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Effects of Household-related Factors on Residential Direct CO_2 Emissions in Thailand from 1993 to 2015: a Decomposition Analysis

Kittikun Poolsawat, Wongkot Wongsapai*

Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, 239 Suthep, Muang, Chiang Mai 50200, Thailand
wongkot@eng.cmu.ac.th

Multiple household-related driving factors of the residential direct CO_2 emissions in Thailand have not yet been sufficiently addressed or quantified. In this paper, a logarithmic mean divisia index (LMDI) decomposition analysis investigated seven effects, including the emission of coefficient effect, the energy structure effect, the energy intensity effect, the household income effect, the urbanization effect, the household size effect and the household effect, on the residential direct carbon emissions that impacted the changes in residential direct CO_2 emissions in Thailand from 1993 to 2015. The results showed that the increase in residential direct carbon emissions is mainly attributed to the growing of household income and the increasing number of households. The expansion of urbanization contributed marginally to the increase in emissions. The shrinking household size was a main inhibitory factor and the decline in energy intensity was responsible for the diminishing emissions.

1. Introduction

An increased urbanization causes a continuous increase in people's quality of life and energy consumption in the residential sector (Poolsawat, 2017), while energy consumption is a major source of greenhouse gas (GHG) emissions and environmental problems. In Thailand, the final energy consumption in residential sector during 1993 - 2015 had increased from 7,370 ktoe in 1993 to 11,683 ktoe in 2015 (Department of Alternative Energy Development and Efficiency, 2017). The growth of residential sector has grown rapidly and continuously, contributing to increased household effect and the factors that affect the energy use in this sector.

This paper studies on the comparative analysis of factors influencing the residential direct CO_2 emissions changes. The analysis includes the effects of household-related emissions in Thailand by using the decomposition techniques, which is a powerful tool for indicating the residential direct CO_2 emissions.

2. Research methodology and data

2.1 Decomposition analysis

To quantify the impacts of different factors on the changes in energy consumption and CO_2 emissions, various decomposition methods have been proposed. Among them, the most widely applied methods are the structure decomposition analysis (SDA) (Ang, 2004) and index decomposition analysis (IDA) (Wachsmann et al., 2009). Compared with the SDA which is based on the input–output table (issued in the special year), IDA has the advantages of using annually updated data, and is popular among both domestic and foreign scholars (Xu et al., 2014). Details on these two kinds of IDA methodologies were given: the Laspeyres index decomposition analysis by Howarth et al. (1991) and the Divisia index decomposition analysis by Ang and Zhang (2000). For the application of the Laspeyres index method, a large residual term, which is a significant part of the examined changes, is left unexplained (Ang et al., 1998). Based on the Divisia index, Ang and Liu (2001) proposed the LMDI method, and Ang (2004) deduced that the LMDI method was better than other IDA

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methods due to its theoretical foundation, adaptability, ease of use and result interpretation, and other desirable properties. Therefore, this study employs the LMDI method.
The LMDI analysis of CO_2 emissions from residential direct energy consumption in year *t* can be conducted by the following Eq(1):

$$C^t = \sum_{ij} C^t_{ij} = \sum_{ij} \frac{C^t_{ij}}{E^t_{ij}} \text{ x } \frac{E^t_{ij}}{E^t_i} \text{ x } \frac{E^t_i}{RI^t_i} \text{ x } \frac{RI^t_i}{P^t_i} \text{ x } \frac{P^t_i}{P^t} \text{ x } H^t = \sum_{ij} CI^t_{ij} \text{ x } ES^t_{ij} \text{ x } EI^t_i \text{ x } HPI^t_i \text{ x } U^t_i \text{ x } HS^t \text{ x } H^t \tag{1}$$

where i represents resident type (i = 1 for urban or 2 for rural); j represents various energy type; C^t represents the total CO_2 emission from residential direct energy consumption in year t; C^t_{ij} represents the CO_2 emissions based on fuel j of resident type i in year t; E^t_{ij} represents the energy consumption based on fuel j of resident type i in year t; E^t_i represents the total residential direct energy consumption of resident type i in year t; RI^t_i represents the residential incomes of resident type i in year t; P^t_i represents the population of resident type i in year t; P^t represents the total population in year t; H^t represents the total number of households in year t; C^t_{ij} = (C^t_{ij}/E^t_{ij}) represents the emissions coefficient of fuel j of resident type i in year t; $ES^t_{ij} = (E^t_{ij}/E^t_i)$ represents the share of fuel type j in the total energy consumption of resident type i in year t; $EI^t_i = (E^t_i/ RI^t_i)$ represents the energy intensity of resident type i in year t; $HPI^t_i = (RI^t_i/P^t_i)$ represents the per capita income of households of resident type i in year t; $U^t_i = (P^t_i/P^t)$ represents the population ratio of resident type i in year t and denotes urbanisation $HS^t_i = (P^t/H^t)$ represents the number of residents per household in year t and denotes household size.
Referring to Ang (2004), the variation in CO_2 emissions between year 0 and year t (C^t_{tot}) can be expressed as the following formula:

$$\begin{aligned}\Delta C^t_{tot} = C^t - C^0 &= \sum_{ij} CI^t_{ij}\, ES^t_{ij} EI^t_i HPI^t_i U^t_i HS^t H^t - \sum_{ij} CI^0_{ij}\, ES^0_{ij} EI^0_i HPI^0_i U^0_i HS^0 H^0 \\ &= CI_{effect} + ES_{effect} + EI_{effect} + HPI_{effect} + U_{effect} + HS_{effect} + H_{effect}\end{aligned} \tag{2}$$

Where CI_{effect} is the emission coefficient effect. It reflects the CO_2 emissions change caused by the variation in the ratio of carbon emissions to energy consumption. As the emission factors for conventional fuels remain constant, this effect is largely determined by the changes in the heat and electricity coefficients over the study period; ES_{effect} is the energy structure effect, referring to the CO_2 emissions change caused by the change in the relative shares of energy forms in total energy consumption; EI_{effect} is the energy intensity effect, which represents the CO_2 emissions change caused by the change in the ratio of energy consumption to residential incomes of households; HPI_{effect} is the per capita household income effect. It reflects the CO_2 emissions change caused by the change in the per capita income of households; U_{effect} is the urbanisation effect and means the CO_2 emissions change caused by the change in the ratio of urban population to total population; HS_{effect} is the household size effect. This effect reflects the CO_2 emissions change caused by the shrinking of household size. The household size was defined as the average number of permanent residents per household: household size = total population/total households; H_{effect} is the household effect. It reflects the CO_2 emissions change caused by the change in the total number of households.
Each effect of Eq(2) can be calculated as follows:

$$CI_{effect} = \sum_{ij} L(C^t_{ij} - C^0_{ij}) \ln\left(\frac{CI^t_{ij}}{CI^0_{ij}}\right) \tag{3}$$

$$ES_{effect} = \sum_{ij} L(C^t_{ij} - C^0_{ij}) \ln\left(\frac{ES^t_{ij}}{ES^0_{ij}}\right) \tag{4}$$

$$EI_{effect} = \sum_{ij} L(C^t_{ij} - C^0_{ij}) \ln\left(\frac{EI^t_i}{EI^0_i}\right) \tag{5}$$

$$HPI_{effect} = \sum_{ij} L(C^t_{ij} - C^0_{ij}) \ln\left(\frac{HPI^t_i}{HPI^0_i}\right) \tag{6}$$

$$U_{effect} = \sum_{ij} L(C_{ij}^t - C_{ij}^0) \ln\left(\frac{U_i^t}{U_i^0}\right) \tag{7}$$

$$HS_{effect} = \sum_{ij} L(C_{ij}^t - C_{ij}^0) \ln\left(\frac{HS^t}{HS^0}\right) \tag{8}$$

$$H_{effect} = \sum_{ij} L(C_{ij}^t - C_{ij}^0) \ln\left(\frac{H^t}{H^0}\right) \tag{9}$$

where

$$L(C_{ij}^t - C_{ij}^0) = \begin{cases} \dfrac{CI_{ij}^t - CI_{ij}^0}{\ln C_{ij}^t - \ln C_{ij}^0}, C_{ij}^t \neq C_{ij}^0 \\ C_{ij}^t, \quad C_{ij}^t = C_{ij}^0 \end{cases} \tag{10}$$

2.2 Data sources

The study period spans from 1993 to 2015. Urban and rural annual data for the income of households is obtained from the Household Socio-Economic Survey (National Statistical Office Thailand, 2017). The population data is obtained from the Official Statistics Registration Systems (Department of Provincial Administration, 2017). The urban and rural annual data on residential direct energy consumption are obtained from the Thailand Energy Statistics (Department of Alternative Energy Development and Efficiency, 2017). To ease the decomposition analysis of the data, the data is organised where all kinds of the residential direct energy consumption are classified into six types, i.e. electricity LPG kerosene fuel wood charcoal and paddy husk.

3. Results and discussion

Figure 1 presents the aggregate and annual results of the decomposition analysis. The increasing and decreasing effects on residential direct CO_2 emissions of Thailand have been showed from 1993 to 2015. The results indicated that only four out of seven of the analysed influencing factors had a decreasing effect on the residential direct CO_2 emissions of Thailand, which are the changes in household size (HS_{effect}), energy intensity (EI_{effect}) and emission coefficient (CI_{effect}). The changes in the income of households, the number of households, urbanisation and energy structure were responsible for the increasing emissions.

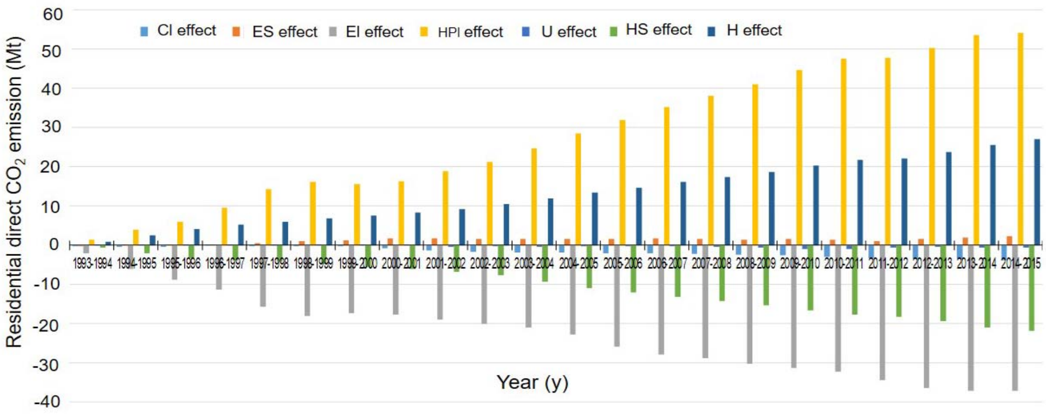

Figure 1: Decomposition results of residential direct CO2 emissions in Thailand from 1993 to 2015

3.1 Household income effect

The household income effect (HPI_{effect}) was the strongest and most stable promoting factor over the 1993 - 2015 period, which contributed 30.21 Mt to the aggregate increase of residential direct CO_2 emissions. This effect increased the residential direct CO_2 emissions during the whole study period. It could be explained by the remarkable growth of income in both urban and rural households, as shown in Figure 2. From 1993 to

2015, the incomes of urban and rural households rose from 12,142 THB to 32,350 THB and from 5,273 THB to 21,994 THB, representing an annual average growth rate of 4.66 % and 7.04 %.

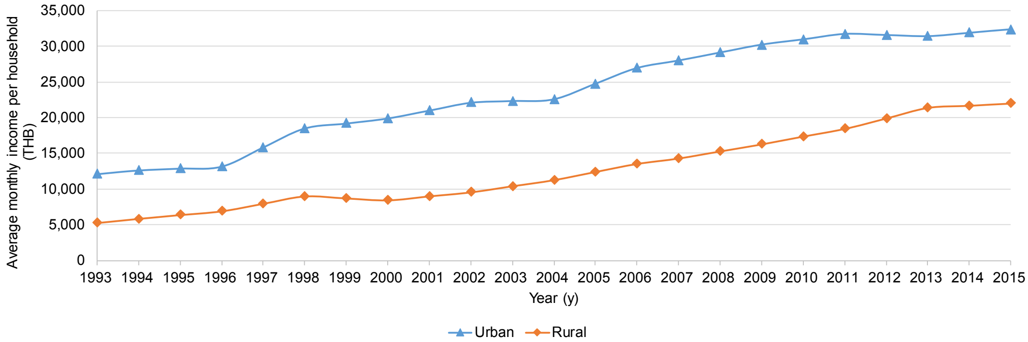

Figure 2: Income of households in the urban and rural areas of Thailand from 1993 to 2015

3.2 Household effect

The household effect (H_{effect}) was another factor that led to the increase in residential direct CO_2 emissions over the 1993 - 2015 period, which contributed 13.58 Mt to the aggregate change of residential direct CO_2 emissions. In this case, the household effect refers to the residential direct CO_2 emissions change caused by the change in the total number of households in Thailand. As shown in Figure 3, the number of households in Thailand increased to 24.71 M households in 2015 from 13.34 M households in 1993, with an annual growth rate of 2.85 %. The number of urban households showed a linear growth trend and increased from 2.80 M households to 10.39 M households. The number of rural households fluctuated around a generally stable level of about 6 M households. The above data revealed that the increase in the number of urban households was mainly responsible for the increase in the number of total households and the residential direct CO_2 emissions.

3.3 Household size effect

The household size effect (HS_{effect}) was the only household-related factor that stayed negative over the whole study period, which was the second largest negative effect and contributed 10.87 Mt to the aggregate decrease of residential direct CO_2 emissions. Figure 3 showed that the total household size kept falling since 1993. In 2015, the total household size was 2.66 people compared to 4.37 people in 1993, meaning that the major type of Thailand households has transformed from “four person households” to “three person households.

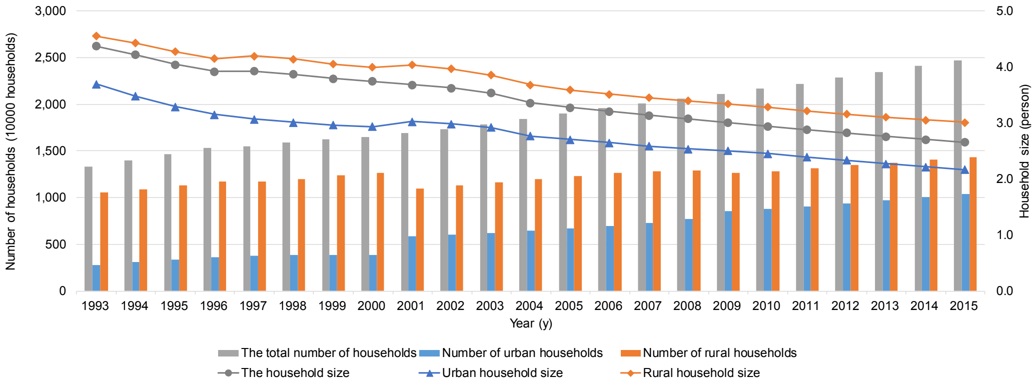

Figure 3: Number and size of household in the urban and rural areas of Thailand from 1993 to 2015

3.4 Urbanisation effect

During 1993 - 2015, the urbanisation effect (U_{effect}) increased the residential direct CO_2 emissions by 0.05 Mt. Figure 4 showed the urbanisation effect did not play an obvious role in the emission increment. Currently, Thailand is constructing a people-oriented, urban-rural integration, efficient, green and low-carbon urbanisation and its urbanisation level is expected to pass 40 % by 2030.

3.5 Other effects

The energy intensity effect (EI_{effect}) was the strongest promoting factor in the reduction of residential direct CO_2 emissions. The energy intensity effect contributed 22.08 Mt to the decrease of residential direct CO_2 emissions from 1993 to 2015. In this paper, energy intensity refers to residential energy consumption per household income. The residential direct energy consumption will inevitably increase with the process of urbanisation.

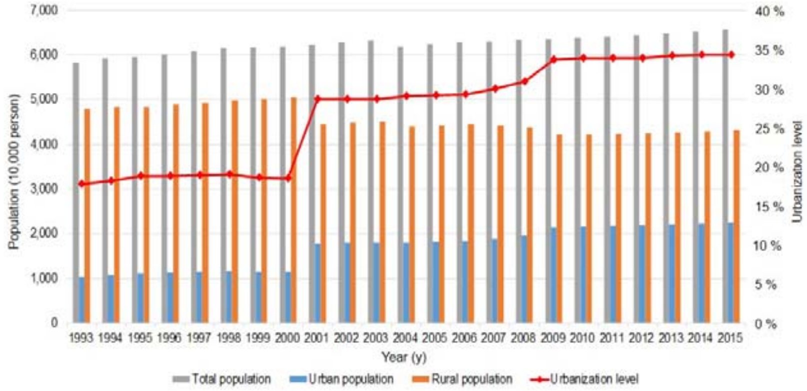

Figure 4: Level of urbanisation and population distribution in Thailand from 1993 to 2015

Continuous urbanisation can serve as a powerful vehicle for promoting income growth of residents with its massive domestic demand as shown in Figure 5. The results showed that the energy structure effect (ES_{effect}) contributed to an increase in residential direct CO_2 emissions by 1.21 Mt. This can be explained by the dramatic increase in the ratio of electricity in both rural and urban areas showed Figure 6 and Figure 7. The emission coefficient effect (CI_{effect}) contributed slightly to the reduction in residential direct CO_2 emissions, which resulted in an accumulated decrease in residential direct CO_2 emissions by 1.55 Mt. As the emission factors for conventional fuels remain constant, this effect is largely determined by the changes in electricity coefficients over the study period. The coefficient for electricity generation showed a certain degree of decrease from 0.742 kg/kWh in 1993 to 0.560 kg/kWh in 2015.

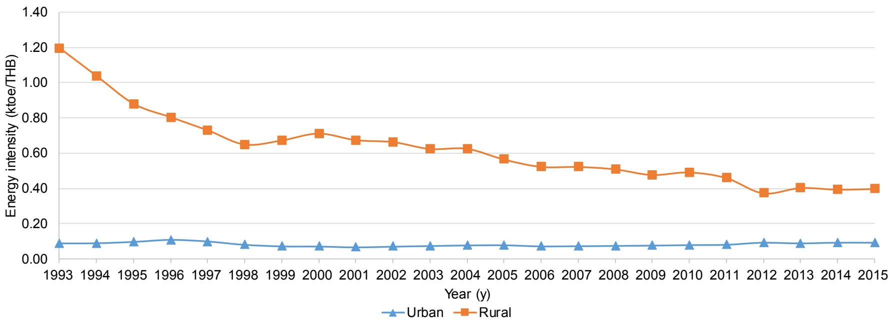

Figure 5: Energy intensity in the urban and rural areas of Thailand from 1993 to 2015

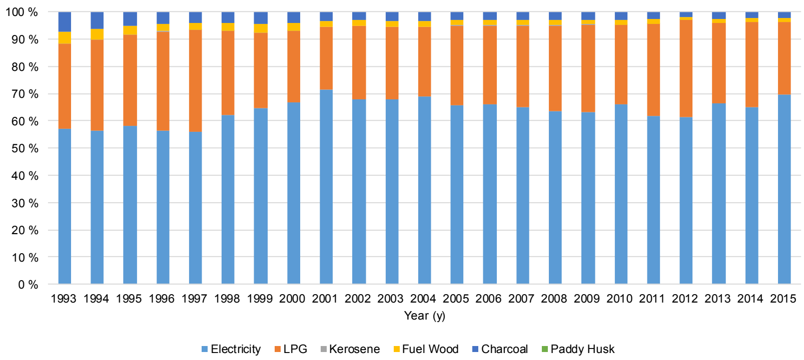

Figure 6: Energy structure of urban areas in Thailand from 1993 to 2015

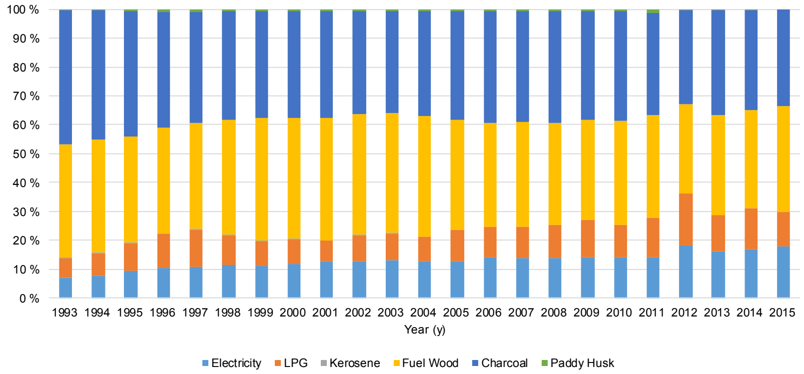

Figure 7: Energy structure of rural areas in Thailand from 1993 to 2015

4. Conclusions

In this paper, the LMDI method was applied to identify the key impact factors for residential direct carbon emissions in Thailand over the period of 1993 - 2015, and focused on the effects of household-related factors. It was found that the household income effect was the most important contributor to the increase of the residential direct CO_2 emissions, followed by the household effect that enhanced residential direct CO_2 emissions by 13.58 Mt. The household size effect was the second largest negative effect and contributed 10.87 Mt to the decrease of the residential direct CO_2 emissions, which is largely dependent on the decline in the household size. The urbanisation effect caused a marginal increase in the residential direct CO_2 emissions. Thailand has experienced the stage of accelerating urbanisation process, and this will increase the pressure on its carbon mitigation. The decreasing in energy intensity was the major contributing effect on the decline in residential direct CO_2 emissions. The emission coefficient effect contributed to a slight decrease in residential direct CO_2 emissions due to the diminishing emission coefficient of electricity. The energy structure effect increased the residential direct CO_2 emissions. To further mitigate the residential direct CO_2 emissions of Thailand, the energy efficiency of residents should be improved. The clean and renewable energy should be widely popularised and used in people's daily life and power generation.

Reference

Ang B.W., 2004, Decomposition analysis for policymaking in energy: which is the preferred method?, Energy Policy, 32, 1131-1139.

Ang B.W., Liu F.L., 2001, A new energy decomposition method: perfect in decomposition and consistent in aggregation, Energy, 26, 537-548.

Ang B.W., Zhang F.Q., 1998, Factorizing changes in energy and environmental indicators through decomposition, Energy, 23, 489-495.

Ang B.W., Zhang F.Q., 2000, A survey of index decomposition analysis in energy and environmental studies, Energy, 25, 1149-1176.

Department of Provincial Administration, 2017, The Official Statistics Registration Systems (1993-2015), <stat.dopa.go.th> accessed 23.06.2017.

Department of Alternative Energy Development and Efficiency, 2017, Thailand Energy Statistics (1993-2015), <www.dede.go.th> accessed 10.06.2017.

Howarth R.B., Schipper L., Duerr P.A., Strom S., 1991, Manufacturing energy use in eight OECD countries: decomposing the impacts of changes in output, industry structure and energy intensity, Energy Econ, 13, 135-142.

National Statistical Office Thailand, 2017, The Household Socio-Economic Survey (1993-2015), <www.nso.go.th> accessed 23.06.2017.

Poolsawat K., Wongkot W., Tachajapong W., Prasitwattanaseree S., 2017, Modelling of End-use Electricity Consumption and Saving Potential in Household Sector in Northern Thailand, Chemical Engineering Transactions, 61,1117-1122.

Wachsmann U., Wood R., Lenzen M., Schaeffer R., 2009, Structural decomposition of energy use in Brazil from 1970 to 1996, Applied Energy, 86, 578-587.

Xu X., Zhao T., Liu N., Kang J., 2014, Changes of energy-related GHG emission in China: an empirical analysis from sectoral perspective, Applied Energy, 132, 298-307.