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Energy-Related CO₂ Emissions Growth in ASEAN Countries: Trends, Drivers and Policy Implications

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Abstract: The primary objective of this paper is to analyse the growth of energy-related CO₂ emissions in ASEAN (Association of Southeast Asian Nations), with specific emphasis on identifying its trends and underlying drivers. This objective is premised on the arguments that: (1) there is a general lack of analysis of energy-related CO₂ emissions growth across ASEAN countries; and (2) such an analysis is critical, because it could enable an assessment to be made of the efficacy of existing energy policies for reducing emissions. Decomposition analysis is the main approach adopted in this paper. The findings of this paper suggest that the growth of energy-related CO₂ emissions has slowed in some major emitters in the region, due to energy efficiency improvement, and, to a lesser extent, a gradual switch in energy fuel mix towards lower emission sources (gas and renewables). However, this improvement is unlikely to drive a major transformation in the energy sectors of the region to the extent considered adequate for redressing the challenge of rising emissions, as indicated by a steady emissions growth in most ASEAN countries over the entire study period (1971–2016). By implication, this suggests that a significant scale-up of existing policy effort is needed to rectify the situations.

Keywords: CO₂ emissions; decomposition analysis; ASEAN countries; Indonesia; Malaysia; Thailand

1. Introduction

The ASEAN (Association of Southeast Asian Nations) region is one of the most dynamic and fast-growing economic regions in the world [1–3]. Energy mix in the region has historically been dominated by fossil fuels, such as coal in Indonesia, the Philippines and Malaysia and oil and gas in Vietnam, Thailand and Singapore [4]. This domination has contributed to the provision of cheap and reliable energy in these countries and consequently to their socioeconomic prosperity [5,6]. It has however made the energy sector the region's largest emitter of greenhouse gases (GHG), and hence the largest contributor to global warming, one of the most pressing challenges facing humanity [7–10].

In the absence of any significant decarbonisation in the energy technology fuel mix, energy-related GHG emissions in the ASEAN region will almost double by 2040, reaching 2.3 billion tonnes [11]. This will worsen the global warming situation and potentially threaten the socioeconomic prosperity of the

region. This is especially true if one notes the fact that the ASEAN region is among the most vulnerable regions in the world to the impacts of climate change. According to the Climate Risk Index [12], five of the twenty countries most affected by climate change are located in the ASEAN region: Myanmar (3), the Philippines (5), Vietnam (9), Thailand (13), and Cambodia (19).

Clearly, there is an imminent need for energy decarbonisation in the ASEAN region. While a myriad of factors is considered essential for facilitating such decarbonisation, sound and effective policies are key factors. A pre-requisite for developing such policies is an understanding of the nature of energy-related GHG emissions growth in the region and its underlying drivers. However, a review of existing literature suggests that most studies have tended to focus on the analysis of emissions growth in large emitting countries, particularly the United States [13–15], major European countries [16–18] and large developing countries, such as China [19–21] and India [22,23]. Relatively few studies have focused on ASEAN countries. Of these, most have focused on assessing issues indirectly related to energy-related GHG emissions, such as energy conservation and efficiency [24–27], energy security [28], alternative fuel [29–32] and renewable energy [33–35]. Limited attention has been paid directly to GHG emissions from fuel combustion.

This lack of attention is probably due to the developmental imperatives (e.g., industrial growth and poverty alleviation) of expanding energy supply in the ASEAN countries [5]. While the issue of rising GHG emissions from combustion of fossil fuels is a concern, it has become subservient to these immediate considerations [29]. Nevertheless, in view of the fact that a significant proportion of future growth of GHG emissions is likely to come from the ASEAN countries [11], it would be worthwhile to develop some analyses focusing on these countries.

Against the above backdrop, the main purpose of this paper is to analyse the growth of energy-related CO₂ emissions in ASEAN countries over the period 1971–2016, with specific emphasis on understanding the nature of this growth and its underlying drivers. Other greenhouse gases are not considered in this analysis, as they constitute a relatively small share of GHG emissions from combustion of fossil fuels.

To the best of our knowledge, this paper is the first of its kind in terms of its focus, namely the growth of energy-related CO₂ emissions in ASEAN countries. Insights gained from the analysis undertaken in this paper, we contend, will make significant contribution to the literature. This contribution comes in two parts. (1) The analysis undertaken in this paper would contribute to the development of an empirical basis for assessing the efficacy of existing policies for emissions reduction in ASEAN countries. This assessment could provide valuable insights for policymakers in the region as they design energy policies to redress the challenge of rising CO₂ emissions from combustion of fossil fuels in their respective countries. (2) This paper could contribute to the development of a complete understanding of the growth of energy-related CO₂ emissions and the relative contribution of various driving factors to this growth. This understanding could establish the foundations on which further analyses on the topic could be built. More specifically, it will enable the identification of the most influential factors behind emissions growth. Further research can then be undertaken to assess the mechanisms through which these factors may have impacted emissions growth.

This paper is organised as follows. Section 2 discusses the methodology employed in this paper to analyse the growth of energy-related CO₂ emissions. Section 3 presents the results of the analysis and discusses key insights for policymakers. Section 4 presents some broad conclusions of the paper.

2. Methodology

2.1. Literature Review

Various methods have been adopted in the literature to assess the growth of energy-related CO₂ emissions. These methods can be categorised into two broad groups: econometric or multivariate-statistical approach and decomposition approach.

The econometric-based approach has been widely used to analyse the impact of some select factors on the growth of energy-related CO₂ emissions, including, economic growth [36–39], foreign direct investment [40,41], renewable energy consumption [42–44], urbanisation and industrialisation [45–47]. In these analyses, the selection of factor(s) is typically determined based on some theoretical foundations or hypothesised statement. Statistical tests are then performed on these so-called exogenous factors to assess their impact on emissions. The main focus of such an assessment is to first identify the factors that have the most statistically significant impacts on emissions, and then examine the mechanisms through which these factors may have impacted emissions [48].

There are also studies that have used the decomposition approach to analyse energy and environmental issues. A comprehensive review of these studies is available in the literature [49–51]. The guiding philosophy of the decomposition approach is the divide-and-conquer principle, where total GHG emissions are broken down, or decomposed, into emissions caused by several quantifiable factors under the *ceteris paribus* condition, and a complete understanding is developed on these factors [48]. In this approach, the selection of factors is typically determined based on the theoretical foundation laid by the environmental literature, specifically the IPAT (impact as a function of population, affluence and technology) [52,53] and Kaya [54,55] identities, where environmental impact is assessed in terms of simple, complete, but well-confined, factors. Identity function is then constructed to represent total emissions as the outcomes of emissions caused by various factors (e.g., population, affluence and technology). The product rule of differentiation is applied on this identity function to explain emissions growth in terms of the summation of weighted-average change in its driving factors [56,57].

The above discussion suggests that the econometric-based approach is a useful tool for assessing the mechanisms through which a particular factor may have impacted emissions. Its usefulness is however questionable on the grounds that it cannot provide a complete understanding of emissions growth and its underlying drivers—the main focus of this paper. In contrast, the underlying analytics of the decomposition approach, as noted above, allows for the assessment to be made in regard to the nature of energy-related CO₂ emissions growth and the relative contribution of various driving factors to this growth. This assessment could enable the identification of the most influential factors behind emissions growth and provide a guidance for future research on the topic. In view of this advantage of the decomposition approach, the core methodological framework employed in this paper centres on the application of the decomposition approach.

There are various techniques of decomposition methods. These techniques differ in terms of the weight applied: Laspeyres index method relies on the base-period weight, Paasche index, on the end-period weight, and Divisia index is the average of the two extremes [19]. Further, the latter method is classified into two: arithmetic mean Divisia index (AMDI) and logarithmic mean Divisia index (LMDI), which differs in terms of the mathematical application of the weight-term (i.e., simple arithmetic or slightly more complicated logarithmic) [58].

The method employed in this paper is developed based on the LMDI method proposed by Ang and Liu [59]. In addition to a robust theoretical foundation, and ease of formulation and interpretation, which is common to most decomposition analysis methods, the appropriateness of LMDI is mainly justified on the following grounds. The first is its ability to provide “perfect” decomposition without unexplained residual term. It is widely recognised that residual term is large in both cross-country decomposition, where large variation between countries (for example, GDP per capita for Cambodia and Singapore) exists, as well as in time-series decomposition, where residual from analysis accumulates over time [58]. A large residual term, as argued by Ang and Liu [60], may “lead to problems in result interpretation and the question about the usefulness of the results obtained”. Second, it satisfies both factor- and time-reversal tests, where the variations estimated across all factors, and between all years, are equal in absolute terms [48]. Lastly, it can effectively handle a problem of zero and negative value arising in data of consecutive years [50,58].

2.2. LMDI Method Adopted in This Paper

The LMDI method has been used for assessing energy-related GHG (specifically, CO₂) emissions and its underlying drivers in various countries and country groups [61–63]. In these studies, emissions growth has been decomposed into five factors. In contrast, seven factors are considered in this paper. These factors are however grouped into three broad categories, namely population, affluence and technology, in order to be consistent with the IPAT identity [52,53], due to its ease of interpreting the causes of emissions. The driving factors considered in this paper are summarised in Figure 1.

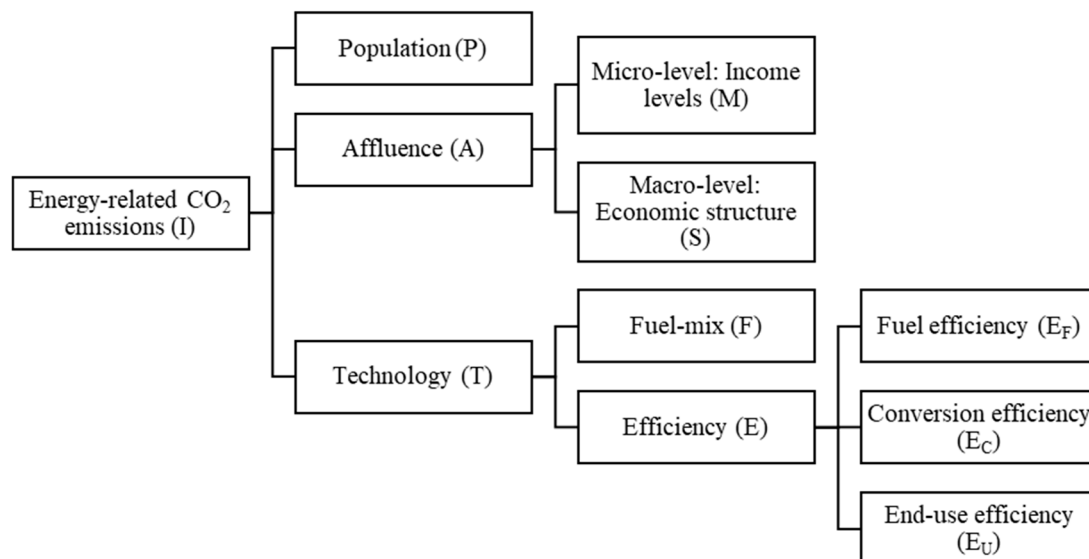


Figure 1. Driving factors of energy-related CO₂ emissions.

The mathematical expression of IPAT identity, employed in this paper, begins as follows:

$$I = \sum_j I_j = P \cdot A \cdot T = \sum_j P \cdot \frac{Y_j}{P} \cdot \frac{I_j}{Y_j} \quad (1)$$

where I_j is the amount of CO₂ emissions from sector j for a particular country. In this equation, total CO₂ emissions (I) is first decomposed into a product of three key components: population (P), affluence ($A = \sum_j Y_j/P$) and technology ($T = I_j/Y_j$), where Y_j is the level of output produced (or, conversely, income obtained) by sector j .

The affluence is further decomposed into two components: income levels ($M = Y/P$) and economic structure ($S = Y_j/Y$). Similarly, the technology is decomposed into two components: fuel mix ($F = FE_{fj}/FE_j$) and efficiency ($E = \sum_f I_{fj}/Y_j$), where subscript f denotes fuel types. The measure of efficiency (E) captures the intensiveness of CO₂ emissions embedded in the products produced in each sector; the lower is the value of this indicator, the higher contribution it makes to reduce CO₂ emissions. Such a measure of efficiency is further decomposed into three components: carbon intensity of primary energy consumption (fuel efficiency, $E_F = I_{fj}/PE_{fj}$), efficiency of converting primary energy into final energy (conversion efficiency, $E_C = PE_{fj}/FE_{fj}$) and efficiency of final energy use in end-use sector j (end-use efficiency, $E_U = FE_j/Y_j$). These three efficiency components reflect the three segments of energy supply chain, namely fuel supply, conversion and end-use.

The above noted formulations result in an expanded IPAT identity as in Equation (2):

$$I = \sum_{fj} I_{fj} = \sum_{fj} P \cdot \frac{Y}{P} \cdot \frac{Y_j}{Y} \cdot \frac{FE_{fj}}{FE_j} \cdot \frac{I_{fj}}{PE_{fj}} \cdot \frac{PE_{fj}}{FE_{fj}} \cdot \frac{FE_j}{Y_j} \quad (2)$$

where PE and FE denote primary energy and final energy, respectively. Equation (2) can be written in a symbolised form as:

$$I = P \cdot M \cdot S \cdot F \cdot E_F \cdot E_C \cdot E_U \quad (3)$$

Equation (3) forms the basis for decomposing total CO₂ emission growth in this paper. That is, the observed historical growth in CO₂ emissions is attributable to seven factors identified in this equation. Following Ang [50], Equation (3) is differentiated with respect to time, then each factor in this equation is integrated over the continuous time-period, and finally Sato–Vartia logarithmic method is used to approximate the time-differentiation [64,65]. This process of decomposing changes in total CO₂ emissions is implemented in this paper both additively and multiplicatively.

For additive decomposition, the components (P , M , S , F , E_F , E_C , and E_U) on the right-hand-side of Equation (3) are expressed in absolute terms (MtCO₂-e per toe). This results in the formulation of decomposition equation as follows:

$$\begin{aligned} \Delta I = & \omega \cdot \ln\left(\frac{P_t}{P_s}\right) + \omega \cdot \ln\left(\frac{M_t}{M_s}\right) + \sum_j \omega_j \cdot \ln\left(\frac{S_{t,j}}{S_{s,j}}\right) + \sum_{fj} \omega_{fj} \cdot \ln\left(\frac{F_{t,fj}}{F_{s,fj}}\right) + \sum_{fj} \omega_{fj} \\ & \cdot \ln\left(\frac{E_{Ft,fj}}{E_{Fs,fj}}\right) + \sum_{fj} \omega_{fj} \cdot \ln\left(\frac{E_{Ct,fj}}{E_{Cs,fj}}\right) + \sum_j \omega_j \cdot \ln\left(\frac{E_{Ut,j}}{E_{Us,j}}\right) \end{aligned} \quad (4)$$

where subscripts s and t refer to the value of variables at the start and end of the time interval of interest. ω is the logarithmic mean of CO₂ emissions over those two periods, and is further defined as:

$$\omega_{fj} = \frac{I_{t,fj} - I_{s,fj}}{\ln I_{t,fj} - \ln I_{s,fj}} \quad (5)$$

For multiplicative decomposition, the components (P , M , S , F , E_F , E_C , and E_U) on the right-hand-side of Equation (3) are expressed as indices in the following exponential form:

$$\begin{aligned} dI = & \exp\left[\omega \cdot \ln\left(\frac{P_t}{P_s}\right)\right] + \exp\left[\omega \cdot \ln\left(\frac{M_t}{M_s}\right)\right] + \exp\left[\prod_j \omega_j \cdot \ln\left(\frac{S_{t,j}}{S_{s,j}}\right)\right] \\ & + \exp\left[\prod_{fj} \omega_{fj} \cdot \ln\left(\frac{F_{t,fj}}{F_{s,fj}}\right)\right] + \exp\left[\prod_{fj} \omega_{fj} \cdot \ln\left(\frac{E_{Ft,fj}}{E_{Fs,fj}}\right)\right] \\ & + \exp\left[\prod_{fj} \omega_{fj} \cdot \ln\left(\frac{E_{Ct,fj}}{E_{Cs,fj}}\right)\right] + \exp\left[\prod_{fj} \omega_{fj} \cdot \ln\left(\frac{E_{Ut,j}}{E_{Us,j}}\right)\right] \end{aligned} \quad (6)$$

where ω is defined slightly differently to Equation (5) as:

$$\omega_{fj} = \frac{(I_{t,fj} - I_{s,fj}) / (\ln I_{t,fj} - \ln I_{s,fj})}{(I_t - I_s) / (\ln I_t - \ln I_s)} \quad (7)$$

2.3. Data Considerations

The previous section discusses the decomposition method employed in this paper. This method is used for analysing CO₂ emissions for nine ASEAN countries. Laos is not included in this analysis, due to the lack of energy consumption data. The timeframe for the analysis is 1971–2016, for six ASEAN countries (Indonesia, Malaysia, Myanmar, Philippines, Thailand and Singapore). For Brunei, Vietnam and Cambodia, the timeframes for the analysis are 1975–2016, 1990–2016 and 1995–2016, respectively. The selection of these timeframes is mainly based on data availability, as time-series data are incomplete for Brunei, Vietnam and Cambodia.

Data on population, primary and final energy consumption and CO₂ emissions are taken from the International Energy Agency online databases [66,67]. This paper considers four types of primary energy sources, namely coal, natural gas, oil and non-fossil energy. These energy sources are either used directly in three economic sectors (namely, agriculture, industry and services), or used to generate

electricity consumed in these three sectors. This paper also considers five types of final energy sources, namely coal, natural gas, oil, non-fossil energy and electricity. These energy sources are used as final energy consumed in the agricultural, industrial and services sectors.

GDP data are taken from the World Bank's world development indicators database [68]. Real GDP in 2010 prices, in purchasing power parity terms, is used in this paper. This selection is based on the considerations that: (1) real GDP excludes GDP changes caused by inflation; and (2) purchasing power parity excludes the influence of exchange rate variations in determining standards of living across countries. It therefore better reflects the comparable value of a country's economic output (or income), and hence the measure of affluence. In addition, sectoral share of GDP is also collected for three sectors, namely agriculture, industry and services. This information is used to analyse the impacts of economic structural change on emissions growth.

3. Analysis of Energy-Related CO₂ Emissions Growth

This section analyses the growth of energy-related CO₂ emissions in ASEAN countries over the period 1971–2016, based on empirical results obtained from the application of the methodology described in the previous section. The results of the analysis are presented in Table 1 (trends in the growth of energy-related CO₂ emissions) and 2 (underlying driving factors). Details and policy insights are discussed in the following.

Table 1. Energy-related CO₂ emissions growth: Main trends.

Countries	Annual Emissions (Mt)				Annual Growth Rate (%)		
	1971	1990	2010	2016	1971–1989	1990–2009	2010–2016
Brunei	0.4	3	7	6	34.2	6.7	−2.4
Cambodia	n.a.	n.a.	5	9	n.a.	n.a.	13.3
Indonesia	25	134	362	455	22.9	8.5	4.3
Malaysia	13	50	190	216	15.0	14.0	2.3
Myanmar	5	4	8	21	−1.1	5.0	27.1
Philippines	24	37	77	114	2.9	5.4	8.0
Singapore	6	29	44	45	20.2	2.6	0.4
Thailand	16	81	223	244	21.4	8.8	1.6
Vietnam	n.a.	17	126	187	n.a.	32.1	8.1
ASEAN	105	355	1041	1298	12.5	9.7	4.1

Notes: 1. Annual growth rate is calculated from annual emissions. 2. n.a. not available. Source: Estimates based on methodology described in Section 2.2.

3.1. Brunei

In Brunei, the growth of annual energy-related CO₂ emissions appears to have decelerated from 34.2% during 1971–1989 to 6.7% during 1990–2009. Fuel mix is the main driver behind this decelerating trend, contributing to a 62% reduction in emissions growth (see Table 2). Brunei's annual energy-related CO₂ emissions began to decrease from 2010 onwards, reaching 6 Mt in 2016. This emissions reduction is mainly caused by improved efficiency at both the fuel supply and conversion segments of the energy supply chain, probably reflecting intensified efforts made by the government since the early 2010s to reduce the country's energy intensity, especially in the power sector, by promoting the uptake of more efficient generation technologies [69]. Another factor responsible for the emissions reduction is lower income levels, due probably to reduced revenues from the country's petroleum sector; this sector accounts for more than half of gross value added [69].

Table 2. Energy-related CO₂ emissions growth: Key drivers.

Countries	Time Phases	Population	Affluence			Technology			
			Income	Structure	Fuel Mix	Efficiency			Overall
						Fuel	Conversion	End-Use	
Brunei	1975–1989	33	−28	52	19	25	−28	27	24
	1990–2009	45	−18	−31	−62	−10	151	25	166
	2010–2016	43	−54	13	24	−87	−124	87	−124
Cambodia	1971–1994	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	1995–2009	23	67	9	48	2	−26	−23	−47
	2010–2016	13	42	5	39	2	6	−8	0
Indonesia	1971–1989	29	49	0.7	53	1	−14	−26	−39
	1990–2009	28	57	1.5	34	−4	6	−28	−26
	2010–2016	39	130	−0.1	32	30	−27	−103	−100
Malaysia	1971–1989	39	56	11	28	13	−32	−16	−35
	1990–2009	37	51	−0.4	15	−1	−4	3	−2
	2010–2016	53	106	2	19	11	−38	−53	−80
Myanmar	1971–1989	521	168	−349	−258	−29	132	−285	−182
	1990–2009	51	420	121	31	−63	−13	−446	−522
	2010–2016	6	39	11	57	9	2	−23	−12
Philippines	1971–1989	114	43	16	9	−51	55	−87	−83
	1990–2009	73	59	14	71	27	−32	−112	−117
	2010–2016	23	64	4	14	8	6	−19	−5
Singapore	1971–1989	28	89	2	4	10	−32	1	−21
	1990–2009	103	128	−18	3	−59	−57	0	−116
	2010–2016	114	234	−57	2	−118	−85	10	−193
Thailand	1971–1989	24	65	4	19	6	−1	−18	−13
	1990–2009	18	69	3	31	−30	−20	28	−22
	2010–2016	18	135	−17	22	−57	−12	10	−59
Vietnam	1971–1989	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	1990–2009	8	48	−4	30	−3	−5	26	18
	2010–2016	14	62	−5	19	0.1	0.3	10	10

Notes: 1. Figures presented in the table are the contribution (%) made by various factors to total CO₂ emissions growth. 2. Positive contribution means increased emissions growth, whereas negative contribution means decreased emissions growth. 3. n.a., not available. Source: Estimates based on methodology described in Section 2.2.

Based on the above discussion, we identified two issues that policymakers in the country may like to consider while designing policies to reduce energy-related emissions. First, the end-user segment has made limited contribution to emissions growth, despite various energy efficiency policies having been introduced with specific emphasis on this segment [70]. Therefore, policymakers should give higher priority to energy efficiency improvement in the end-use segment by, for example, gradually proceeding electricity price reform and incrementally removing residential electricity subsidies, introducing more stringent efficiency standards for cooling and lighting systems, encouraging public transport, and promoting the uptake of energy efficient vehicles (such as, electric vehicles).

Second, fuel mix continues to make noticeable contribution (24% during 2010–2016) to emissions growth, suggesting a general lack of energy technology switch towards low emissions technologies (especially, renewables). For example, fossil fuels (especially, oil and gas) still dominated Brunei's energy fuel mix in 2019, representing more than 95% of total primary energy supply. The share of renewable, mainly from solar PV and bioenergy, was less than 1% [69]. Stronger policy support for renewable energy is therefore needed to exploit the country's significant solar and biomass potential.

3.2. Cambodia

Cambodia's annual energy-related CO₂ emissions have grown steadily from 5 Mt in 2010 to 9 Mt in 2016, representing a growth rate of 13.3% per annum (see Table 1). The main factors responsible for this increasing trend are population growth, rising income levels and growing reliance on fossil fuels for energy consumption; these three factors jointly accounted for almost 95% of emissions growth

over the period 2010–2016 (see Table 2). This is understandable if one notes that Cambodia has made noticeable socioeconomic progress in recent years with GDP growing at an average rate of 7.0% per annum from 2006 to 2016, and poverty level falling from 47.8% in 2007 to 14.0% in 2014. This socioeconomic progress has brought about significant growth in energy demand, most of which has been met by oil, coal and traditional biofuels (for example, wood) [71]. Besides, it is also worth noting that improved end-use efficiency in Cambodia, as shown in Table 2, has reduced emissions growth by 8% over the period 2000–2016. This effect has however been offset by worsening fuel supply and conversion efficiency, as indicated by positive contributions (2% and 6%, respectively) made by these two factors to emissions growth.

The above discussion suggests that socioeconomic prosperity is the main driver for emissions growth in Cambodia, as population growth and rising incomes have brought about significant growth in energy demand, and most of this demand has been met by fossil fuels (especially, oil and coal) and traditional biofuels. Further, it is also expected that Cambodia's socioeconomic progress would remain strong in the years to come, and the energy sector would play a vital role in supporting this progress. This role will, however, be challenged by foreseeable energy import dependence as a result of increasing energy demand and limited indigenous supply of fossil fuels. We suggest that the uptake of renewable sources and energy efficiency improvement are attractive options for redressing this challenge. In fact, these options are well recognised by policymakers. For example, Cambodia's National Energy Sector Development Policy gives high priority to capacity expansion, especially from low emissions technologies, and energy efficiency improvement by, for example, the removal of electricity price subsidies [71].

3.3. Indonesia

Indonesia's annual energy-related CO₂ emissions have increased considerably from 25 Mt in 1971 to 455 Mt in 2016. This has primarily been driven by population growth, rising income levels, and growing reliance on fossil fuels for energy consumption (see Table 2). However, this increasing trend, as presented in Table 1, has slowed down over the study period (1971–2016); the annual rate of emissions growth decreased from 22.9% during 1971–1990 to 8.5% during 1989–2009 and 4.3% during 2010–2016. Energy efficiency improvement seems to be the main contributing factor to this trend, as indicated by significant contributions (–39% to –100%) made by energy efficiency to emissions reduction, as presented in Table 2. Besides, fuel mix remains one of the main contributing factors to emissions growth in Indonesia, despite a steady reduction in its contribution from 53% during 1971–1989 to 34% during 1990–2009, and 32% during 2010–2016.

The above discussion suggests that policymakers should consider scaling up existing policy support for renewable energy and energy efficiency improvement because existing policy is unlikely to drive a major transformation in Indonesia's energy sector, especially to the extent considered sufficient for redressing the challenge of rising energy-related emissions. A recent forecast developed by APEC [69] should support this viewpoint. According to this forecast, a continuation of current policy (the business-as-usual scenario) would see a more than twofold increase in primary energy supply between 2016 and 2050, and more than 60% of primary energy supply would still come from fossil fuels in 2050.

3.4. Malaysia

Similar to Indonesia, energy-related CO₂ emissions have grown steadily over the entire study period (1971–2016), although this growth has somewhat decelerated, due mainly to energy efficiency improvement and, to a lesser extent, increasing use of renewables. This implies that existing policies are unlikely to transform the Malaysia's energy sector, especially to the extent considered adequate for redressing rising CO₂ emissions from combustion of fossil fuels. A significant scale-up of existing policy effort is, therefore, needed. This viewpoint is supported by a recent forecast developed by APEC [69]; it is expected that total primary energy supply would increase by 60% between 2016 and

2050 led by strong growth in oil, followed by gas and coal, under the business-as-usual scenario (reflecting a continuation of existing energy plans and policies). Renewables are also expected to experience rapid growth. Despite this growth, renewables remain the smallest element in the country's energy fuel mix, only representing about 10% of total primary energy supply.

3.5. Myanmar

In Myanmar, the growth of annual energy-related CO₂ emissions appears to have decreased slightly from 5 Mt in 1971 to 4 Mt in 1990. This decreasing trend has been reversed since 1990 with annual emissions increasing steadily from 4 Mt in 1990 to 8 Mt in 2010 and 21 Mt in 2016. A slowdown in overall energy efficiency improvement is the main factor responsible for this increasing trend, as indicated by a sharp reduction in the contribution of energy efficiency improvement to emissions reduction from −522% during 1990–2009 to −12% during 2010–2016. Fuel mix has also made noticeable contribution to the emissions growth over the period 1990–2016, and this contribution has increased from 31% during 1990–2009 to 57% during 2010–2016.

The above discussion suggests that energy-related emissions have grown significantly since 1990, and this growth started to accelerate in the early 2010s, as the country has been reconnected with the world economy following major economic and political reforms in 2011. Further, it is expected that the country's energy-related emissions levels would continue to increase in the years to come if economic growth remains strong. To address the challenge of rising emissions, policymakers should put a major focus on improving energy efficiency. Here, particular attention should be given to efficiency improvement in the residential sector—the largest and fast-growing energy consuming sector. For example, more stringent energy efficiency standards on lighting, refrigerators and air conditions could be implemented to improve energy efficiency in the residential sector. Improved residential energy efficiency would not only achieve energy savings but also promote social welfare by lowering energy bills. Besides, Myanmar has one of the world's lowest absolute and per capita emissions, primarily due to its predominantly hydro-based power system and low industrial development [72]. This does not mean that renewable energy development should assume low priority in policy making. Rather, high priority should still be given to promote the uptake of renewable energy, especially in isolated rural areas, where electrification through grid-extensions is widely considered as less cost-effective.

3.6. Philippines

An acceleration in emissions growth has been observed in the Philippines over the period 1971–2016, from 2.9% during 1971–1989 to 5.4% during 1990–2009 and 8.0% during 2010–2016. This acceleration in emissions growth is mainly attributable to rising income levels; the contribution of income levels to emissions growth, as shown in Table 2, has increased steadily from 43% in the 1970s and 1980s to 59% in the 1990s and 2000s and 64% in the early-to-mid 2010s. A recent slowdown in energy efficiency improvement, especially in the end-use segment of the energy supply chain, has also made sizeable contribution to this accelerated emissions growth (see Table 2). This suggests that additional policy effort should be made to improve energy efficiency as the means of curbing energy-related emissions growth. Improved energy efficiency could also ease the energy security concerns by reducing the needs for energy import. In fact, ensuring energy self-sufficiency is a key item on the government's policy agenda as set out in, for example, Energy Sector Accomplishment Report 2016 [73]. Besides, policymakers should also consider scaling up the existing policy support for renewable energy, which could reduce the country's reliance on fossil fuels for energy consumption. The spectre of dwindling gas reserves (for example, the Malampaya field) may also provide stimulus for renewable energy.

3.7. Singapore

Annual energy-related CO₂ emissions in Singapore have grown steadily from 6 Mt in 1971 to 45 Mt in 2016, primarily driven by population growth and rising income levels. However, this growth

has decelerated from 20.2% during 1971–1989 to 2.6% during 1990–2009 and 0.4% during 2010–2016. This deceleration in emissions growth is mainly attributable to energy efficiency improvement; the contribution of overall energy efficiency improvement to emissions reduction has increased considerably from –21% during 1971–1989 to –116% during 1990–2009 and –193% during 2010–2016, as presented in Table 2. However, energy efficiency improvement has been slow in the end-use segment, as indicated by positive contribution (10% during 2010–2016) of end-use efficiency to emissions growth. This suggests that more policy efforts should be made to improve end-use efficiency. These efforts should put a major focus on the industry sector—the largest and fast-growing energy consuming sector. Besides, economic structure has also made sizeable contribution (–18% to –57%) to the slowdown in emissions growth. This probably reflects higher growth in less energy-intensive sectors, particularly information and communication sectors as well as the finance and insurance sectors.

3.8. Thailand

In Thailand, energy-related CO₂ emissions increased considerably over the past four and a half decades, from 16 Mt in 1971 to 244 Mt in 2016 (Table 1). Emissions grew strongly (by 21.4% per year) during 1971–1989, driven by population, economic (income) growth, growth in emissions-intensive economic sectors (structure), and the increased use of emissions-intensive technology (fuel mix) (Table 2). These four underlying factors of emissions growth were a result of achieving the country's aspirations of a higher economic status during this period [74].

While CO₂ emissions in the subsequent period continued to increase, the rate of growth has considerably slowed, to an average annual growth of 8.8% during 1990–2009 and 1.6% during 2010–2016 (Table 1). Most of the above-noted factors continued to make a large contribution to emissions growth as its economies continued to expand. Energy efficiency improvements however led to the slowdown in emissions growth, especially in the fuel supply and conversion segments of the energy supply chain (Table 2). In more recent years, economic structural transformation, from emissions-intensive heavy manufacturing sectors to less-emissions-intensive light manufacturing and services sectors, also contributed to reduced emissions growth rate.

Despite the recent efficiency improvements in the supply-side of the energy sector, reducing CO₂ emissions in Thailand is likely to remain a challenging task. Based on the above discussion, two specific challenges are identified in this paper. First, a strong government initiative to improve end-use energy efficiency would be needed to reduce emissions intensity of this sector, which has been increasing continuously since 1990 (Table 2). Such an increase in emissions intensity was driven mainly by increased use of electrical appliances in the household [69]. Specifically, increased demand for space cooling has resulted in a doubling of ownerships of air conditioning over the past two decades.

The second challenge is to reverse the contribution of fuel mix on CO₂ emissions, which has contributed to emissions growth since 1970s (Table 2). Due to the domestic availability of low-cost coal, however, increased electricity demand is likely to continue to be met on this energy source as a part of the government strategy for fuel diversification [75]. Such a policy will pose a considerable challenge for emissions reduction in the years to come. Without the change in the direction of this policy stance, the policymakers should strongly emphasise adopting efficient coal technologies, such as ultra-supercritical technologies, as a key priority for electricity generation sector. Alternatively, the Thai government should play a key role in the region to promote the integration of regional energy markets, specifically the development of the ASEAN Power Grid and Trans-ASEAN Gas Pipeline, in order to reduce its reliance on coal.

3.9. Vietnam

Energy-related CO₂ emissions in Vietnam have grown considerably, from 17 Mt in 1990 to 187 Mt in 2016 (Table 1). This growth was particularly strong between 1990 and 2009, where emissions grew at an average rate of 32.1% per annum (Table 1), driven primarily by population growth and rising income levels (Table 2). This growth has however slowed down to 8.1% per year between 2010 and

2016, due mainly to reduced contribution of fuel mix to emissions growth, from 30% during 1990–2009 to 19% during 2010–2016. End-use energy efficiency improvements also partly contributed to the slowdown in emissions growth; the contribution from this factor reduced from 26% during 1990–2009 to 10% during 2010–2016. Throughout this period, however, rising income from strong economic growth has increasingly contributed to CO₂ emissions, from 48% during 1990–2009 to 62% during 2010–2016 (Table 2).

As the economy of Vietnam is expected to grow more than fourfold by the middle of this century [69], this will strongly lead to significantly higher CO₂ emissions than the current level. This suggests that fuel mix and energy efficiency improvements must begin to make a strong contribution to curtail CO₂ emissions. One of the key challenges is to transform its electricity generation mix. There has been an increase in the share of fossil-based power plant in electricity generation mix, from 46% in 2000 to 57% in 2016 [67]; majority of this comes from coal. The share of coal-fired power plants alone is likely to exceed half of total electricity generation by 2030 [76]. However, as its coal resources begin to dwindle, and due to its proximity to the Asian gas markets, the government should focus on increasing natural gas supply into the country through the development of LNG regasification terminals [69]. Importing LNG for use in fossil-based power plant could provide a short-term solution to reduce CO₂ emissions.

4. Conclusions

This paper has developed an assessment of the growth of energy-related CO₂ emissions, for nine ASEAN countries, over the period 1971–2016. The motivation for this assessment resides in the following arguments: (1) limited attention has been paid to analyse the growth of energy-related CO₂ emissions in ASEAN; and (2) this analysis is critical, because it can contribute to the establishment of an empirical basis for assessing the efficacy of existing policies for reducing emissions from combustion of fossil fuels in the region. Decomposition analysis based on the Logarithmic-Mean Divisia Index (LMDI) is the main approach employed to develop the assessment in this paper.

The analysis undertaken in this paper suggests that energy-related CO₂ emissions have grown steadily in most ASEAN countries over the entire study period (1971–2016), driven primarily by population growth, rising income levels and growing reliance on fossil fuels for energy consumption. This emissions growth has decelerated in some major emitters in the region, such as Indonesia, Malaysia, Singapore, Thailand and Vietnam. This decelerating trend in emissions growth is mainly attributable to energy efficiency improvement and, to a lesser extent, a gradual switch in energy fuel mix towards lower emission sources (gas and renewables). In contrast, emissions growth in Myanmar and the Philippines has accelerated, especially in recent years, due mainly to a less-than-expected improvement in energy efficiency.

These findings imply that existing policy are unlikely to transform the energy sectors of the region to the extent considered adequate for redressing the impending challenge of rising CO₂ emissions from combustion of fossil fuels. A significant scale-up of existing policy effort is needed. This effort would not only reduce energy-related emissions but also ease the concerns about energy import dependence that may arise from rising energy demand and limited indigenous supply of fossil fuels (for example, in Cambodia, Singapore, Thailand and Vietnam) and promote rural development by renewable-based microgrids (for example, in Myanmar).

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