Decomposition Analysis of CO_2 Emission in ASEAN: An Extended IPAT Model
Chontanawat, J.
Energy Procedia, 153, **October, 186-190. 2018**

The definitive version of this article was published as Chontanawat, J. (2018). Decomposition analysis of CO2 emission in ASEAN: An extended IPAT model. Energy Procedia, 153, October, 186-190.

Decomposition Analysis of CO_2 Emission in ASEAN: An Extended IPAT Model

Jaruwan Chontanawat

King Mongkut's University of Technology Thonburi, 126 Prachu-Uthit Rd., Thungkru, Bangkok 10140, Thailand

Abstract

Association of Southeast Asian Nations (ASEAN) is one of the most diverse regions. 3.6% of global greenhouse-gas emissions was released in 2013 and is expected to rise substantially due to increasing population and income. Understanding how greenhouse-gas emissions in the region have evolved is an important first step to develop appropriate policies and this paper analyses the historical increase in CO_2 emissions over the period 1971/2013, based on IPAT/Kaya approach combined with Variance analysis technique. Main findings indicate that: (1) population growth and increased income per capita have the largest contribution to emission growth; (2) fossil fuels increasingly become the dominant fuel and reversing this is a challenging task; (3) Energy efficiency gains have been achieved but it is the only factor that reduced emissions; and (4) the effect of changes in carbon intensity of fossil energy was negligible. These results should help Governments frame effective policies.

Keywords: Decomposition Analysis; CO_2 Emission; ASEAN; IPAT.

1. Introduction

Southeast Asia is the region that in recent years has experienced rapid economic and population growth with high energy dependency and also significant rise in energy consumption and pollution emissions. Continuous urban growth has resulted in a changing of people's life-styles and an improvement of their living standards which has stimulated energy consumption dramatically. It can be seen that there are vast differences in the scale and patterns of energy use and energy source endowments in the region [1,2]. Therefore it is very interesting to understand how the economic growth, energy consumption and carbon emission evolved during the last few decades, how these variables link to each other, and how their fuel mix changed, etc. This could be useful and beneficial for the government of the region to form the appropriate energy and environmental schemes/policies (policy planning) in order to maintain the balance of energy demand and supply. This would include enhancing energy security, ensuring affordability and improving energy efficiency under the umbrella of sustainability. The main objective of the study is to understand the observed magnitudes and patterns of the factors influencing regional emissions, which is a necessity for the prediction of future climate changes and for human governance of climate change. We focused on CO_2 emissions from fossil-fuel combustion, the dominant anthropogenic forcing flux. We have conducted the Kaya identity by means of IPAT equation, on annual time-series data on national emissions, population, energy consumption, and gross domestic product (GDP), combining with Variance analysis in order to decompose the driving forces of CO_2 emissions in ASEAN.

Nomenclature

I	CO_2 emission flux in Mt of CO_2 emissions
P	population in million persons
GDP	real GDP: defined and measured at constant price in million 2005 USD
PES	primary energy supply in ktoe
FEC	fossil fuel consumption in ktoe
A	GDP per capita or affluence (A = GDP/P) in 2005 USD per capita
E	energy intensity (E = PES/GDP) in ktoe per million 2005 USD
F	fuel mix (F = FEC/PES) in ktoe of fossil fuel consumption per ktoe of primary energy supply
C	CO_2 per unit of energy (C = I/FEC) in Mt of CO_2 emissions per ktoe

2. Materials and Methods

This research aims to analyse the main driver of change in CO_2 emissions in the region for the periods 1971-2013 using IPAT/ Decomposition methods. The main variables used in the models consist of energy consumption, Gross domestic product, population, and CO_2 emissions. This study uses the annual data of ASEAN which comprises of Brunei, Cambodia, Indonesia, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam (Lao is excluded as the data is not available), ranging from 1971 to 2013. The energy and CO_2 data are mainly from [3]. The GDP and population are drawn from [4].

2.1. IPAT Analysis

IPAT identity has been a widely accepted method since 1970s to analyze the environment, population, technology and economy for identifying the forces driving environmental impacts. The pioneer work belongs to [5-8]. Since 2000 there have been a number of literature on index decomposition analysis, on which the IPAT model is based, for environmental emissions, energy and technology. The important work belongs to [9-20]. Most studies confirm that IPAT model is an easily understandable, widely utilized framework for analyzing the driver of environmental change.

In this study, we analyze the impact factors of CO_2 emission in ASEAN. First, to diagnose drivers of trends in CO_2 emissions, we used time series for 1971 – 2013 of the IPAT factors I, P, A, E, F, and C based on Kaya Identity. All quantities are normalized to 1 in the year 1971 to show the relative contributions of changes in IPAT factors to changes in emissions as follows:

$$Ii = Pi \times (GDPi/Pi\ ) \times (PESi/GDPi) \times (FEi/PESi)\ \times (Ii/FEi) \tag{1}$$

$$= P_i \times A_i \times E_i \times F_i \times C_i$$

2.2. Variance Analysis

To decompose the factors influencing CO_2 emissions, we use variance analysis technique introduced by [15,16]. This model is the IPAT based identity [6], where emission is expressed as the product of its identities driving forces as mentioned above. The IPAT identity based upon index decomposition analyses allows identification of the relationship between the driving factors and environmental impacts as follows.

From Kaya Identity in Eq.1, CO_2 emissions in region/country 'i' at time period 't' can be expressed as Eq.2.

$$I_i(t) = P_i(t) \times A_i(t) \times E_i(t) \times F_i(t) \times C_i(t) \tag{2}$$

At time 't+1', the resulting emission 'Ii' can be expressed as

$$I_i(t+1) = P_i(t+1) \times A_i(t+1) \times E_i(t+1) \times F_i(t+1) \times C_i(t+1) \tag{3}$$

An analysis of the difference between CO_2 emission in time 't' and 't+1' is called 'variance analysis'. The process decomposes the difference in five components: population variance, affluence variance, energy intensity variance, substitution variance, and emission variance. The following equation expresses the total variance of CO_2 emission between time 't+1' and 't'.

Total emission variance:

$$\Delta I_{i(t)} = \Delta P_i(t) + \Delta A_i(t) + \Delta E_i(t) + \Delta F_i(t) + \Delta C_i(t) \tag{4}$$

Eq.5 determines the change in emission due to population change, which is called 'population effect' or population variance. If there is a change in population, with other factors remaining constant, there must be a proportionate change in emission so that the population effect may be held solely responsible for this effect.

Population variance:

$$\Delta P_i(t) = \Delta P_i(t) \times A_i(t) \times E_i(t) \times F_i(t) \times C_i(t)$$
$$= [P_i(t+1) - P_i(t)] \times A_i(t) \times E_i(t) \times F_i(t) \times C_i(t) \quad (5)$$

In the same way as population variance, the other variances can be expressed as:
Income variance:

$$\Delta A_i(t) = P_i(t+1) \times \Delta A_i(t) \times E_i(t) \times F_i(t) \times C_i(t)$$
$$= P_i(t+1) \times [A_i(t+1) - A_i(t)] \times E_i(t) \times F_i(t) \times C_i(t) \quad (6)$$

Energy intensity variance:

$$\Delta E_i(t) = P_i(t+1) \times A_i(t+1) \times \Delta E_i(t) \times F_i(t) \times C_i(t)$$
$$= P_i(t+1) \times A_i(t+1) \times [E_i(t+1) - E_i(t)] \times F_i(t) \times C_i(t) \quad (7)$$

Substitution variance:

$$\Delta F_i(t) = P_i(t+1) \times A_i(t+1) \times E_i(t+1) \times \Delta F_i(t) \times C_i(t)$$
$$= P_i(t+1) \times A_i(t+1) \times E_i(t+1) \times [F_i(t+1) - F_i(t)] \times C_i(t) \quad (8)$$

Emission intensity variance:

$$\Delta C_i(t) = P_i(t+1) \times A_i(t+1) \times E_i(t+1) \times F_i(t+1) \times \Delta C_i(t)$$
$$= P_i(t+1) \times A_i(t+1) \times E_i(t+1) \times F_i(t+1) \times [C_i(t+1) - C_i(t)] \quad (9)$$

3. Results

3.1. Results from IPAT Analysis

According to the IPAT identity which is expressed as $I=P\times A\times E\times F\times C$ (where P = pop, A = GDP/Pop, E = PES/GDP, F = FEC/PFS, and C = CO_2/FEC), the drivers of trend in ASEAN emissions for 1971-2013 are shown in Fig.1. All quantities are normalized to 1 in the year 1971 to show the relative contributions of changes in Kaya factors to changes in emissions. It can be seen that the increase in the growth rate of the regional emission (I) is a combination of the increase of population (P), per capita GDP (A), Fuel mix (F), and the reductions of energy intensity (E) and emission intensity of energy (C).

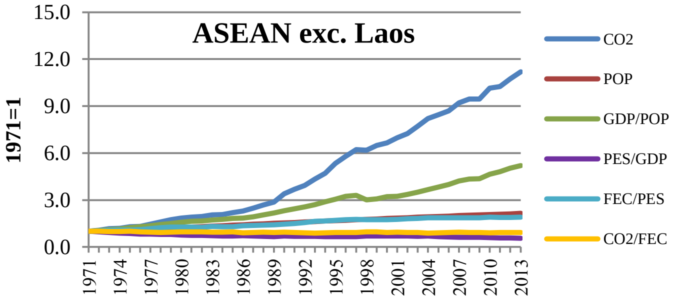

Fig. 1. Factors in IPAT identity in ASEAN

3.2. Results from Variance Analysis

The decomposition results of CO_2 emission in ASEAN is shown in Table 1 and Fig. 2. The results show the increasing of emission between 1971 and 2013, 1,065.12 Mt of CO_2. The positive effects were GDP per capita or affluence, substitution effect, and population effect, while the energy intensity and emission factor effect gave the negative impact, respectively. These results are similar to [21] that the main driving factors were affluence, fuel-mix, and population respectively, while end-use efficiency and carbon coefficient were the offset factors in CO_2 emissions. The income effect or GDP per capita accounts for 944.34 Mt of CO_2, contributing the most to the change of CO_2 (89% in share), followed by substitution effect: 593.38 Mt of CO_2 (56%), population effect: 12.61 Mt of CO_2 (11%). Whereas the energy intensity effect reduces the CO_2 emission for 510.59 Mt of CO_2 (48%), followed by emission intensity effect: 81.84 Mt of CO_2 (8%).

Table 1. Decomposition results of CO_2 emissions in ASEAN from 1971-2013 (unit in Mt of CO_2)

	1971-1980	**1981-1990**	**1991-2000**	**2001-2013**	***1971-2013***
Population variance	25.35	42.33	61.72	117.60	*119.84*
Income variance	76.41	98.29	141.67	512.66	*944.34*
Energy Intensity variance	-48.10	-24.04	6.00	-260.91	*-510.59*
Substitution variance	43.04	46.73	94.84	82.90	*593.38*
Emission intensity variance	-7.59	-6.92	4.26	-12.25	*-81.84*
Change in CO_2 emissions (ΔCO_2)	**89.10**	**156.39**	**308.48**	**440.00**	***1,065.12***

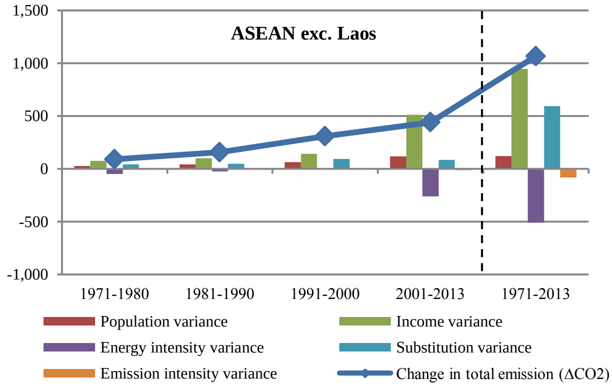

Fig. 2. Decomposition results of CO_2 emissions in ASEAN from 1971-2013 (unit in Mt of CO_2)

It can be concluded that affluence or GDP per capita is the most crucial factor in increasing CO_2 emission of the region where their economy has been growing rapidly. The contribution of substitution effect which is about half indicates that the region still relies on fossil fuels and this effect increases CO_2 emission quite substantially. The results from the study show the interesting point that energy intensity seems to be the most crucial factor to reduce CO_2 emissions in the region. Particularly in the last sub-period, this effect contributes significantly to CO_2 reduction for 260.91 Mt of CO_2 (59% in share). During this sub-period energy intensity declines quite substantially (compared with the previous period) with negative growth. This led to the reduction in emission of 510.59 Mt of CO_2 (48% in share) for the entire period. The contribution of emission factor is rather small. This is due to the fact that the economy of the region still relies on fossil fuels which generate large emissions, therefore an improvement in the quality of fuels used is needed.

4. Conclusion

In this study we have analysed the trends behind the change in CO_2 emission in ASEAN. The decomposition technique was used to explain the change in terms of population, affluence, energy consumption and technology (IPAT). This provides interesting results regarding factors behind changes in CO_2 emissions. Growth in income level and population are the major driving forces of emission with the income effect being the strongest and increasing over time, and the population effect influenced by GDP per capita. Rising population and affluence cause an increase in emissions but higher income does not generate a proportional rise in emissions. Energy mix effect is also a crucial contributing factor in increasing in CO_2, as countries rely on fossil fuel. Offsetting this the energy intensity effect is predominant while the emission intensity is less significant. With unavoidable growth in population and economic growth it is necessary to find ways of arresting emission via technology and policies to reduce energy and emission intensity and the greater use of alternative energy. Although reducing energy intensity is the most effective choice, it is not possible due to the present energy intensive production. Hence it is important to decouple energy use from a higher level of emission. The study shows that fuel substitution and decreasing of emission intensity of each fuel through continuous technological up-grades have considerable potential to cut emissions. Proper energy management is likely to be the best way to sustain a higher level of economic growth with the present growth in population.

Acknowledgements

This research was funded by the Economy and Environment Program for Southeast Asia (EEPSEA), Philippines, and King Mongkut's University of Technology Thonburi, Thailand.

References

[1] International Energy Agency (IEA). (2013) "Southeast Asia Energy Outlook." *World Energy Outlook Special Report*. Paris.

[2] International Energy Agency (IEA). (2015a) "Southeast Asia Energy outlook." *World Energy Outlook Special Report*. Paris.

[3] International Energy Agency (IEA). (2015b) IEA Data Base. Paris.

[4] World Bank (2015). "World Development Indicators (WDI)". CD-ROM. Washington, D.C.

[5] Paul R. Ehrlich, and John P. Holdren. (1990) "Impact of population growth." *Science*, 171(3977) : 1212-1217.

[6] Y. Kaya. (1990) "Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios", Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group. Paris.

[7] Peter T. Soulé, and Jennifer L. DeHart. (1998) "Assessing IPAT using production and consumption based measures of I: research on the environment." *Social Science Quarterly* 79(4) : 754-765.

[8] B.W. Ang, F.Q. Zhang, and Ki-Hong Choi (1998) "Factorizing changes in energy and environmental indicators through decomposition." *Energy* 23(6) : 489-495.

[9] B.W. Ang, and F.Q. Zhang. (2000) "A survey of index decomposition analysis in energy and environmental studies." *Energy* 25(12) : 1149-1176.

[10] B.W. Ang. (2005) "The LMDI approach to decomposition analysis: a practical guide." *Energy Policy* 33(7) : 867-871.

[11] Richard Wood, and Manfred Lenzen. (2006) "Zero-value problems of the logarithmic mean Divisia index decomposition method." *Energy Policy* 34(12) : 1326-1331.

[12] Michael R. Raupach, Gregg Marland, Philippe Ciais, Corinne Le Que´re´, Josep G. Canadell, and Gernot Klepper. (2007) "Global and regional drivers of accelerating CO_2 emissions." *Proceedings of the National Academy of Sciences*, 104(24) : 10288-10293.

[13] Budy P. Resosudarmo, Frank Jotzo, Arief A.Yusuf, and Ditya A. Nurdianto. (2008) "Decomposing CO_2 emission from fossil fuel combustions in Indonesia to understand the options for mitigation." in the 37th Australian conference economists, Australia.

[14] Ditya A. Nurdianto, and Budy P. Resosudarmo. (2011) "Prospects and challenges for an ASEAN energy integration policy." *Environmental Economics and Policy Studies* 13(2) : 103-127.

[15] Ratnakar Pani, and Ujjaini Mukhopadhyay. (2011) "Variance analysis of global CO_2 emission - A management accounting approach for decomposition study." *Energy* 36(1) : 485-499.

[16] Ratnakar Pani, and Ujjaini Mukhopadhyay. (2013) "Management accounting approach to analyse energy related CO_2 emission: A variance analysis study of top 10 emitters of the world." *Energy Policy* 52 : 639-655.

[17] Congrong Yao, Kuishuang Feng, and Klaus Hubacek. (2015) "Driving forces of CO_2 emissions in the G20 countries: An index decomposition analysis from 1971 to 2010." *Ecological Informatics* 26 : 93-100.

[18] Boqiang Lin, and Houyin Long. (2016) "Emissions reduction in China's chemical industry – Based on LMDI." *Renewable and Sustainable Energy Reviews* 53 : 1348-1355.

[19] Feifei Li, Zhe Xu, and Hui Ma. (2018) "Can China achieve its CO_2 emissions peak by 2030?" *Ecological Indicators* 84: 337-344.

[20] Bing Wang, Qian Wang, Yi-Ming Wei, and Zhi-Ping Li. (2018) "Role of renewable energy in China's energy security and climate change mitigation: An index decomposition analysis." *Renewable and Sustainable Energy Reviews* 90 (2018) : 187-194.

[21] Suwin Sandu, Deepak Sharma and Ronnakorn Vaiyavuth (2012) "Energy-related greenhouse-gas emissions in the ASEAN: a decomposition analysis." in the 3rd IAEE Asian Conference, Kyoto.