribution in the economy came from the commercial sector, which was relatively steady at around 40% on average during the study period. Meanwhile, the transportation sector had the smallest contributor to Indonesia's economy. The structural changes in Indonesia from an agricultural to a mainly manufacturing economy demonstrates a significant development in its economic policies. This structural shift is the key indicator of the successful transition to industrialisation in Indonesia.

Composition of total energy consumption by sector

Total energy consumption in ASEAN-6 accounted for around 276 million tonnes of oil equivalent (MToE) in 2016. In 2016 (Table 2), total energy consumption

Table 2. Energy Consumption shares and annual growth rate of ASEAN-6

Country	Sectors	Annual growth rate energy consumption (%)						Share of total (%)						
		71-81	81-91	91-97	97-01	01-11	11-16	71	81	91	97	01	11	16
Indonesia	Manufacturing	17	12	8	3	3	0	35	49	56	56	52	46	41
	Transportation	9	6	9	3	6	5	58	44	38	38	38	45	51
	Commercial	13	12	15	9	5	5	2	2	3	3	5	6	6
	Agriculture	11	5	9	17	−1	−3	5	4	3	3	5	3	2
	AGGREGATE	12	9	8	4	4	2							
Vietnam	Manufacturing	9	2	7	5	8	8	66	83	71	63	61	59	63
	Transportation	8	11	16	7	11	4	34	12	20	26	27	33	29
	Commercial	N/A	34	16	13	4	8	0	2	5	7	9	6	6
	Agriculture	N/A	16	11	0	4	3	0	3	4	4	3	2	2
	AGGREGATE	8	4	9	6	8	7							
Thailand	Manufacturing	5	8	11	1	4	5	51	47	42	42	44	45	48
	Transportation	6	11	10	−2	4	4	34	38	43	43	40	38	39
	Commercial	10	17	13	1	6	0	3	4	7	8	8	10	8
	Agriculture	4	6	8	2	3	−4	12	11	8	7	8	7	5
	AGGREGATE	5	10	10	−1	4	3							
Singapore	Manufacturing	10	2	6	36	10	2	27	30	20	25	45	56	60
	Transportation	7	5	1	1	4	−3	65	59	54	49	36	28	23
	Commercial	17	22	3	3	5	2	8	11	26	26	20	17	18
	Agriculture	N/A	6	3	9	70	136	0	0	0	0	0	0	0
	AGGREGATE	8	6	2	11	7	1							
Philippines	Manufacturing	4	2	8	-5	3	3	36	43	38	35	30	36	31
	Transportation	0	4	12	0	−1	8	54	42	49	55	56	47	50
	Commercial	16	3	7	10	4	7	3	9	9	8	12	16	17
	Agriculture	2	-4	7	−7	2	8	7	6	3	2	2	2	2
	AGGREGATE	2	2	10	−1	1	6							
Malaysia	Manufacturing	5	6	9	4	2	3	60	57	50	48	46	41	38
	Transportation	6	9	10	7	3	8	36	38	43	42	44	44	50
	Commercial	7	12	12	10	6	2	4	5	7	7	9	12	11
	Agriculture	98	N/A	119	−28	54	−11	0	0	1	2	0	3	1
	AGGREGATE	5	8	10	5	3	5							

in the manufacturing and transportation sectors accounted for more than 80% of all consumption in ASEAN-6 countries. The trend of total energy consumption from 1971 to 2016 clearly demonstrates the dominance of these two sectors' share compared to the remaining sectors. The increase in energy consumption from manufacturing and transportation is potentially due to advances in technology, while the increase in the commercial sector is a result of increasing incomes due to economic development. Energy consumption in Indonesia increased from 4,648 KTOE in 1971 to 92,946 KTOE in 2016, with an average annual growth rate of 7.18%. For the same period, total energy consumption in both manufacturing and transportation sector also increased from 1,625 KTOE and 2,692 KTOE in 1971 to 37,732 and 47,249 KTOE in 2016 with an average annual growth rate of 8.32% and 6.74%, respectively. Indonesia's manufacturing and transportation sector were responsible for the largest share of the

Table 3: Energy intensity trend ASEAN-6

Country	Sectors	Energy Intensity (KTOE/ million 2010 USD prices)						
		1971	1981	1991	1997	2001	2011	2016
Indonesia	Manufacturing	0.32	0.38	0.29	0.25	0.27	0.22	0.17
	Transportation	1.56	1.18	1.05	1.12	1.24	0.62	0.51
	Commercial	0.00	0.01	0.01	0.01	0.02	0.02	0.02
	Agriculture	0.01	0.01	0.02	0.02	0.04	0.02	0.02
	Aggregate EI	0.08	0.12	0.13	0.14	0.16	0.13	0.12
Vietnam	Manufacturing	1.41	1.95	1.63	1.20	1.00	1.06	1.00
	Transportation	2.13	0.79	1.14	1.63	1.70	2.11	1.89
	Commercial	0.00	0.02	0.03	0.04	0.05	0.05	0.05
	Agriculture	0.00	0.02	0.02	0.03	0.03	0.03	0.03
	Aggregate EI	0.28	0.31	0.26	0.27	0.28	0.36	0.37
Thailand	Manufacturing	0.48	0.28	0.24	0.28	0.26	0.25	0.27
	Transportation	1.19	1.17	1.26	1.41	1.01	0.85	0.78
	Commercial	0.01	0.01	0.02	0.03	0.03	0.04	0.03
	Agriculture	0.07	0.07	0.09	0.10	0.10	0.10	0.08
	Aggregate EI	0.16	0.13	0.16	0.20	0.18	0.18	0.17
Singapore	Manufacturing	0.07	0.07	0.04	0.04	0.09	0.11	0.12
	Transportation	0.48	0.26	0.19	0.12	0.10	0.09	0.07
	Commercial	0.01	0.01	0.02	0.01	0.01	0.01	0.01
	Agriculture	0.00	0.01	0.01	0.02	0.03	0.00	0.00
	Aggregate EI	0.05	0.06	0.05	0.03	0.04	0.04	0.04
Philippines	Manufacturing	0.17	0.15	0.16	0.20	0.15	0.14	0.11
	Transportation	1.70	1.01	1.10	1.59	1.18	0.59	0.62
	Commercial	0.01	0.02	0.02	0.03	0.03	0.03	0.03
	Agriculture	0.04	0.03	0.02	0.02	0.02	0.01	0.02
	Aggregate EI	0.14	0.11	0.11	0.16	0.13	0.09	0.09
Malaysia	Manufacturing	0.91	0.49	0.33	0.28	0.30	0.23	0.21
	Transportation	1.76	0.87	0.96	0.87	0.93	0.66	0.66
	Commercial	0.02	0.02	0.03	0.03	0.04	0.04	0.03
	Agriculture	0.00	0.00	0.01	0.03	0.01	0.03	0.01
	Aggregate EI	0.21	0.16	0.17	0.19	0.21	0.15	0.15

country's end-use energy demand accounting for around 80 per cent (Table 2). Both the manufacturing and transportation sectors are the highest energy-consuming sectors in Indonesia across the study period, where both sectors share approximately 90% of energy use across all sectors in 2016. Table 2 shows the summary of ASEAN-6 countries' energy consumption shares and an annual growth rate of energy consumption from 1971 to 2016.

Like other developing countries worldwide, the large transportation energy consumption in these ASEAN-6 countries is mainly due to rapid population growth and urbanisation. Here the growing numbers of vehicles, increased urbanisation and traffic congestion were the major causes of high energy consumption in the transportation sector. This tendency has also been apparent in all other ASEAN countries (ACE, 2017).

Energy intensity

Energy intensity reflects not only how much energy is utilised in the economy but also the changes in energy consumption across sectors. Aggregate energy Intensity in Indonesia has fluctuated moderately in a range of 0.08 to 0.16 oil equivalent per million dollars (constant 2010 $US prices) from 1971 to 2016 (see Table 3). The highest energy intensity in Indonesia came from the transportation sector with 1.56 in 1971 that decreased to 0.51 in 2016. Following the transportation sector, the manufacturing sector was second highest at 0.32 in 1971 and declined to 0.17 in 2016. While the commercial and agriculture sectors had the smallest energy intensity ranging from 0 to 0.04 from 1971 to 2016. Table 3 shows the summary of ASEAN-6 countries energy intensity from 1971 to 2016.

From 1997 to 2016, the intensity of the two major energy-using sectors (manufacturing and transport) in Indonesia dropped significantly, although the aggregate energy intensity had not declined substantially. In 1997, the transportation and manufacturing sector energy intensity decreased from 1.12 and 0.25 to 0.51 and 0.17, respectively. However, the aggregate energy intensity only reduced from 0.14 in 1997 to 0.12 in 2016. The reason for this trend is that the level of the energy intensity of transport sector is three to four times that of the manufacturing sector, therefore the big shift to transport in output has increased the aggregate energy intensity, despite of the decline in the intensity of transport sector. Overall, there was a significant drop in the manufacturing and transportation sectors aggregate energy intensity in most ASEAN-6 countries. For instance, in Indonesia, the manufacturing sector energy intensity in 2016 declined by 50% compared to the 1971 level. Indeed, the transportation energy intensity of Indonesia decreased even further compared to the manufacturing sector as in 2016 it dropped to one third compared to its level in 1971. These significant decreases not only occurred in Indonesia but also in Malaysia. Energy intensity in the manufacturing and transportation sector in Malaysia in 2016 dropped to one-fourth and less than a half, respectively, compared to its level in 1971.

Sub-periods decomposition

This study examined ASEAN-6 energy intensity into sub-periods decomposition analysis. The analysis was conducted for seven sub-periods: 1971 to 1981, 1981 to 1991, 1991 to 1996, 1996 to 1998, 1998 to 2001, 2001 to 2011 and 2011 to 2016 (Fig. 2). These sub-periods analyses aim to provide information about the changes that occurred in the ASEAN-6 economy during the study period; specifically, before and after the Financial Crisis. Indonesia had a significant structural change throughout the first three sub-periods (1971 to 1981, 1981 to 1991 and 1991 to 1996), where the structural effect surged the aggregate energy intensity. During the period of crisis (1996 to 1998 and 1998 to 2001), the energy intensity increased by 14% and 7%, respectively. Both energy intensity increases were due to the increase in intensity effect. However, in the last two periods of 2001 to 2011 and 2011 to 2016, the aggregate energy intensity in Indonesia fell quite significantly to around 19% and 13%, respectively, compared to the base years of 2011 and 2016. Indonesia's energy intensity trend confirmed the previous result of Voigt *et al*. (2014) which showed that the structural effect peaked from 1999 to 2000 and decreased thereafter, shaping the overall trend of Indonesia's energy intensity. Similarly, to Indonesia, Malaysia also had a significant structural change in the first three sub-periods (1971 to 1981, 1981 to 1991 and 1991 to 1996). During the period of crisis, aggregate energy intensity in Malaysia increased by 1% and 8%, respectively. However, in the last two sub-periods of 2001 to 2011 and 2011 to 2016, energy intensity declined by around 25% and 2%, respectively.

Singapore had the lowest aggregate energy intensity during the period 1981 to 1991 and 1991 to 1996 due to the high intensity effect. In Singapore, the role of structural effect was not as significant as intensity effect across the sub-periods analysis except in 1971 to 1981, where the structural effect brought up energy intensity to 147% of that prevailed in 1971, while the intensity effect led to a fall in aggregate energy intensity to 70%. During the period of crisis (1996 to 1998 and 1998 to 2001) energy intensity increased by 1% and 25%, respectively, compared

Fig. 2: Period wise energy intensity decomposition (A, B, C, D, E and F)

to the 1996 and 1998 base levels. However, in the last period of 2011 to 2016, energy intensity decreased by 11% compared to the 2011 base level. Thailand's energy intensity fell by 18% from 1971 to 1981, but the next two periods — 1981 to 1991 and 1991 to 1996 — the energy intensity increased by around 20% to 23%. Both increases in energy intensity were due to the increase in the structural effect and intensity effect. However, during the crisis period 1996 to 1998 and 1998 to 2001, the energy intensity declined by 3% to 4%, due to the decreasing intensity effect. The decrease in energy intensity also occurred until the end of sub-periods of (2001 to 2011 and 2011 to 2016). In the beginning period 1971 to 1981, Vietnam's energy intensity increased by 9% compared to the 1971 base level, due to an increase in the intensity effect. But in the period 1981 to 1991, the energy intensity decreased by 15% compared to the 1981 base level. During the crisis period of (1996-1998 and 1998-2001), energy intensity increased to around 2% as a result of an increase in the structural effect. The energy intensity peaked in the period 2001 to 2011 for around a 31% increase compared to the 2001 base level, due to the increase in both structural and intensity effect. However, at the end of the 2011 to 2016 period, energy intensity decreased about 2% compared to the 2011 base level; this occurred due to a decrease in the intensity effect. Energy intensity in the Philippines from 1971 to 1981 decreased by around 22% compared to the 1971 base level, where this due to a decrease in intensity effect. From 1981 to 1991, energy intensity only increased by 2%, however, from 1991 to 1996, energy intensity surged by around 35% compared to the 1991 base level. This was due to an increase in the intensity effect. During the Financial Crisis, energy intensity only increased by 3% compared to the 1996 base level. In the last three periods: 1998 to 2001, 2001 to 2011 and 2011 to 2016, energy intensity decreased by 13%, 31% and 2%, respectively, due to the fall intensity effect.

Comparing regional aggregate energy intensity

The aim of this sub-section is to measure regional disparities that can simultaneously capture both temporal changes and spatial differences in energy efficiency developments within each individual country in the ASEAN-6 by employing a Spatial-Temporal Index Decomposition Analysis (ST-IDA). The purpose of the spatial-temporal graph (as seen in Fig. 3) is to show a better picture of each ASEAN-6 performance across countries over a given period. It (Fig. 3) describes a multi-country performance and captures how the structural effect and the intensity effect changes over time amongst each ASEAN-6 country. As this subsection aims to provide the performance and interpret the evolution of intensity effect and structural effect of each ASEAN-6 countries before and after the 1997 economic crisis, thus it analyses the variations of the aggregate energy intensity for all ASEAN-6 countries for three consecutive years including 1973, 1997 and in 2016. The Financial Crisis was considered as part of the study in order to interpret the evolution of energy intensity at an economy level in all ASEAN-6 countries during the study period. Following the ST-IDA approach developed by Ang *et al.,* (2016), the reference region is constructed based on the weighted averages of the energy intensity and value-added shares of the ASEAN-6 countries for the selected three-year period. The reference region serves as a benchmark for ASEAN-6 countries. As shown in Fig. 3, the changes in aggregate energy intensity are described by the moves of points and arrows along with the plot diagram that depicts the changes in intensity effect and structure effect. The results of decomposition for every country for 1971, 1997 and 2016 are indicated by dots that are joined by arrows. For the reference country, the production share values, and energy intensity are calculated employing the weighted averages of the six ASEAN countries over the three years period. The origin value of (1,1) describes the reference region with an aggregate energy intensity of 0.14 KToE per million US dollars (KToE/10^6 USD) at constant 2010 prices in US dollars. This study utilises a multiplicative decomposition, therefore, the intensity and structure effects are conveyed in ratio estimations, where the measures in the y-axis and x-axis imply the ratio change from the benchmark country. Thus, a value of 1.1 means that the effect is determined to be 10% greater as compared to the benchmark country, while on the other hand, a value of 0.9 implies that the effect is 10% lower as considered to the reference country.

Fig. 3 can be divided into four quadrants, namely Quadrant I, II, III and IV. From this Figure, a positive improvement in either intensity or structural effects are represented by the country moving towards a smaller value along an axis over a period of time, which is related to the decreasing of aggregate energy intensity over time. On the other hand, a country shifting towards a greater value along an axis indicates a negative development, which contributes to an increase in aggregate energy intensity over time. Quadrant III is set in the bottom left corner and represents the best quadrant (the most energy efficient countries), where the countries in this quadrant represent fewer intensive industries and more efficient energy usage compared to the benchmark country. During the three-year study period there are only two countries that are located in Quadrant III: Singapore (in 1971) and the Philippines (in 2018). The aggregate energy intensity in these countries showed a lower than the aggregate energy intensity of the reference country. On the other hand, Quadrant I is located in the top right corner which represents the worst quadrant (or the least energy efficient nations). The countries in this quadrant have a higher structure effect (having a more intensive industry in the economic structure) and a higher intensity effect (using less efficient energy usage technology) compared to the reference country. There are two countries positioned in Quadrant I: Malaysia (in 1997) and Thailand (in 2016). Additionally, Quadrant IV is positioned in the top left which depicts those countries with less intensive industries and less efficient energy usage compared to the reference country. Most of the ASEAN-6 countries had some time of aggregate energy intensity in this quadrant, except Singapore, since Singapore was more developed compared to the rest of the ASEAN-6 countries. This situation is consistent with the fact that most of the ASEAN-6 countries are developing countries; therefore, their economy uses less energy (using less energy-intensive sectors of the economy) in the beginning of their economic development. However, along with the advancement of its economy, their economic structure shifting from less energy-intensive to a more energy-intensive sector economy over time. The shifting of economic structure can be seen from the increasing value along the horizontal axis over time. Almost all ASEAN-6 countries have shifted from Quadrant IV to another Quadrant, except Vietnam. Vietnam stayed in Quadrant IV, showing its economy comprises of less intensive industry and less efficient in energy usage compared to the rest of ASEAN-6 countries. Last, Quadrant II is in the bottom right corner. This describes the countries with a higher structure effect, but less intensity effect compared to the ASEAN-6 average. There are two countries located in this quadrant: Indonesia (in 2016) and Singapore (in 1997 and 2016). It is interesting to note that Singapore went through less intensive industry (in 1971) to more intensive industry (in 1997), but in 2016, Singapore was approaching Quadrant III showing industry in Singapore become less intensive and more energy efficient. From Fig. 3, all of the ASEAN-6 countries have improved their aggregate energy intensity (AEI) over time. The AEI of the ASEAN countries influenced by the structural and intensity factors. The graph showed that the developing countries develop their economies from less intensive energy sectors to more intensive energy sectors, for instance from agriculture to the manufacturing sector. The structural effects have improved over time; however, the magnitude is not as great as the intensity factors. This situation implies that the government economic policies are significant in determining the result of the overall energy efficiency over time in the ASEAN-6. The overall industrialisation process of the ASEAN-6 countries can be observed from the changes in its economic structure in all the ASEAN-6 economies over the 45 years of analysis. Four trends can be observed from the ASEAN-6 economy in terms of structural changes (Table 1). First, the commercial sector played a substantial role in the overall economic structures that accounted for more than 40% of the aggregate economic structure of the ASEAN-6 from 1971 to 2016. Second, the role of the manufacturing sector has increased almost two-fold in the ASEAN-6 countries, except for Singapore and the Philippines, whereas in Indonesia the share from this sector has increased almost four-fold. Third, the declining share of the agricultural sector to the total economic output of most of the ASEAN-6 countries, except Singapore. The share of the agriculture sector was prominent at the beginning

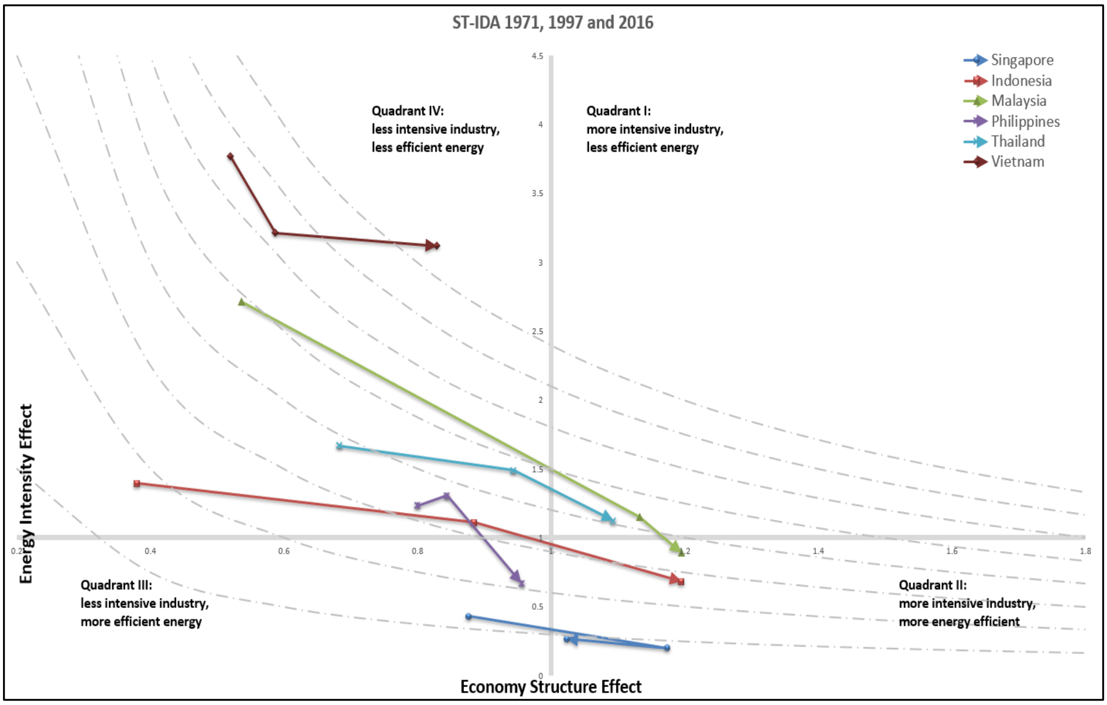

Fig. 3: Spatial-temporal IDA, 1971–1997–2016

of the 1970s, however, as most of the ASEAN-6 countries have expanded their economies, their reliance on agriculture sector decreased quite significantly over time, except for Singapore which had minimal reliance on agriculture. Fourth, the aggregate share of the transportation sector's output is the smallest during the study period, but the output from this sector increased slightly over time. The output from the transportation sector increased almost two-fold in almost all the ASEAN-6 countries, whereas in Indonesia the share from this sector increased around four-fold. The ASEAN-6 countries increased their energy consumption substantially during the period of study. The trend of total energy consumption from 1971 to 2016 demonstrates the dominance of both manufacturing and transportation sectors that accounted for more than 80% of aggregate energy consumption in the ASEAN-6. In Indonesia, particularly, both sectors consumed approximately 90 per cent of total energy use during the study period, while energy consumption from commercial and agriculture sectors was negligible. In general, the level of energy intensity in Indonesia had an average trend compare to other ASEAN countries. It increased moderately in the middle period but declined steadily at the end of the period. The increasing trend of energy intensity in Indonesia occurred mostly as a result of the high magnitude of the structural effect over the intensity effect which indicated the industry mix was becoming more energy intensive. The role of the agriculture sector was significant at the beginning of the 1970s and comprised around a half of the economic structure. However, as Indonesia's expanded its economy, the reliance on agriculture sector decreased slightly over time and reached around 20% of the economy in late 2016. On the other hand, the increasing share of manufacturing and commercial sectors in the economy played a significant role in the overall economic structural changes, where both sectors accounted for around 70% of the economy. This evidence shows that industrialisation in Indonesia has become a great influence on the overall economy. Energy consumption growth in Indonesia has not coincided with the deteriorating of energy intensity, mainly because of structural shifts in the economy and new investment in the economic sector. From 2000 to 2016, the aggregate value-added was doubled, total energy consumption rose but less than the aggregate value-added growth, noting that the energy intensity improved (or decreased). Other ASEAN countries also experienced a similar trend, whereas the energy intensity has improved over time. The improvement in intensity effect in all ASEAN-6 countries has become the primary driving force for the aggregate energy intensity to decline, while the magnitude of the structural effect is limited. Based on the energy intensity patterns of ASEAN-6, Indonesia and Malaysia demonstrated a greater impact on structural changes than other ASEAN countries. The structural changes had a more significant impact on increasing the aggregate energy intensity in Indonesia and Malaysia than in the other ASEAN-6 countries. In other words, this shows that these countries made substantial industrialisation process by moving from less energy-consuming sectors such as agriculture to more energy-intensive sectors such as manufacturing.

CONCLUSION

This study decomposed the changes in aggregate energy intensity in the ASEAN-6 countries for the period 1971 to 2016. For this goal, this study employed a multiplicative LMDI-II method and ST-IDA. This study demonstrated that the aggregate trend of the changes of ASEAN energy intensity fluctuated moderately for all ASEAN-6 countries, where variations in energy intensity appeared in these countries. As an overall trend, energy intensity in Singapore was the lowest and markedly stable during the study period, while Vietnam had the highest and more fluctuating energy intensity. Indonesia, Malaysia, the Philippines and Thailand have more moderate energy intensity trend compare to other ASEAN-6 countries. Two distinct periods are evident in terms of trends in aggregate energy intensity in Indonesia, and in some other ASEAN countries (Thailand, Malaysia and the Philippines). For Indonesia, aggregate energy intensity rose steadily by an average of 3% per year from 1971 to 1999, more than doubling over this period, while from 1999 to 2001 energy intensity fell by 1% per annum on average, falling by 17% overall. While this change in the trend after the Financial Crisis is also evident in the three countries mentioned, it is most pronounced in Indonesia and becomes a central theme of this analysis. By 2016 Indonesia's aggregate energy intensity was towards the bottom of the range of the five larger developing members of ASEAN-6, is below that of Thailand and Malaysia and well below that of Vietnam, but above that of the Philippines. Each of these countries has an energy intensity much higher than Singapore. As observed in the analysis, the main energy consumer in all ASEAN-6 countries comes from the manufacturing and transportation sector, where these two sectors account for more than 70% of total national energy usage. In Indonesia these two sectors consumed more than 80% of total energy consumption during the study period. In addition to its consumption share, both manufacturing and transportation energy intensity in Indonesia had dropped significantly compared to its level in 1971. In 2016, the manufacturing energy intensity declined to a half and the transportation decreased up to one-third compared to its level in 1971. From the above findings, it can be observed that Indonesia experienced a substantial structural shift in its economy from less energy-consuming sectors (that is, agriculture) to more energy-intensive sectors (that is, manufacturing). In terms of sectoral energy intensity reduction, the manufacturing and transportation sectors were the two highest sectors that drove the aggregate energy intensity to decline. The significant drop in both transportation and manufacturing sector energy intensity needs to be further investigated.

AUTHOR CONTRIBUTIONS

D. Setyawan performed all of the process in developing this paper, including, compiled the data, interpreted the data, the literature review, experimental design, analysed, prepared the manuscript text, manuscript edition, and manuscript finalisation for journal publication.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

ACE	ASEAN Centre for Energy
ADB	Asian Development Bank
AEI	Aggregate energy intensity
ASEAN	Association of South East Asian Nations
BoE	Barrels of Oil Equivalent
CO_2	Carbon dioxide
C1, C2	Country 1, Country 2
C1,0	Country 1 in year 0
C2,0	Country 2 in year 0
Cu	Country as the benchmark
DEA	Data Envelopment Analysis
DINT	Intensity effect
DSTR	Structural effect
DTOT	Aggregate energy intensity
EU	European Union
EU-27,EU-15	Twenty-seven or fifteen member states of the European Union
exp	Exponential
GDP	Gross Domestic Product
GHG	Greenhouse Gas Emissions
IDA	Index Decomposition Analysis
IEA	International Energy Agency
IMF	International Monetary Fund
KToE	Kilotonne of Oil Equivalent
LMDI-II	Logarithmic Mean Divisia Index II
MBoE	Million Barrels of Oil Equivalent
MToE	Million tonnes of oil equivalent
OECD	Organisation for Economic Co-operation and Development
SFA	Stochastic Frontier Analysis
ST-IDA	Spatial-Temporal Index Decomposition Analysis
TFC	Total Final Energy Consumption
TFEE	Total-Factor Energy Efficiency
ToE	Tons of Oil Equivalent
UNSD	United Nations Statistics Division
US$	United States Dollars
USA	United States of America
%	Percentage
$\sum$	Sum
w	weighted
ln	Natural logarithm
Sk	Share k sectors
I	Energy Intensity
k	Number of sectors included in the formula

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