ENERGY-RELATED GREENHOUSE-GAS EMISSIONS IN THE *ASEAN*: A DECOMPOSITION ANALYSIS

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Abstract

The Association of Southeast Asian Nations is one of the most dynamic and diverse regions in the world. Although the region currently accounts for 3.5% of global greenhouse-gas emissions, this share is expected to increase substantially due to population growth and increasing urbanisation and industrialisation. This is likely to have implications for the development of regional climate policies. Understanding how greenhouse-gas emissions for countries in the region has evolved in the past is an important first step to develop meaningful policies. This paper analyses the historical development in CO_2 emissions for the ASEAN countries over the period 1971 to 2009, using an index decomposition method. The key results show that: (1) population growth and increased levels of affluence are the largest contributors to emissions growth in most countries; (2) fossil fuels have increasingly become the dominant fuel source in the region despite recent global environmental pressures – reversing this trend will be a challenging task; (3) production structures for most countries have increasingly become concentrated towards energy-intensive industrial sector; (4) the region has achieved energy efficiency gains at both end-use and conversion levels – in fact this is the only factor that led to reduced emissions; and (5) the effect of changes in carbon intensity of primary energy was only negligible and no meaningful trend can be observed. These results should be useful for framing effective climate policy response, both at the country and regional levels.

1. Introduction

The Association of Southeast Asian Nations (ASEAN) is one of the most dynamic and diverse regions in the world. The region comprises of ten countries. These countries have contrasting energy demand profiles, levels of access to modern energy services, and energy resource endowments. The energy demand in the region has grown appreciably over the past four decades, driven essentially by high economic growth, underpinned by increased urbanisation and industrialisation. This has resulted in increased greenhouse-gas emissions. A large proportion (approximately 60%) of these emissions have come from fossil-fuel combustion (WRI 2011).

Despite large growth in energy consumption, energy consumption per capita in the region (0.9 tonnes of oil equivalent) is considerably lower than the developed world average. Moreover, almost 30% of the population in the region still do not have access to electricity (IEA 2009). With expected increases in population (by 30% by 2050; UN 2011), coupled with ever increasing urbanisation and industrialisation, energy demand is expected to increase substantially. Unless there are fundamental changes in the patterns of economic production and fuel-mix, the greenhouse-gas emissions are expected to grow significantly in the years to come. For example, according to IEA (2009), the region's share of global emissions could reach 5% in 2030; currently this share is around 3%.

Such an increase in emissions is likely to have implications for the development of regional climate policies. Although the region is currently not bound by any international agreement to lower its emission, the pressure to do so is likely to arise soon. For example, according to IPCC, average global emissions need to be reduced to 50% of 1990 emissions level by 2050 in order to contain the temperature at 2°C; this is equivalent to limiting emission at around 1.2 million tonnes per person. The current regional per capita emission level (1.7 million tonnes) has already exceeded this target level.

In order to design effective climate policies that are in accord with the regional diversity as well as economic and population outlooks, it is important to understand how greenhouse-gas emissions for each country in the region have evolved in the past. Understanding this evolution also means that any potential challenges for designing appropriate policies can be identified and steps taken to address these challenges.

Against this backdrop, this paper analyses the historical trends in CO_2 emissions (one of the major greenhouse-gases) for the ASEAN countries over the past four decades. Specifically, this paper decomposes the change in CO_2 emissions in order to analyse the relationship between the underlying factors that drive emissions growth.

The next section provides a contextual backdrop by briefly introducing the energy-economy-environment situation in the ASEAN. Section 3 discusses the methodology employed, and data adopted for the analysis. The results are then presented and discussed in section 4. The final section provides concluding remarks.

2. Energy-economy-environmental context

ASEAN was first established in 1967. Its initial members were Indonesia, Malaysia, Philippines, Singapore and Thailand. Brunei joined the group in 1984, followed by Vietnam in 1995, Laos and Myanmar in 1997, and Cambodia in 1999, making the ASEAN a group of 10 countries.

ASEAN is one of the most dynamic and diverse regions in the world. While the region's population increased by 1.9% per year between 1971 and 2009, its economy grew by more than 5% per year (Table 1). Over the same period, the energy demand in the region grew by 4.4% per year. This has resulted in increased greenhouse-gas emissions, at an annual average rate of 6.2%. The corresponding annual average increases in world's population, economic growth, energy consumption, and greenhouse-gas emissions are 1.6%, 3.1%, 2% and 1.9% per year, respectively. Not just in terms of absolute amount, the growth in emissions per person for the ASEAN is also higher (4.2% per year) than the world average (0.4% per year). This clearly shows that all indicators for the ASEAN, particularly CO_2 emissions, have grown at a faster rate than the world average.

Table 1: Key energy-economy-environmental indicators for the ASEAN

	Population				Gross Domestic Product				Energy use				CO_2 emissions			
	(million)		share	growth	(billion 2000 USD)		share	growth	(Mtoe)		share	growth	($MtCO_2$-e)		share	growth
	1971	2009	%	% pa	1971	2009	%	% pa	1971	2009	%	% pa	1971	2009	%	% pa
Low income																
Cambodia	7	14	2	1.8	2	7	1	7.7	3	5	1	3.1	0	4	0	8.5
Laos	3	6	1	2.1	1	3	0	6.0	na	na			0	2	0	3.5
Myanmar	27	48	8	1.5	na	na			8	15	3	1.7	5	10	1	2.2
Lower-middle income																
Indonesia	121	237	41	1.8	30	259	28	5.9	35	202	39	4.7	25	376	37	7.4
Philippines	36	92	16	2.5	31	120	13	3.7	16	39	8	2.4	23	71	7	3.0
Vietnam	44	86	15	1.8	11	59	6	6.8	17	64	12	3.5	16	114	11	5.3
Upper-middle income																
Malaysia	11	28	5	2.4	13	137	15	6.4	6	67	13	6.6	13	164	16	7.0
Thailand	38	69	12	1.6	20	174	19	5.8	14	103	20	5.5	17	228	22	7.0
High income																
Brunei	0	0	0	2.9	4	7	1	1.8	0	3	1	7.8	0	8	1	8.2
Singapore	2	5	1	2.3	11	142	16	7.1	3	18	4	5.2	6	45	4	5.5
ASEAN	**290**	**585**	**9**	**1.9**	**122**	**907**	**2**	**5.4**	**102**	**517**	**4**	**4.4**	**106**	**1,022**	**4**	**6.2**
World	**3,763**	**6,764**		**1.6**	**12,646**	**39,690**		**3.1**	**5,534**	**11,787**		**2.0**	**14,085**	**28,999**		**1.9**

Note: Most figures in the Table are rounded-off, and thus '0' reflects a very small amount, that is, less than 0.5.
Sources: World Bank (2011), IEA (2011a,b).

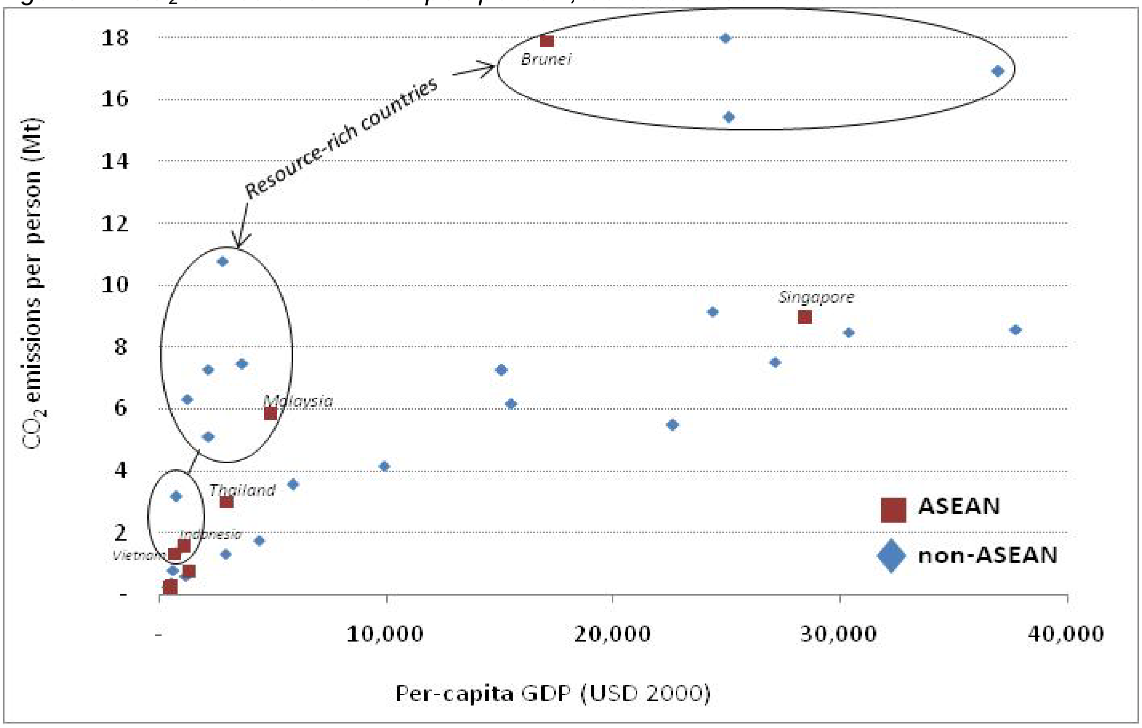
The majority of people in the region live within the middle income ranges (Table 1); 72% live in the lower-middle income countries (Indonesia, Philippines and Vietnam), and 17% live in the upper-middle income countries (Malaysia and Thailand). Indonesia alone is a home for more than 40% of people in the region, and accounts for more than two-thirds of CO_2 emissions. Thailand, Malaysia, Vietnam and Philippines collectively accounts almost half of the region's population, and 56% of total emissions. As these middle income countries catching up an income level of the more developed ones such asBrunei and Singapore, emissions are expected to rise.

Between 1971 and 2009, all countries experienced increased CO_2 emissions, both in absolute and per person terms. Indonesia, Thailand and Malaysia collectively accounted for almost 80% of this increase, while accounting for 55% and 65% of growth in population and GDP, respectively. During this period, these three countries were able to cross their income threshold (that is, Indonesia became the lower-middle income country, while Thailand and Malaysia became upper-middle income countries) by aggressively promoted their economy toward exports of industrial products.

The region accounts for 3.5% of the world's greenhouse-gas emissions (Table 1). While this represents only a small proportion of total world's emissions, it should be noted that this number has increased noticeably over the past four decades, when it contributed just 0.7% of world's greenhouse-gas emissions. With significant potential in terms of economic growth in the future (given that the majority of the countries in the region are classified as low and lower-middle income countries), as well as requirements for energy services to meet that growth, the region's share of global emissions is expected to rise.

Figure 1 shows the relationship between per-capita income and per-capita CO_2 emissions for some ASEAN and non-ASEAN countries. The figure clearly shows that there are two paths for emissions to grow as income rises – one for the countries that are endowed with abundant energy resources and the other for countries that rely on energy imports. CO_2 emissions in resource-rich countries are generally likely to be higher than in countries that rely on imports, for a similar income level. Take Brunei and Singapore, the two high income ASEAN countries, as an example. While an average emissions per person in Singapore are around 9 Mt, they are 18 Mt in Brunei (the country blessed with oil and gas resources). CO_2 emissions per person in Brunei are about the same as other resource-rich developed nations, including Australia and Canada.

Figure 1: CO_2 emissions & GDP per person, selected countries



Data sources: World Bank (2011), IEA (2011a).

The two upper-middle income countries in ASEAN, namely, Malaysia and Thailand, also follow similar paths. CO_2 emissions in resource-rich Malaysia are 6 Mt per person, while in energy-importing country such as Thailand, they are about 3.5 Mt. The Figure also shows that CO_2 emissions in Thailand are slightly higher than countries which share similar characteristics, in terms of resource availability as well as income level. Assuming that other less developed ASEAN countries were to follow this path, it can be seen from the figure that oil- and gas-based Indonesia as well as coal-based Vietnam will soon join emissions levels of Malaysia, while others will track emissions paths of Thailand and Singapore.

3. Method and data

Index decomposition analysis is a widely applied technique for investigating the contributory factors that drive historical energy consumption and associated environmental effects. There are a number of decomposition methods that can be employed for this purpose (Liu and Ang 2003). This paper employs the logarithmic-mean divisia index (LMDI) method proposed by Ang and Liu (2001) because it has various advantages over other index decomposition methods (Ang 2004).

Many studies have employed LMDI method to analyse factors underlying CO_2 emissions growth for various countries or groups of countries (see, for example, Lee and Oh 2006, Oh et al. 2010, Sandu and Petchey 2009, Zhao et. al 2010). However, these studies disentangle the sources of emissions growth into at the most five factors. This paper extends the number of factors considered by decomposing annual change in CO_2 emissions into seven underlying factors, namely, those associated with *population* growth, growth in per capita income (*affluence*), changes in the sectoral composition of output (*structure*), changes in sectoral energy intensity (*end-use efficiency*), changes in sectoral *fuel-mix*, changes in efficiency of transforming primary energy into final energy (*conversion efficiency*), and changes in CO_2 intensity of primary energy (*carbon-coefficient*).

In theory, a carbon-coefficient of fuel should be constant based on the chemical composition of different types of fossil fuel. This however differs in practice as any particular type of fossil fuel, say coal, comes from various supply sources which vary in their composition of both combustible and non-combustible components (IPCC 2006). The carbon-coefficient effect captures this variation.

In formulating a mathematical expression, let assume that CO_2 emissions (C) from the combustion of fuel f in sector i for each country can be written as:

$$C=\sum_{fi}C_{fi}=\sum_{fi}P\cdot\frac{Y}{P}\cdot\frac{Y_i}{Y}\cdot\frac{FE_i}{Y_i}\cdot\frac{FE_{fi}}{FE_i}\cdot\frac{PE_{fi}}{FE_{fi}}\cdot\frac{C_{fi}}{PE_{fi}}=\sum_{fi}P\cdot A\cdot S_i\cdot I_i\cdot M_{fi}\cdot T_{fi}\cdot E_{fi} \quad (1)$$

where

P = total population (person);
Y = GDP (real US$);
FE = final energy consumption (tons of oil equivalent, toe);
PE = primary energy consumption (tons of oil equivalent, toe);
A = GDP per person, which represents level of affluence (real US$ per person) ($=Y/P$);
S = share of sectoral output, which represents economic structure (percent) ($=Y_i/Y$);
I = sectoral energy intensity (toe per real US$) ($=FE_i/Y_i$);
M = share of final energy, or fuel-mix (percent) ($=FE_{fi}/FE_i$);
T = fuel conversion, or transformation, intensity (toe primary energy input per toe final energy output) ($=PE_{fi}/FE_{fi}$);
E = carbon-coefficient of fuel (tons CO_2-e per toe of primary energy) ($=C_{fi}/PE_{fi}$).

Equation 1 is the basis for decomposing changes (in this paper) in total CO_2 emissions between any two periods. This decomposition is done both additively and multiplicatively. For the additive decomposition, each of the component on the right-hand-side of Eq. 1 is expressed in absolute terms (i.e., $MtCO_2$-e per toe). The additive property of the LMDI method allows to express a given change in emissions as the sum of a change in each contributory factor:

$$
\Delta C = \omega \cdot \ln\left(\frac{P_t}{P_o}\right) + \omega \cdot \ln\left(\frac{A_t}{A_o}\right) + \sum_i \omega_i \cdot \ln\left(\frac{S_{i,t}}{S_{i,o}}\right) + \sum_i \omega_i \cdot \ln\left(\frac{I_{i,t}}{I_{i,o}}\right) + \sum_{fi} \omega_{fi} \cdot \ln\left(\frac{M_{fi,t}}{M_{fi,o}}\right) + \sum_{fi} \omega_{fi} \cdot \ln\left(\frac{T_{fi,t}}{T_{fi,o}}\right) + \sum_{fi} \omega_{fi} \cdot \ln\left(\frac{E_{fi,t}}{E_{fi,o}}\right) \quad (2)
$$

where the subscripts *o* and *t* refer to the value of the variables at the start and end of the interval of interest. The variable ω_{fi} is the logarithmic mean of CO_2 emissions across the start and end periods and is defined as:

$$
\omega_{fi} = \frac{E_{fi,t} - E_{fi,o}}{\ln E_{fi,t} - \ln E_{fi,o}} \quad (3).
$$

For the multiplicative decomposition, each of the component on the right-hand-side of Eq. 1 is expressed as an index. Here, it expresses a given change in emissions as the product of a change in each factor:

$$
\Delta C = \exp\left[\omega \cdot \ln\left(\frac{P_t}{P_o}\right)\right] \times \exp\left[\omega \cdot \ln\left(\frac{A_t}{A_o}\right)\right] \times \exp\left[\prod_i \omega_i \cdot \ln\left(\frac{S_{i,t}}{S_{i,o}}\right)\right] \times \exp\left[\prod_i \omega_i \cdot \ln\left(\frac{I_{i,t}}{I_{i,o}}\right)\right] \times \exp\left[\prod_{fi} \omega_{fi} \cdot \ln\left(\frac{M_{fi,t}}{M_{fi,o}}\right)\right] \times \exp\left[\prod_{fi} \omega_{fi} \cdot \ln\left(\frac{T_{fi,t}}{T_{fi,o}}\right)\right] \times \exp\left[\prod_{fi} \omega_{fi} \cdot \ln\left(\frac{E_{fi,t}}{E_{fi,o}}\right)\right] \quad (4).
$$

The variable ω_{fi} is defined slightly differ to Eq. 3, as:

$$
\omega_{fi} = \frac{\left(E_{fi,t} - E_{fi,o}\right) / \left(\ln E_{fi,t} - \ln E_{fi,o}\right)}{\left(E_t - E_o\right) / \left(\ln E_t - \ln E_o\right)} \quad (5).
$$

Each of the seven terms on the right-hand-side of Equations 2 and 4 represents the contributory factors, as defined above, for total change in CO_2 emissions between any two periods.

This paper employed the above mathematical formulations to decompose historical change in CO_2 emissions for nine ASEAN countries (all except Laos). Laos is excluded in the analysis because of the lack of the most important variable for the analysis, which is energy consumption data. The paper employed time-series data covering the period between 1971 and 2009 for the variables considered. However, due to the lack of complete time-series data for some countries, this means that the analysis that covers the whole time-period can be conducted for just six countries. For Brunei, Vietnam and Cambodia, the decomposition of CO_2 emissions is conducted for the periods 1975-2009, 1985-2009 and 1995-2009, respectively.

Population, GDP, energy consumption (both primary and final), and CO_2 emissions data are taken from the International Energy Agency online databases (2011a,b). The GDP data are based on purchasing power parities at US dollars constant prices in 2000. This set of GDP data is selected so that it represents the comparable value of the country's output, which is reflecting not just the variations in exchange rates between currencies, but also its purchasing power. This output is assumed to produced from three sectors of the economy, including agriculture, industrial and services. Thus, the structural effect captures in Equations 2 and 4 reflects the change in relative share of output from these three sectors. The transport sector is included within the services sector, as its main purpose is to provide transport services to the economy instead of producing a consumable products. Data on this sectoral share of output is taken from World Bank's world development indicators database (World bank 2011).

There are five types of final energy included in the analysis, which include coal, oil, gas, non-fossil and electricity. These final energy are used directly as an end-use energy in the three economic sectors. Similar to the structure effect, the fuel-mix effect reflects the shift in relative share of these final energy use. Finally, four types of primary energy are included – coal, oil, gas and non-fossil. Not only that the primary energy is used directly in the form of final energy in the end-use sectors, it is also used in the transformation sectors to convert primary energy into final energy such as electricity. In this paper, each of this primary energy is apportioned into the three end-use sectors based on conversion efficiency of fuels, that is based on the average amount of primary energy input for converting into the equivalent amount of final energy.

4. Results and discussions

This section presents the contributions of various effects to the changes in CO_2 emissions in nine ASEAN countries (that is, all except Laos), as obtained from the application of Equations 2 and 4. The results are summarized in Table 2, and detailed time-series trends are provided in Appendix A.

The key results are as follows:

i. The level of *affluence* is by far the largest contributor to emissions growth in the ASEAN. It contributed to more than 60% (1.7 Mt per year) of average annual increase in emissions over the period 1971-2009. This is clearly the largest contributor for most countries, except for Brunei, Cambodia and Philippines. In fact, Brunei is the only country in the region that experienced declining affluence level throughout the study period (as a result of lack of investment in sectors other than oil and gas), which led to reduced CO_2 emissions. In contrast, the growth in emissions due to increased affluence level is particularly strong in Indonesia (5.6 Mt per year), Thailand (3.3 Mt per year), Vietnam (2.4 Mt per year) and Malaysia (2.1 Mt per year).

   The average annual CO_2 emissions due to increased standard of living in the ASEAN has grown at an increasing rate. For example, CO_2 emissions in the region increased by 0.8 Mt per year during the 1970s, 1 Mt per year during the 1980s, 1.5 Mt per year during the 1990s, and at a particularly high rate of 3.3 Mt per year over the past decade. These trends reflect the patterns of economic growth in most countries in the region, including Indonesia, Malaysia, Singapore, Thailand, Vietnam and Myanmar. Perhaps this is a reflection of economic development stage – as countries move from a low-income towards high-income level. Take Singapore as an example. This factor contributed to an increase of 0.6 Mt of CO_2 per year during the 1970s. As incomes increased, emissions also increased, at an annual rate of 0.8 Mt in 1980s and 1.5 Mt in 1990s. However, over the past decade this rate has slowed to 1 Mt per year. It is yet to be seen whether this reflects a reversal of trend or just the result of short-term economic impacts associated with the global financial crisis in 2008 (see figure in Appendix A). As the majority of countries in the region are still classified as either low income or lower-middle income countries (see Table 1), the potential of increasing affluence to contribute to future growth in emissions is significant.

   The recent global economic recession does not seem to have appreciably impacted upon the growth in emissions across the region. The impact appears to be concentrated in some of the export-oriented countries such as Singapore, Malaysia and Thailand, as well as in Cambodia (see figure in Appendix A).

Table 2: Average annual change in energy-related carbon-dioxide emissions

		CO_2 emissions	Population		Affluence		Structure		End-use efficiency		Fuel-mix		Conversion efficiency		Carbon coefficient	
		Mt	Mt	*%*	Mt	*%*	Mt	*%*	Mt	*%*	Mt	*%*	Mt	*%*	Mt	*%*
ASEAN	1970s	1.4	0.4	*(29)*	0.8	*(57)*	0.1	*(9)*	- 0.4	*(-26)*	0.5	*(32)*	- 0.1	*(-6)*	0.1	*(4)*
	1980s	1.4	0.6	*(44)*	1.0	*(71)*	0.1	*(4)*	- 0.4	*(-29)*	0.5	*(38)*	- 0.3	*(-22)*	- 0.1	*(-6)*
	1990s	4.3	1.0	*(22)*	1.5	*(36)*	0.2	*(6)*	0.2	*(6)*	1.1	*(27)*	- 0.1	*(-2)*	0.2	*(6)*
	2000s	3.7	1.3	*(35)*	3.3	*(88)*	0.1	*(4)*	- 1.6	*(-43)*	1.3	*(36)*	- 0.6	*(-16)*	- 0.1	*(-4)*
	Overall	**2.8**	**0.8**	***(29)***	**1.7**	***(61)***	**0.2**	***(5)***	**- 0.5**	***(-19)***	**0.9**	***(33)***	**- 0.3**	***(-10)***	**0.0**	***(0)***
Brunei	1970s	0.0	0.0	*(73)*	0.0	*(165)*	0.0	*(107)*	- 0.1	*(-227)*	- 0.0	*(-24)*	0.0	*(0)*	0.0	*(6)*
	1980s	0.1	0.0	*(28)*	- 0.0	*(-45)*	0.1	*(46)*	0.1	*(47)*	0.0	*(20)*	- 0.0	*(-37)*	0.0	*(41)*
	1990s	0.1	0.1	*(52)*	- 0.0	*(-17)*	0.0	*(8)*	0.1	*(44)*	0.0	*(22)*	0.1	*(90)*	- 0.1	*(-99)*
	2000s	0.2	0.1	*(52)*	- 0.1	*(-33)*	- 0.1	*(-48)*	0.4	*(191)*	- 0.2	*(-87)*	- 0.1	*(-64)*	0.2	*(89)*
	Overall	**0.1**	**0.1**	***(47)***	**- 0.0**	***(-27)***	**- 0.0**	***(-5)***	**0.1**	***(103)***	**- 0.0**	***(-27)***	**- 0.0**	***(-11)***	**0.0**	***(21)***
Cambodia	1970s															
	1980s															
	1990s	0.2	0.0	*(21)*	0.1	*(42)*	0.0	*(10)*	- 0.1	*(-37)*	0.2	*(82)*	- 0.0	*(-18)*	0.0	*(1)*
	2000s	0.2	0.1	*(29)*	0.2	*(97)*	0.0	*(8)*	- 0.2	*(-84)*	0.2	*(120)*	- 0.1	*(-67)*	- 0.0	*(-2)*
	Overall	**0.1**	**0.0**	***(26)***	**0.1**	***(81)***	**0.0**	***(8)***	**- 0.1**	***(-71)***	**0.1**	***(109)***	**- 0.0**	***(-53)***	**- 0.0**	***(-1)***
Indonesia	1970s	4.4	0.9	*(21)*	2.1	*(46)*	0.6	*(13)*	- 1.1	*(-25)*	2.6	*(58)*	- 0.7	*(-16)*	0.1	*(3)*
	1980s	4.7	1.5	*(33)*	3.6	*(76)*	0.4	*(9)*	- 1.9	*(-41)*	2.3	*(49)*	- 1.0	*(-21)*	- 0.3	*(-6)*
	1990s	14.6	2.7	*(19)*	4.0	*(27)*	0.4	*(3)*	2.1	*(14)*	3.2	*(22)*	0.5	*(3)*	1.7	*(11)*
	2000s	12.3	3.9	*(32)*	12.0	*(98)*	1.0	*(8)*	- 9.1	*(-74)*	5.4	*(44)*	- 0.5	*(-4)*	- 0.6	*(-5)*
	Overall	**9.2**	**2.4**	***(25)***	**5.6**	***(61)***	**0.6**	***(7)***	**- 2.6**	***(-28)***	**3.4**	***(37)***	**- 0.4**	***(-4)***	**0.2**	***(3)***
Malaysia	1970s	1.2	0.4	*(32)*	0.9	*(74)*	0.2	*(13)*	- 0.6	*(-49)*	0.2	*(15)*	0.2	*(21)*	- 0.1	*(-6)*
	1980s	2.0	0.8	*(42)*	0.9	*(46)*	0.2	*(11)*	0.1	*(5)*	0.6	*(29)*	- 1.1	*(-57)*	0.5	*(24)*
	1990s	6.2	1.9	*(31)*	2.8	*(45)*	0.6	*(9)*	0.1	*(1)*	0.8	*(13)*	- 1.1	*(-18)*	1.2	*(19)*
	2000s	6.0	2.6	*(43)*	3.7	*(62)*	- 0.1	*(-1)*	- 1.3	*(-22)*	1.0	*(16)*	0.7	*(12)*	- 0.6	*(-10)*
	Overall	**4.0**	**1.5**	***(37)***	**2.1**	***(53)***	**0.2**	***(6)***	**- 0.4**	***(-11)***	**0.7**	***(16)***	**- 0.3**	***(-9)***	**0.3**	***(7)***
Myanmar	1970s	0.0	0.1	*(301)*	0.1	*(252)*	- 0.0	*(-112)*	- 0.1	*(-279)*	- 0.0	*(-90)*	0.0	*(8)*	0.0	*(20)*
	1980s	0.0	0.1	*(204)*	- 0.0	*(-12)*	- 0.1	*(-195)*	- 0.0	*(-48)*	- 0.1	*(-123)*	0.0	*(102)*	- 0.0	*(-28)*
	1990s	0.4	0.1	*(19)*	0.3	*(68)*	- 0.0	*(-9)*	- 0.2	*(-50)*	0.3	*(69)*	- 0.0	*(-5)*	0.0	*(8)*
	2000s	0.2	0.1	*(48)*	0.8	*(421)*	0.3	*(152)*	- 0.7	*(-405)*	0.1	*(61)*	- 0.2	*(-133)*	- 0.1	*(-44)*
	Overall	**0.1**	**0.1**	***(60)***	**0.3**	***(194)***	**0.0**	***(21)***	**- 0.3**	***(-183)***	**0.1**	***(55)***	**- 0.1**	***(-37)***	**- 0.0**	***(-10)***
Philippines	1970s	1.5	0.8	*(52)*	0.9	*(60)*	0.1	*(7)*	- 0.6	*(-38)*	0.1	*(7)*	0.2	*(16)*	- 0.1	*(-4)*
	1980s	0.1	0.8	*(562)*	- 0.2	*(-126)*	0.1	*(98)*	- 0.4	*(-282)*	- 0.0	*(-19)*	0.4	*(255)*	- 0.6	*(-388)*
	1990s	3.2	1.2	*(37)*	0.4	*(11)*	0.4	*(14)*	- 0.4	*(-14)*	1.7	*(52)*	- 0.2	*(-7)*	0.2	*(7)*
	2000s	0.1	1.3	*(926)*	1.8	*(1274)*	0.1	*(85)*	- 3.8	*(-2,669)*	1.1	*(780)*	- 0.9	*(-622)*	0.5	*(326)*
	Overall	**1.2**	**1.0**	***(84)***	**0.7**	***(58)***	**0.2**	***(17)***	**- 1.3**	***(-109)***	**0.7**	***(60)***	**- 0.1**	***(-12)***	**0.0**	***(1)***
Singapore	1970s	0.8	0.1	*(16)*	0.6	*(69)*	0.0	*(4)*	- 0.0	*(-1)*	0.0	*(3)*	- 0.1	*(-13)*	0.2	*(23)*
	1980s	0.8	0.3	*(40)*	0.8	*(102)*	- 0.0	*(-2)*	- 0.0	*(-4)*	0.0	*(4)*	- 0.3	*(-38)*	- 0.0	*(-4)*
	1990s	2.1	1.0	*(51)*	1.5	*(71)*	- 0.0	*(-1)*	- 0.3	*(-17)*	0.1	*(5)*	- 0.1	*(-4)*	- 0.1	*(-5)*
	2000s	0.3	1.0	*(327)*	1.0	*(317)*	- 0.3	*(-84)*	- 0.1	*(-23)*	- 0.3	*(-95)*	- 1.4	*(-447)*	0.3	*(106)*
	Overall	**1.0**	**0.7**	***(65)***	**1.0**	***(97)***	**- 0.1**	***(-7)***	**- 0.1**	***(-10)***	**- 0.0**	***(-4)***	**- 0.5**	***(-50)***	**0.1**	***(9)***
Thailand	1970s	1.9	0.6	*(30)*	1.2	*(61)*	0.1	*(3)*	- 0.3	*(-14)*	0.3	*(18)*	- 0.2	*(-8)*	0.2	*(9)*
	1980s	3.2	0.7	*(23)*	2.3	*(71)*	0.1	*(5)*	- 0.7	*(-21)*	0.7	*(23)*	0.1	*(2)*	- 0.1	*(-3)*
	1990s	9.4	1.1	*(12)*	3.6	*(38)*	0.2	*(2)*	2.3	*(24)*	2.8	*(30)*	- 0.1	*(-1)*	- 0.5	*(-6)*
	2000s	7.0	1.8	*(26)*	5.9	*(85)*	0.1	*(1)*	0.3	*(5)*	1.2	*(17)*	- 1.5	*(-22)*	- 0.8	*(-12)*
	Overall	**5.5**	**1.1**	***(20)***	**3.3**	***(60)***	**0.1**	***(2)***	**0.4**	***(8)***	**1.3**	***(24)***	**- 0.4**	***(-8)***	**- 0.3**	***(-6)***
Vietnam	1970s															
	1980s	0.1	0.5	*(437)*	0.4	*(407)*	- 0.4	*(-369)*	- 0.4	*(-374)*	0.5	*(499)*	- 0.4	*(-351)*	- 0.2	*(-150)*
	1990s	2.3	0.4	*(19)*	1.4	*(60)*	0.5	*(20)*	- 0.9	*(-41)*	1.2	*(53)*	- 0.1	*(-6)*	- 0.1	*(-5)*
	2000s	7.3	0.9	*(12)*	4.2	*(58)*	0.3	*(4)*	- 0.9	*(-12)*	3.5	*(47)*	- 0.4	*(-5)*	- 0.3	*(-3)*
	Overall	**4.0**	**0.6**	***(16)***	**2.4**	***(60)***	**0.2**	***(6)***	**- 0.8**	***(-21)***	**2.0**	***(51)***	**- 0.3**	***(-7)***	**- 0.2**	***(-5)***

Note: Numbers in parenthesis are percentage contribution of the average annual change in CO_2 emissions. A negative sign means negative contribution of CO_2 emissions.

ii. The second major contributor to emissions growth in the region is the effect of fuel-mix. Changes in the type of final energy consumption over the past four decades contributed to 33% (0.9 Mt per year) of average annual increase in CO2 emissions. This is the result of increasing dominance of emission-intensive fossil fuels as energy sources. Data from the IEA (2011b) suggests that the share of fossil fuels has consistently increased in most countries in the region (except, in Singapore), which has led to increased CO2 emissions. These countries increased their reliance on coal and/or oil, either for direct consumption in the end-use sectors (in Cambodia, Indonesia, Thailand and Vietnam) or as a fuel to produce electricity (in Indonesia, Malaysia, Philippines and Thailand). Apart from Singapore, Brunei also experienced declining trends in CO_2 emissions, even though the country increased its reliance on fossil fuel, from a share (in total final energy) of 56% in 1975 to almost 70% in 2009 (ibid). However, this was because of the changes in fuel-mix from relatively more emission-intensive oil to less emission-intensive gas. While Myanmar reduced the share of coal and oil in the economy, which should have led to lower emissions, it also reduced its reliance on non-fossil (renewable) fuels. These were replaced by gas from the newly-found large gasfields in the country such as Yetagun and Yadana. All these observations are consistent with the results for individual country as shown in Table 2.

    Despite increasing global environmental pressures, the average annual emissions resulting from increased reliance on fossil fuels has grown at increasing rates. For example, regional CO_2 emissions grew by 0.5 Mt per year during the 1970s and 1980s, 1.1 Mt per year during the 1990s and 1.3 Mt per year over the past decade. These trends are particularly noticeable for Indonesia, Vietnam, Cambodia, and, to a smaller extent, Malaysia.

    Reversing these trends will be a challenging, but not impossible, task. For example, emissions in Thailand followed a similar pattern to the countries mentioned above, until the 1990s. Over the past decade however emissions seem to have slowed. This could be partly a result of the government's initiative to increase the share of ethanol, biodiesel and natural gas-based vehicle fuels in place of traditional gasoline and diesel fuels in light of sustained high international oil prices. If other countries were to reduced their emissions from this source, it would require a similarly strong policy signal from the government, as well as access to alternative non-fossil energy.

iii. Increased *population* contributed to 29% (0.8 Mt per year) of average annual increase in CO_2 emissions. It is obvious that countries with high rates of population growth show strong rates of growth in emissions. Indonesia experienced the largest emissions growth in absolute amount (2.4 Mt per year), given its largest population base. Philippines, Malaysia, Brunei and Singapore show the highest rate in emissions growth as they experienced strong population growth over the past four decades. It is anticipated, based on United Nation's population projections (UN 2011), that Philippines, Malaysia and Brunei will continue to show strong growth in CO_2 emissions, while Thailand will experience a slower growth.

iv. Changes in the *structure* of economic output in the region contributed to 5% (0.2 Mt per year) of average annual increase in CO_2 emissions. Emissions from this source have consistently increased at this rate throughout the study period.

    The production structures for most countries (except Brunei and Singapore) have increasingly become concentrated towards energy-intensive industrial sectors. The share of industrial output has increased almost exclusively at the expense of agriculture output. Only in Myanmar did it replace output from the services sector. In contrast, the high income countries, such as Brunei and Singapore, show opposite trends. Their economic structures have become concentrated towards less-energy-intensive services sectors at the expense of the industrial sector.

    These trends broadly follow the pattern of economic development as suggested by Medlock III (2009). Based on this pattern, it can be expected that most countries in the region will experience economic structural change over the next few decades, particularly away from the industrial sector, which would lead to declining CO_2 emissions. However, no country besides Singapore has so far shown any inclination to move away from this sector, which suggests that emissions would continue to increase. Even in Brunei, where the share of industrial output had reduced from 90% in 1975 to about 50% in 1998, the industrial sector has recently regained its importance in the nation's production structure, contributing more than 70% of total output in 2009 (World Bank 2011).

Another aspect that needs mentioning is trade in goods and services. Changes in the trade pattern, and the associated movement of greenhouse-gas emissions embodied in tradable products, is an important issue to understand in a globalized world where demand in one country can be satisfied from production in other country. In a climate change context, this aspect gives rise to the issue of carbon leakage. Data from the World Bank (2011) shows that the ASEAN region is a net exporter of goods, and a net importer of services. Given that both agricultural and industrial goods are generally more energy-intensive than services, and that the region currently relies heavily on fossil fuels to meet its energy needs, this implies that ASEAN is a net exporter of CO_2 emissions. Moreover, the net export of goods from the region has increased over the past decade, while the net import of services has declined (ibid). Thus, the anticipated economic structural change in the region (as discussed above) and economic policies that focus towards the future source of economic growth (that is, domestic consumption versus exports) will add further complexity to any global negotiations in an attempt to limit world's greenhouse-gas emissions.

v. The region has achieved energy *efficiency* gains at both end-use and conversion levels. A combination of these improvements has equally offset increased emissions from population growth, that is 0.8 Mt per year. While the ASEAN-wide reduction in end-use intensity contributed more to reducing emissions (at 0.5 Mt per year) than did an improvement in conversion efficiency (0.3 Mt per year), the reduction in the former did not occur consistently throughout the study period, unlike the latter. End-use energy intensity for the whole region declined over most of the period, except during the 1990s. Lower energy prices during that period could be a reason for such an increase in energy intensity.

End-use energy intensity declined for most countries within the region. Brunei and Thailand are exceptions to this. In Brunei, energy intensity increased throughout the study period, which led to an increase in associated CO_2 emissions. Since the country is blessed with abundant energy resources, particularly oil and gas, the effectiveness of energy usage for production purpose is perhaps not a major priority in the country. For Thailand, end-use energy intensity declined during the 1970s and 1980s when it was an agriculture-based economy. Since then energy intensity has increased as the country concentrated on industrialisation. This is a typical trend for middle income countries where they experienced increase in emissions due to deteriorating sectoral energy intensities. This is because these countries generally pursue economic development policies that foster growth in energy-intensive sectors, as discussed above, and also set energy prices that are artificially low (Lee & Oh 2006). Indonesia and Philippines experienced significant improvements in end-use energy efficiency, resulting in annual average emissions reductions of 2.6 Mt and 1.3 Mt, respectively.

Unlike end-use intensity, an improvement in conversion efficiency occurred in all ASEAN countries. In Singapore, this has contributed to 50% (0.5 Mt per year) of average annual emissions reduction over the past four decades. Most of the reduction in CO_2 emissions occurred over the past fifteen years (see Appendix A). Thailand also followed the trend in Singapore, with overall emissions reduction of 0.4 Mt per year. This rate has exactly offset increased CO_2 emissions from increased end-use intensity in the country.

vi. For the region as a whole, the effect of changes in *carbon-coefficient* of sectoral primary energy use during 1971-2009 on changes in CO_2 emissions was negligible. It caused CO_2 emissions to increase by just 0.01 Mt per year. At a country level, the results are mixed. While it contributed to reduced emissions in Thailand and Vietnam, emissions from Malaysia and Indonesia have increased. While negligible it is not possible to observe any trend in CO_2 emissions from this source; it fluctuates throughout the study period.

5. Conclusions

This paper has analysed the historical development of CO_2 emissions and its underlying factors for nine ASEAN countries over the period between 1971 and 2009, by using the log-mean divisia index decomposition method. It analyses the influence of the following factors on CO_2 emissions – population, affluence, structure, end-use efficiency, fuel-mix, conversion efficiency and carbon-coeffficient.

The major findings are as follows. First, the level of affluence contributed to most of the growth in CO_2 emissions in six out of nine countries. It is also the major contributor of emissions growth in the region. Second, the fuel-mix effect contributed strongly to CO_2 emissions growth in the region as emission-intensive fossil fuels increasingly become dominant fuel sources. However, this was not the case in high income countries where emissions from this source declined. Third, the population effect contributed positively to emissions growth in every country in the region. The countries with high rate of population expansion also show strong rate of growth in emissions. Fourth, the structural effect contributed positively to emissions growth in the region as a whole, as the regional production structure has increasingly concentrated towards energy-intensive industrial sector. This effect was more profound in lower-middle income countries than in the upper-middle income countries. In high income countries, however, emissions from this source actually declined. Fifth, the only effect that contributed negatively to CO_2 emissions growth is related to efficiency, both for end-use and conversion sectors. While improvement in conversion efficiency contributed to emissions reduction across every country in the region, the reduction in end-use intensity occurred in all except two countries, one a resource-rich country and the other with high level of industrial sector. Last, the effect of changes in carbon-coefficient was only negligible, and no meaningly conclusion can be drawn from this factor.

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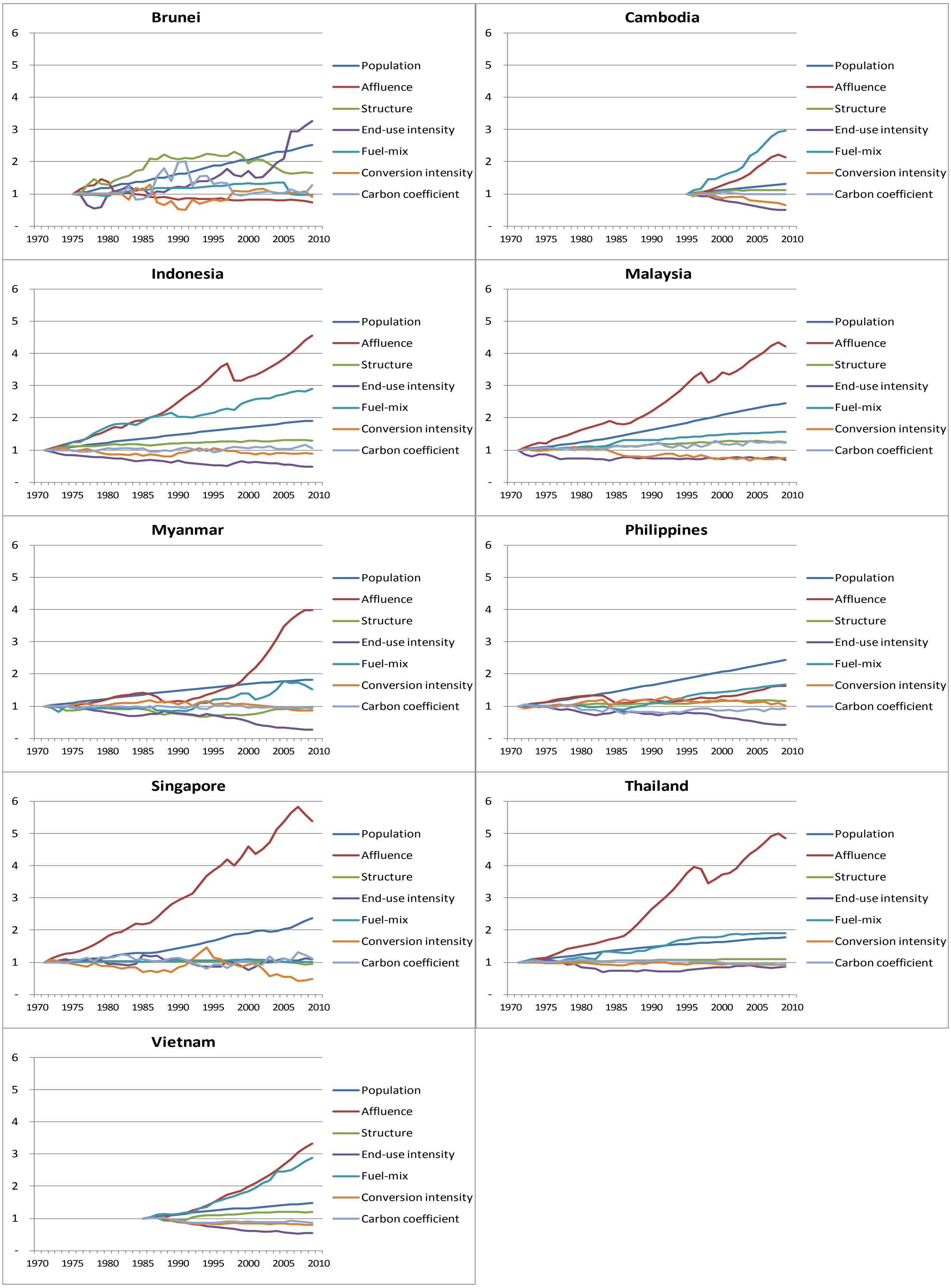
Appendix A. Time-series decomposition results for each ASEAN country



Note: These graphs are the results from the application of Equation 4.