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Household Energy Consumption Behaviour for Different Demographic Regions in Thailand from 2000 to 2010

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Abstract: Since 1995, the residential sector has been a fast-growing energy consumption sector in Thailand. This sector contributes dramatically to the growth of Thailand's electricity and oil demand. Our study analysed Thailand's residential energy consumption characteristics and the seven underlying factors affecting the growth in energy use of five demographic regions using an energy input–output method. Embodied energy decomposition revealed that direct energy consumption accounted for approximately 30% of total residential energy use, whereas indirect energy consumption was at 70%. During the studied period, the growth in indirect energy use for all household groups was primarily the result of higher consumption of 'commerce', 'air transport', 'manufacturing', 'food and beverages' and 'agriculture' products. Moreover, each influencing driver contributes differently to each household's growth in energy demand. The number of households was the leading factor that dominated the increases in residential energy use in the Greater Bangkok and Central regions. Growth in residential energy consumption in the Northern, Northeastern and Southern regions was strongly dominated by changes in income per capita. Consumption structure and using energy-efficient products had a moderate impact on all regions' energy consumption. Thus, our findings provide additional energy-saving strategies to restrain further growth in residential energy demand.

Keywords: residential energy consumption; Thailand; structural decomposition analysis; hybrid input–output

1. Introduction

Energy consumption in Thailand's residential sector grew steadily from 1995 to 2015 and accounted for approximately 15% of the country's energy consumption. This was prominent due to the increasing residential and commercial energy consumption. In 1995, the residential sector consumed 970 ktoe of petroleum products and 1246 ktoe of electricity. In 2015, household petroleum product consumption was doubled compared to that in 1995, at 1826 ktoe, whereas electricity consumption tripled to 3624 ktoe [1]. Thus, the residential sector contributes dramatically to the rapid growth of Thailand's demand for electricity and oil. Therefore, energy policies and conservation efforts in the residential sector which restrain the further growth of energy demand in Thailand are required.

Two voluntary energy plans exist that focus on the reduction of residential energy demand as announced by the Ministry of Energy [2,3]: (1) Thailand 20-year Energy Efficiency Development

Plan (2015–2036) or EEP 2015 and (2) Alternative Energy Development Plan 2015 or AEDP 2015. The first plan focuses on the highly efficient energy label of appliances (called Label#5), including air conditioners (ACs), refrigerators, and water heaters, and energy-saving awareness through various multimedia channels was promoted to the public. The second plan promotes the use of renewable electricity for self-consumption projects in households by offering feed-in-tariff schemes from the government, such as solar rooftop and solar hot water system installations.

However, increasing the use of energy-efficient products in households may not be an efficient energy conservation policy given the rebound effects (use that is more frequent and of longer duration) such as in China [4], Beijing [5] and the United States [6]. Moreover, installing renewable energy technologies in homes is still expensive [7]. Therefore, understanding the key determinants that affect fast-growing household energy consumption that has received less attention by policy debates, such as the role of economics and the social behaviour of households, is necessary for developing new ideas for energy conservation policy instruments. Finding the underlying factors of household energy consumption growth that are unique to each country will assist policymakers in identifying challenges and opportunities to properly design effective residential energy conservation policies, e.g., in China [8–10], Italy [11] and The Netherlands [12].

The factors that dominate the change in residential energy usage reportedly vary by country, between urban and rural regions and between high- and low-income groups such as in China [9,13], India [14,15] and Mexico [16], thus implying that each country needs a country-specific designing policy [12,17]. However, the studies that focused on finding the underlying factors of the increases in Thailand's household energy consumption rarely found anything interesting, particularly at the regional level.

Therefore, this study fills this gap by complying with Thailand's regional data and revealing the factors that influence the change in residential energy consumption (REC) in five demographic regions from 2000 to 2010. The magnitude of the effects of seven influencing factors on changes in regional energy demand were quantified, including energy efficiency, production technology advancement, household consumption structure, residential expenditure shares on income, income level per household, household size and number of households. The finding provides quantitative evidence for designing effective energy conservation policies.

The remainder of this paper is organised as follows. Section 2 reviews previous studies' findings on REC, Section 3 presents the selected methodology and applies it to an REC, Section 4 presents the data used in the analysis, Section 5 provides the empirical results and a discussion and the conclusion and policy suggestions are made in Section 6.

2. Literature Reviews

According to Figure 1, the residential energy consumption (REC) growth index was lower than the national energy consumption growth rate, implying that the energy consumption growth rate of the residential sector was low relative to the national growth rate. If only commercial energy is measured, since 1990, the household electricity consumption growth index has been higher than the national energy consumption index. Moreover, since 2005, growth in the household oil product consumption index has surpassed that of the national energy consumption index, indicating that the resident sector was a fast-growing energy demand sector. From 1990 to 2014, the average annual growth in demand for electricity and oil products in the residential sector was 6.9% and 5.5%, respectively, whereas the national energy consumption growth rate was only 5.23%.

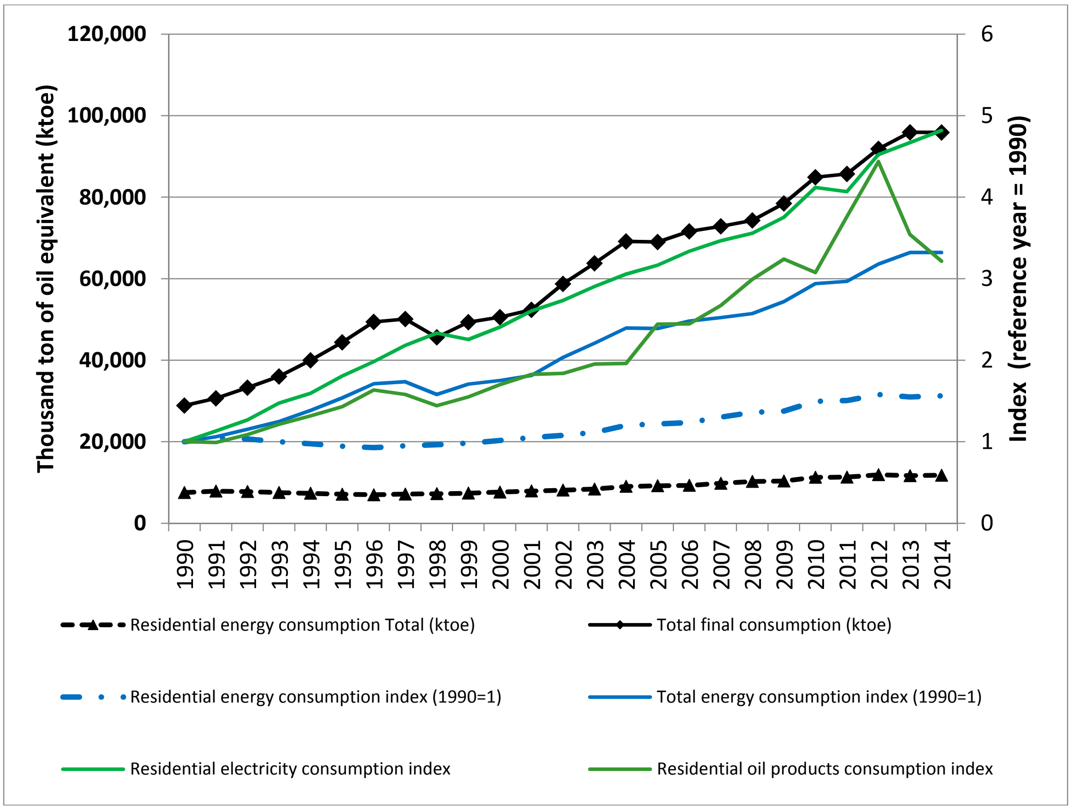

Figure 1. Thailand's residential energy consumption (REC) in ktoe from 1990 to 2014 [18].

Various factors affect changes in residential energy use, which can be summarised into three main factors: economic, social and geographic. Addressing these influence factors can significantly contributes to comprehend residential energy demand and help policymakers understand how these factors affect changes in household energy consumption.

2.1. Factors Influencing Changes in REC

2.1.1. Economic Factors

A relationship exists between economic factors and energy use. Lin et al. [19] used 2011 REC panel data for 28 provinces of China and stated that population growth, residential energy use per capita and GDP per capita (indicator of the level of economic development or household income) are the main contributors of the growth of China's REC. Ding et al. [8] used panel data for 30 provinces and found that economic factors, including the income level, have significant positive influences on increasing household energy consumption in China. Zhao et al. [9] revealed that elevated income and urbanisation in China have led to a large share of energy expenditures in total living expenditures. The residential consumption structure shifted toward more energy-using activities, causing higher energy demand. In India, from 1983 to 1994, higher household incomes and expenditures were the largest contributors to the increasing energy demand, followed by the population increase [20]. Reinders et al. [21] stated that the increase in household energy requirements given higher total household expenditures in 11 EU countries was not the result of climate effects (number of degree days). Moreover, higher-income households systematically purchase more expensive and better energy-efficient equipment, resulting in decreasing energy consumption. In The Netherlands, income has a strong influence on household electricity consumption [12]. The factors influencing REC were studied in Australia, Brazil, Denmark, India and Japan by Lenzen et al. [17]. Apart from Brazil, households became less energy intensive as incomes and expenditures increased. Li and Lin [22] analysed the impacts of urbanisation and industrialisation on energy consumption increases in 73 countries. They found that urbanisation produces negative effects on energy demand in low-income countries but is not a significant energy demand factor in middle- and high-income countries. Industrialisation influenced decreases in energy consumption for middle- and high-income groups. Thus, energy conservation strategies should vary depending on the levels of economic development.

2.1.2. Socioeconomic–Demographic Factors

Rosas-Flores and Gálvezb [16] found that living in urban and rural environments affects energy use behaviour in Mexico. Fuel-wood is the main fuel used for heating water and cooking in rural areas, whereas natural gas and LPG were more preferable than fuel-wood in urban areas. Lenzen et al. [17] indicated that socioeconomic–demographic variables (such as age, household size, urbanity, education and others) influenced changes in residential energy requirements but at different levels of impact within each country. Ding et al. [8] indicated that urbanisation does not affect the quantity of change in energy consumption in China but affects the structure and efficiency of energy consumption behaviour; moreover, urbanisation dominates the switch from traditional biomass consumption to commercial energy use as a result of the desire for convenience and comfort [9,23]. Scholars found that the age of a family member correlated with energy consumption levels in Hangzhou, China [24] and Japan [25]. Brounen et al. [12] revealed that apart from income effects, the electricity consumption of Dutch households varies on the basis of family structure. Linden et al. [26] conducted a survey comprising 600 Swedish households and found that only energy-efficient product development could not achieve energy savings from the residential sector. To reduce the residential sector's energy use, better instruction and information on how to efficiently use appliances must be delivered to motivate people to adopt more energy-efficient behaviour. Novianto et al. [7] showed that the residential period of stay and the cooking period significantly affect the energy use by Thailand households, whereas the number of hours of sleep in a household affects China's residential energy use. The number of family members influences household's energy use in the metropolitan areas in Bangkok [27], and Indonesia, and the household size affects U.S.A. residential energy use [28].

2.1.3. Geographic Factors

The number of heating degree days has a positive effect on household fuel consumption in China, Japan, Canada and the United States [29]. Although the number of heating degree days is the same, the energy consumption level is different in each country. In contrast, some studies indicated different results. Indonesia and Thailand are in a tropical climate with similar average temperatures [7]. However, more than 60% of Thailand's households always use ACs, whereas only 14% of Indonesian households prefer to regularly use ACs. Instead, more than 60% of Indonesian households are comfortable with using an electric fan. The weather condition has no effect on increasing electricity and natural gas consumption in the U.S.A. households [30].

2.2. Input–Output Analysis and Structural Decomposition Analysis of Changes in Energy Consumption

The theory of input–output (IO) analysis was proposed by Leontief [31], and a systematic introduction and application of the theory can be found in Miller and Blair [32]. The IO analysis framework was first extended to environmental IO analysis (EIO) by Bullard and Herendeen [33] to examine energy use [32] The EIO has been widely used in energy and emissions studies for countries and at the provincial level [20,34–39]. Moreover, the two common decomposition techniques applied in energy studies are index decomposition analysis (IDA) and input–output-based structural decomposition analysis (SDA). These two techniques are widely accepted by scholars in the study of the influential factors of changes in energy consumption. However, the benefit of SDA over IDA is that conducting two-stage SDA can be decomposed into a larger number of factors than IDA [38]. Moreover, using SDA can capture the impact of indirect energy consumption, whereas IDA assesses the impact of only direct consumption [38]. Poortinga et al. [40] illustrated that households consumed more than half of their energy used indirectly by using energy intensive products and services. Reducing indirect energy consumption results in significant energy savings to a country.

Several recent studies used SDA to examine the factors that cause changes in energy consumption and emissions over time, such as in Singapore [41], Xinjiang city, China [42,43], Taiwan [44] and Thailand [45]. Existing studies applied SDA to calculate the hidden factors of the residential environmental burden, e.g., the increase in the residential consumption level was the strongest factor that caused China's indirect emission increase, whereas population growth and consumption structure slightly affected the emissions growth [46]. The increase in household expenditures per capita was the largest contributor to the increase in Indian household energy consumption during 1983–1994, followed by changes in population and consumption structure [20]. Singapore's population growth, which increased by 25% from 2000 to 2010, was not a positive factor for energy consumption increases [41]. However, population and income growth were important drivers of embodied emissions increases.

The combinations of influential factors that affect the growth in REC in various countries are unique and have different magnitudes of impacts; thus, no common policies exist. Therefore, a country-specific study of the drivers of growth in REC is necessary for Thailand. Recent studies that analysed the influential drivers of the changes in Thailand's REC are rare. Therefore, our study provides comprehensive results on the driving forces of Thailand's REC by dividing households into five groups by region from 2000 to 2010. The input–output SDA methodology was applied in this study, and its key findings provide insights into developing practical energy conservation measures against growth in residential energy demand in the future.

3. Methodology

3.1. Energy Input–Output Analysis

In this study, we examine households' energy consumption by considering both direct and indirect energy requirements. The non-competitive imports assumption is used in the extended IO framework, following the recommendations of Su and Ang [47]. The fundamental IO analysis equation with a non-competitive import assumption can be formulated as

$$X_i = Z_{ij} + f_{ik}, \tag{1}$$

where X is the total output vector of n industries within the economy (n $\times$ 1), Z is the intermediate input square matrix (n $\times$ n) and f is the final demand matrix with dimensions n $\times$ k, where k is the number of final consumption categories. Kok et al. [48] introduced three types of methods based on the IO analysis to calculate household energy requirements by indicating their strengths and limitations. The study indicated that the hybrid IO with the household expenditure method is more accurate than other methods and is the most suitable method for describing the total energy requirements at the household level.

To construct an energy hybrid-unit IO table, the energy sectors in the original IO table were changed to a physical unit of energy (e.g., Joule or thousand tonnes of oil equivalents (ktoe)) reference from national energy statistics reports. We use e (row) as a subscript to denote the energy sector, and e is the energy type. Z_{ej} represents energy consumption in physical units by type for non-energy sector production. The amount of energy consumed per unit of value of industry output, called energy intensity, is represented by η_j, which equals $\sum Z_{ej}/X_i$. Then, the total household energy consumption, represented as Q_h, can be formulated as

$$Q_h = \eta_j\,(L_d)\,(f_{hh}) = \eta_j\,(L_d)\,(f_{h,1} + \ldots + f_{h,m}), \tag{2}$$

where L_d is the domestic Leontief inverse matrix and f_{hh} is the household consumption vector. Note that the household consumption value (f_{hh}) is referred from the household expenditure survey and not from the consumption data of the originate IO data set. m represents the different household groups.

3.2. SDA of Change in Energy Consumption

The volume of energy consumption in the household sector is affected by several factors. The degree to which each factor contributes to the overall changes in energy consumption can be mathematically analysed through the structure decomposition analysis methodology.

Therefore, in this study, we conducted the SDA two-polar decomposition method to express the main influential factors and quantify the magnitude of these effects on Thailand's growth in household energy consumption, divided into five regions. The two-polar decomposition technique is often used in the literature on SDA and is a widely accepted tool for policymaking and energy researchers [32]. The result of the average polar technique is very close to that of the Generalised Fisher index technique; however, constructing the equation is more simplified [32,38].

First, the absolute change in energy consumption between year t_1 and t_2 (t_1 is the earlier year) can be decomposed into three factors: the energy intensity effect (Δη), the production structure effect (L_d) and the final demand change effect (Δf), expressed in Equation (3). The two-polar decomposition technique is applied:

$$\begin{aligned}\Delta Q_h &= Q_{h,t2} - Q_{h,t1} = \eta(L_d)\,(f_{hh})_{t2} - \eta(L_d)\,(f_{hh})_{t1} \\ &= (1/2)\,(\eta L_{d,t2} + \eta L_{d,t1})\,(\Delta f_{hh}) + (1/2)\,(\Delta\eta L_d)\,(f_{hh,t2} + f_{hh,t1}),\end{aligned} \tag{3}$$

Then, ($\Delta\eta L_d$) is further disaggregated as derived in Equation (4):

$$\Delta\eta L_d = (1/2)\,\Delta\eta\,(L_{d,t2} + L_{d,t1}) + (1/2)\,(\eta_{t2} + \eta_{t1})\,\Delta L_d \tag{4}$$

Combining Equation (4) into Equation (3) results in

$$\begin{gathered}\Delta Q_h = (1/2)\,(\eta L_{d,t2} + \eta L_{d,t1})(\Delta f_{hh}) + \\ (1/4)\,\Delta\eta\,(L_{d,t2} + L_{d,t1)}\,(f_{hh,t2} + f_{hh,t1}) + \\ (1/4)\,(\eta_{t2} + \eta_{t1})\,\Delta L_d\,(f_{hh,,t2} + f_{hh,t1}).\end{gathered} \tag{5}$$

The final demand (f) was further decomposed into five factors, as derived in Equation (6):

$$f_{hh} = (f_i/\textstyle\sum f_{hh})\cdot(\sum f_{hh}/c)\cdot(c/p)\cdot(p/w)\cdot w, \tag{6}$$

where $\sum f_{hh}$ is the summation of household consumption or total household expenditures, c represents the household income, p represents the population and w represents the number of households. Then, we define the variable as follows:

$$f_{hh} = \beta\cdot\mu\cdot\,\Theta\,\cdot s\cdot w,$$

where

β is the matrix representing household consumption structure, as ($f_i/\sum f_{hh}$);
μ represents the household expenditure shares on income, equal to ($\sum f_i/c$) in Equation (6);
Θ represeerepresents household income per capita, equal to (c/p) in Equation (6);
s represents the size of a household in terms of number of members, equal to (p/w) in Equation (6);
W represents the number of households.

Thus, the final changes in consumption (Δf) between year t_1 and t_2 can be further derived in a mathematical equation, as shown in Equation (7):

$$\begin{aligned}\Delta f_{hh} = f_{hh,t2} - f_{hh,t1} &= (\beta\cdot\mu\cdot\Theta\cdot s\cdot w)_{t2} - (\beta\cdot\mu\cdot\Theta\cdot s\cdot w)_{t1} \\ &= [(1/2)\,(\Delta\beta)\,(\mu\Theta sw_{t2} + \mu\Theta sw_{t1})] + \\ &\quad [(1/4)\,(\beta_{t2} + \beta_{t1})\,(\Delta\mu)\,(\Theta sw_{t2} + \Theta sw_{t1})] + \\ &\quad [(1/8)\,(\beta_{t2} + \beta_{t1})\,(\mu_{t2} + \mu_{t1})\,(\Delta\Theta)\,(sw_{t2} + sw_{t1})] + \\ &\quad [(1/16)\,(\beta_{t2} + \beta_{t1})\,(\mu_{t2} + \mu_{t1})\,(\Theta_{t2} + \Theta_{t1})\,(\Delta s)\,(w_{t2} + w_{t1})] + \\ &\quad [(1/16)\,(\beta_{t2} + \beta_{t1})\,(\mu_{t2} + \mu_{t1})\,(\Theta_{t2} + \Theta_{t1})\,(s_{t2} + s_{t1})\,(\Delta w)]\end{aligned} \tag{7}$$

Next, we combined Equation (7) into Equation (5). The driving factors of changes in energy consumption between years t_2 and t_1 can be derived into mathematical Equation (8) as follows:

$$\begin{aligned}\Delta Q_h = &(1/4)\,\Delta\eta\,(L_{d,t2} + L_{d,t1})\,(f_{hh,t2} + f_{hh,t1}) + \\ &(1/4)\,(\eta_{t2} + \eta_{t1})\,\Delta L_d(f_{hh,,t2} + f_{hh,t1}) + \\ &(1/4)\,[(\eta L_{d,t2} + \eta L_{d,t1})\,(\Delta\beta)\,(\mu\Theta sw_{t2} + \mu\Theta sw_{t1})] + \\ &(1/8)\,[(\eta L_{d,t2} + \eta L_{d,t1})\,(\beta_{t2} + \beta_{t1})\,(\Delta\mu)\,(\Theta sw_{t2} + \Theta sw_{t1})] + \\ &(1/16)\,[(\eta L_{d,t2} + \eta L_{d,t1})\,(\beta_{t2} + \beta_{t1})\,(\mu_{t2} + \mu_{t1})\,(\Delta\Theta)\,(sw_{t2} + sw_{t1})] + \\ &(1/32)\,[(\eta L_{d,t2} + \eta L_{d,t1})\,(\beta_{t2} + \beta_{t1})\,(\mu_{t2} + \mu_{t1})\,(\Theta_{t2} + \Theta_{t1})\,(\Delta s)\,(w_{t2} + w_{t1})] + \\ &(1/32)\,[(\eta L_{d,t2} + \eta L_{d,t1})\,(\beta_{t2} + \beta_{t1})\,(\mu_{t2} + \mu_{t1})\,(\Theta_{t2} + \Theta_{t1})\,(s_{t2} + s_{t1})\,(\Delta w)]\end{aligned} \tag{8}$$

Subsequently, herein, the changes in total energy consumption by the household group are decomposed into effects caused by changes in the seven key components on the right-hand side of Equation (8). The first, second and third terms represent the effects caused by the changes in energy efficiency, production structure and household consumption structure, respectively. The fourth and fifth terms represent the effects caused by changes in expenditures related to the income ratio, called expenditure in this study, and the changes in household income per capita, respectively. The sixth and final terms represent the effects caused by changes in household size and the effects caused by changes in the number of households, respectively.

4. Data

The data required to conduct the analysis described in the methodology section were mainly obtained from several sources. First, we constructed the hybrid-unit IO tables. Thailand's original 2000 and 2010 IO table from NESDB [49], comprising 179 sectors, were aggregated into 23 sectors (18 non-energy sectors and 5 energy sectors) to reconcile with the energy data in physical units, as illustrated in the energy situation annual report and Thailand energy balance [1,50]. The aggregated dataset in this study is shown in Table 1. Next, the 2000 hybrid-unit IO tables were adjusted to constant price tables (2010 prices) using the producer price index maintained by the Product Group from Thailand's Bureau of Trade and Economic Indices [51]. Subsequently, for the private consumption category (household final demand) in the IO table, data from the household expenditure survey in the 2000 and 2010 socio-economic survey [52,53] were used to disaggregate one household group in the IO table into five consumption groups by the demographic region.

Table 1. Recognised sectors and data allocation.

Sector	Hybrid-Unit I/O Sector Classification	I/O Sector	Household Expenditure Survey
1	Agriculture	1–29	Charcoal and firewood Food prepared at home
2	Mining	32–41	n/a
3	Food & beverages	42–66	Non-alcoholic beverage (at home) Alcoholic beverages-drunk at home Alcoholic beverages-drunk away from home Tobacco products Prepared food:-Food taken home
4	Textiles	67–74	Cloth and clothing Footwear
5	Wood and furniture	78–80	Furniture equipment, household textiles and small appliances
6	Paper and paper products	81–83	Personal supplies *
7	Chemical products	84–92	Cleaning supplies Medicine and supplies
8	Non-metallic	95–104	Personal supplies *
9	Metallic	105–107	n/a
10	Fabricated metal	108–111	Personal supplies *
11	Manufacturing others	75–77, 112–134	Vehicles purchase Vehicle repairing & maintenance Recreation equipment and sports
12	Construction	137–144	Repair/maintenance dwelling Estimated rental value of dwelling (Include owned dwelling)
13	Commercial	145–148, 158–178	Service workers in household Rent of dwelling Personal services Medical services (outpatients) Medical services (inpatients) Communication Education Toys, pets, shrubs and recreation Admission, sports fee Reading/religious activities Special ceremony expenses Water supply, underground water Prepared food—Food eaten away from home

Table 1. *Cont.*

Sector	Hybrid-Unit I/O Sector Classification	I/O Sector	Household Expenditure Survey
14	Rail transport	149	Household expenditure on other transportation **
15	Road transport	150–152, 157	Household expenditure on other transportation **
16	Water way transport	153–155	Household expenditure on other transportation **
17	Air transport	156	Special occasion travelling and tour
18	Unclassified	180	Personal supplies *
19	Coal and lignite	30	n/a
20	Crude oil	31	n/a
21	Natural gas	31, 136	NGV, LPG
22	Petroleum products	93–94	Gas used in households (cooking and others) Gasoline Diesel Gasohol NGV, LPG Biodiesel and other alternative energy
23	Electricity	135	Electricity

Remarks: * The value was calculated by the author through the manipulation method using the proportion from the IO data, and by calculating the value from 'personal supplies' expenditure. ** The value was calculated by the author through the manipulation method using the proportion from the IO data and by calculating the value from 'household expenditure on other transportation' expenditure. (Note that other transportation includes taxi, bus, boat, train, electric train and others.)

There are 32 goods and services consumption items on the household expenditure survey. Note that household expenditure data on energy use were not provided on the household expenditure survey. However, such data can be obtained from the household energy consumption report [54,55]. The household expenditure survey and the household energy consumption report were combined. Two items on the household expenditure survey were further disaggregated to include energy expenditures. The first item was the 'Fuel, Lighting and Water Supply' item, which was further disaggregated into four sub-groups: electricity, gas used in households (for cooking and other activities), charcoal and firewood and water supply/underground water. The second item was the 'Local Transportation' item, which was further disaggregated into six sub-groups: gasoline, diesel, gasohol, NGV/LPG, biodiesel and other alternative energy and other transportation (taxi, bus, boat, train, electric train and others). At the end, there were 40 household expenditure items.

Household consumption in the IO data has 23 sectors, as previously mentioned, and the household expenditure survey contained 40 items. Note that several products from the household expenditure survey could be produced from the same sector as that stated in the IO table. Therefore, the proper data matching process was required to ensure the quality of the results. The data allocation in this study is described in Table 1.

Moreover, data on population, number of households and average household size by region were obtained from the 2000 to 2010 Population and Housing Census [56]. The 2000 income by region was obtained from the average monthly income per household report [57], and the 2010 income by region was calculated by the author using a linear regression based on the average monthly income per household from 1998 to 2015 [57] as presented in Appendix A.

5. Result and Discussions

5.1. Total Household Energy Consumption and Decomposition

Using the IO analysis, the embodied energy consumption of five household groups is disaggregated to reveal their direct and indirect energy consumption sources, as illustrated in Figure 2. Energy consumption from the energy sector (direct energy consumption) was found to account for approximately 30% of the total household energy consumption for all household groups. The rest came from indirect energy consumption from consuming products and services. In 2000, the Greater Bangkok region consumed 8542 ktoe, and embodied energy increased to 15,173 ktoe in 2010, representing 78% growth. Besides this, the total energy requirement for households in the Central region was 5253 ktoe in 2000, which increased to 7910 ktoe in 2010. The growth in indirect energy use in the Greater Bangkok and Central regions came from higher consumption of 'commerce', 'air transport', 'manufacturing' and 'food and beverage' products and services. For the both studied periods, the three leading indirect energy consuming sectors for households in the Greater Bangkok region were 'road transport', 'commerce' and 'construction', whereas, the major sources of indirect energy consumption of households in the Central region were the consuming 'agriculture', 'construction' and 'commerce' sectors.

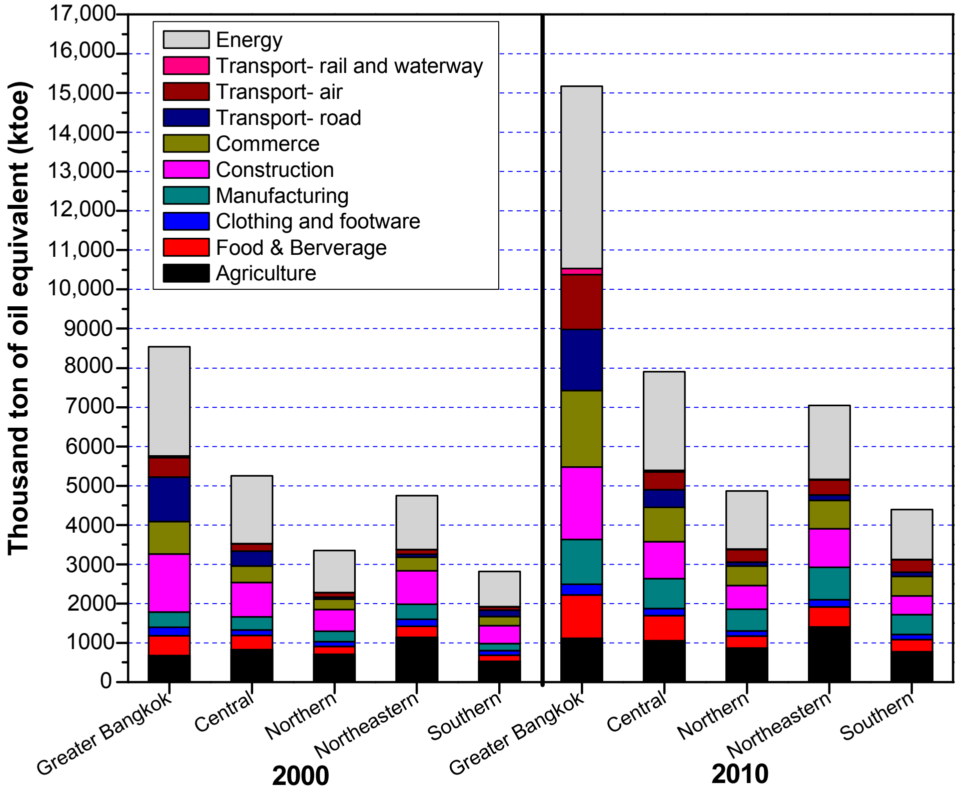

Figure 2. Total household energy consumption in 2000 and 2010 by industry and region.

The embodied energy of households in the Northern region was 4870 ktoe in 2010, a 45% increase from 2000 (3354 ktoe). Moreover, the Southern household group had the lowest total energy consumption among the five regions. In 2000, the embodied energy consumption was 2815 ktoe, which increased to 4398 ktoe in 2010, for a 56% growth. The Northern and Southern households consumed most of their indirect energy from three leading industries: 'agriculture', 'construction' and 'manufacturing products'. The Northern region's growth in embodied energy consumption between the studied periods was due to the higher consumption of 'manufacturing products', 'commerce' and 'air transport'. The major sources of growth in total energy consumption for Southern region households were due to higher consuming products and services from the 'manufacturing', 'agriculture' and 'commerce' sectors.

Finally, the total energy consumption of the Northeastern household region increased by 49% (4746 ktoe in 2000 and 7049 ktoe in 2010). The increase in total energy consumption was from direct (23%) and indirect (77%) energy demand. Among the five regions, the Northeastern region households had the largest indirect energy consumption from agricultural products in both periods. Households in this region significantly consumed more 'manufacturing', 'commerce' and 'agriculture' products from 2000 to 2010, which led to the growth in their indirect energy consumption.

5.2. Drivers of Changes in Energy Consumption

The change in total REC from 2000 to 2010 can be disaggregated into seven factors, as described in Equation (8). The result of the driving factor analysis of Thailand's change in REC is shown in Figure 3. The effect of the change in the number of households (Δw) was the largest contributor to the increases in household energy consumption during the studied period, followed by change in income per capita ($\Delta \Theta$), consumption structure ($\Delta \beta$), production structure (ΔL) and energy efficiency ($\Delta \eta$), which accounted for 82.4%, 59.5%, 37.5%, 20.9% and 18%, respectively. In contrast, the expenditure effect ($\Delta\mu$) was the largest offset factor of Thailand's increase in REC, followed by change in household size (Δs), which accounted for −72.9% and −45.4%, respectively.

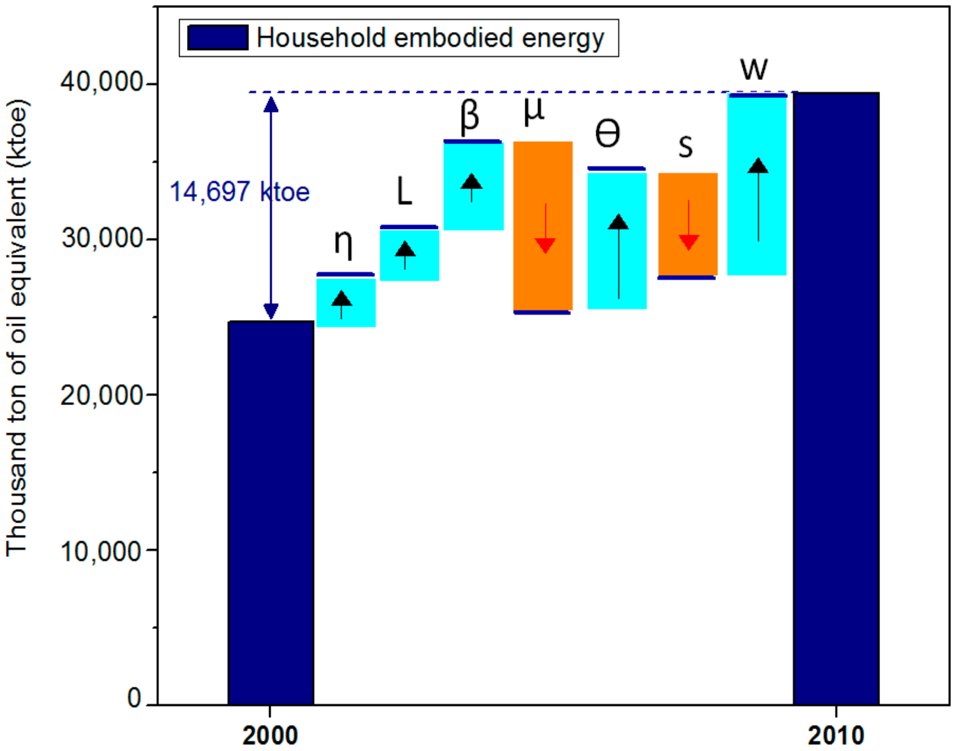

Figure 3. Factors influencing the change in REC from 2000 to 2010.

The drivers that affect the change in energy demand for each household group were further decomposed. The breakdown of the driving factors of the change in REC for each household region is exhibited in Table 2, which can be described as follows.

Table 2. Factors influencing REC change by region.

No	Region	Energy Consumption Change (ΔQ)	Energy Efficiency Effect (η)	Production Structural Change Effect (L)	Consumption Structure Effect (β)	Expenditure Shares on Income Effect (μ)	Incomes per Capita Effect (ϴ)	Size of Household Effect (s)	Number of Households Effect (w)
1	Greater Bangkok	6631	747	512	1471	(2629)	2126	(3262)	7666
	%	100	11	8	22	(40)	32	(49)	116
2	Central	2659	551	639	1303	(2327)	1360	(1184)	2317
	%	100	21	24	49	(88)	51	(45)	87
3	Northern	1519	400	554	1025	(1803)	1232	(675)	785
	%	100	26	36	67	(119)	81	(44)	52
4	Northeastern	2303	615	923	1223	(2477)	2596	(1011)	435
	%	100	27	40	53	(108)	113	(44)	19
5	Southern	1582	328	446	486	(1471)	1426	(540)	906
	%	100	21	28	31	(93)	90	(34)	57

5.2.1. Greater Bangkok Region

The REC in Greater Bangkok increased by 6631 ktoe from 2000 to 2010, as illustrated in Table 2. The increase in the number of households (Δw) was the main factor that caused the increase and accounted for 116% (7666 ktoe) of the increases in energy consumption, followed by the change in income per capita (ΔΘ) and the change in consumption structure (Δβ), which had moderate effects on the increases, accounting for 32% (2126 ktoe) and 22% (1471 ktoe), respectively, of the increases in regional energy consumption. Moreover, changes in energy efficiency (Δη) and production structure (ΔL) have weak impacts on Greater Bangkok's change in energy demand, accounting for only 11% and 8% of the region's increase in energy consumption. In contrast, the change in household size (Δs) and the expenditure share on income (Δμ) were offset factors to the energy increases. The change in household size (Δs) exhibited the strongest negative impact on the Greater Bangkok region than others because household size most sharply declined in this region from 3.7 in 2000 to 2.8 in 2010 (Appendix B).

The change in income per capita (ΔΘ) is a positive factor of Greater Bangkok's increase in energy consumption. However, its percentage value was the lowest among all regions, indicating that the change in the income level had a weaker effect on the region's growth in resident energy consumption compared with other regions.

5.2.2. Central Region

Households in the Central region consumed more energy in 2010 compared with 2000, a difference equal to 2659 ktoe. The change in the number of households (Δw) was the strongest positive factor contributing to increases in residential energy in the Central region (87%, 2317 ktoe), followed by the change in income (ΔΘ) (51%, 1360 ktoe), consumption structure (Δβ) (49%, 1303 ktoe), production structure (ΔL) (24%, 639 ktoe) and energy efficiency (Δη) (21%, 551 ktoe). The impact of the change in the number of households (Δw) of this region had a much lower impact than in the Greater Bangkok region. In contrast, the negative driving factors of the increases were expenditure shares on income (Δμ) and the change in household size (Δs), which accounted for −88% (2327 ktoe) and −45% (1184 ktoe), respectively, of the increased energy use.

5.2.3. Northern Region

The REC in the Northern region had increased by 1519 ktoe. The findings show that increases in household energy consumption in this region were largely dominated by the change in income (ΔΘ) (81%, 1232 ktoe), followed by changes in the consumption structure (Δβ) (67%, 1025 ktoe) and the number of households (Δw) (52%, 785 ktoe).

Changes in energy efficiency (Δη) and production structure (ΔL) had moderate positive effects on increases in energy consumption, accounting for 26% (400 ktoe) and 36% (554 ktoe), respectively, of the increases. However, these changes in percentage terms were higher than their impacts on other regions, except for the Northeastern region. This result implies that households in the Northern region do not favour consuming energy efficiency products and services as much as households in Greater Bangkok, Central and Southern regions.

The offset driving factors to reduce energy demand in the Northern region were the change in expenditures (Δμ), −119% of the energy use increases, followed by the change in household size (Δs), −44% of the increases. The expenditure effect (Δμ) exhibited the strongest offset factor for the Northern household region compared with other regions.

5.2.4. Northeastern Region

The REC increased by 2303 ktoe from 2000 to 2010. Among the five household groups, the change in income per capita (ΔΘ) had the strongest effect on the increases in household energy use in the Northeastern region, contributing 113% (2596 ktoe) of the increases. This result implies that residential energy demand in this region was highly dominated by changes in income levels. The second driving factor of the increase in energy use was the consumption structure, accounting for only 53% (1223 ktoe). Although the change in the number of households (Δw) turned out to be a weak influencing factor, it was actually the lowest among all regions in Thailand. Thus, the change in the number of households has a weaker impact on changes in residential energy demand in the Northeastern region compared with other regions. The effect of this region's changes in energy efficiency (Δη) and production structure (ΔL) was the highest among all regions, implying that household behaviour in the Northeastern region does not favour consuming energy efficiency products and services. The expenditure effect (Δμ) and change in household size (Δs) were negative factors for increases in energy demand for this region, accounting for −108% and −44%, respectively.

5.2.5. Southern Region

The REC in the Southern region increased by 1582 ktoe from 2000 to 2010. Change in the income per capita level (ΔΘ) was the first leading influencing factor of the increases, followed by the change in the number of households effect (Δw), contributing to 90% and 57%, respectively, of the increases in household energy use in the Southern region. The changes in energy efficiency (Δη), production structure (ΔL) and consumption structure (Δβ) had moderate impacts on the increases at 21%, 28% and 31%, respectively. Similar to other regions, the offset factors of the increases in the Southern region's REC were the expenditure effect (Δμ) and the change in household size (Δs), accounting for −93% and −34%, respectively.

All seven factors influenced the changes in residential energy requirements but at different impact levels for each household group. The growth in the number of households (w) strongly affected Greater Bangkok's and the Central region's increases in energy consumption but had a weak impact on energy increases in the Northeastern region. Conversely, the energy demand increases in the Northern and Northeastern regions were highly dominated by the income level (Θ), followed by consumption structure (β).

Energy efficiency (η), production structure (L) and consumption structure (β) effects can reflect the consumption behaviour of each household group. These three factors had the lowest impact on energy use increases in the Bangkok region, followed by the Central and Southern regions. Households in the Greater Bangkok region could be implied as to mostly prefer consuming high efficiency energy and advanced energy technology products and services, decelerating the increase in regional energy demand, followed by the Central and Southern regions.

The expenditure effect is clearly the main leading driver of the reduction in energy demand for all regions, except Greater Bangkok. This result can be explained by referencing Appendix C, for which the expenditure per income share of all household groups significantly decreased from 2000 to 2010. The Northeastern region had the highest expenditure per income share in both the studied years, followed by the Northern, Southern, Central and Greater Bangkok regions. The largest decreases during the studied periods were in the Northeastern and Northern regions.

Moreover, possible reasons exist that explain the relationship between the household size effect and the change in residential energy use in Thailand. The type of living quarter by region (Figure 4) illustrated that people in the Greater Bangkok area preferred to live in apartments/flats/condominiums relative to individuals in other regions. Bangkok and its vicinity is a Central business district wherein land prices continue to increase from urbanisation and industrialisation growth. In Thailand's urban dwellings, ACs are installed in each individual room in the same house or condominium. Each family member has an appliance in his or her own room in urban households in large cities. Therefore, fewer family members result in lower turn-on rates for appliances and lower energy consumption level.

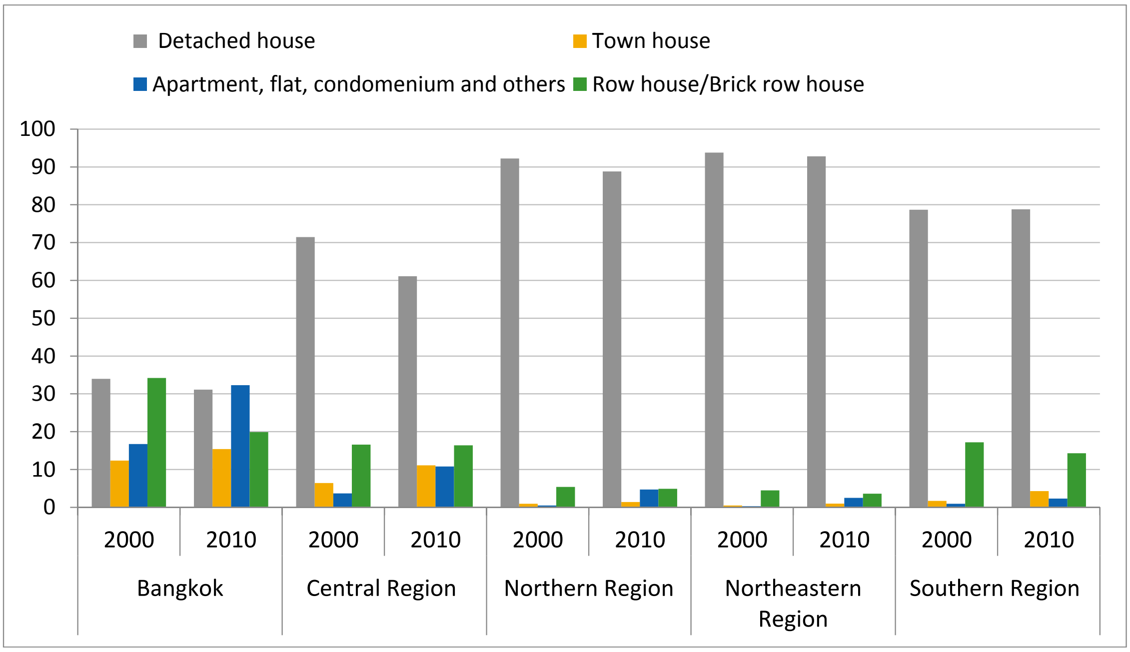

Figure 4. Private households by type of living quarters by region.

6. Conclusions and Policy Implications

Herein, we apply the IO methodology to present five household group energy consumption characteristics and the seven driving forces of the growth in REC from 2000 to 2010 in Thailand. The dataset required to conduct the analysis was obtained from a wide range of sources, as described in the data section. Subsequently, the results of REC structures and the underlying factors of REC growth were explored.

The embodied energy analysis findings revealed that approximately 70% of total residential energy consumption was in the form of indirect energy consumption from consuming products and services. The Greater Bangkok household group was the first leading energy consumer in Thailand of both direct and indirect energy. The group's embodied energy was approximately double that of the Central and Northeastern regions and triple that of the Northern and Southern groups. The Greater Bangkok region consumed a large proportion of its indirect energy by using products and services from the 'road transport', 'commerce' and 'construction' sectors. The other four regions consumed large shares of their indirect energy-using products and services from the 'agriculture', 'construction' and 'commerce' sectors. The indirect energy growth of all household groups came from higher consumption of 'commerce', 'manufacturing', 'food and beverage' and 'air transport' products.

The decomposition analysis of the underlying factors of each household group's growth in residential energy use revealed that changes in the number of households (Δw) strongly dominated the increase in residential energy use in Greater Bangkok and the Central region but is not a crucial factor of the increases in energy consumption in the Northern, Northeastern and Southern regions. The growth in REC in the Northern, Northeastern and Southern regions was strongly dominated by changes in income per capita ($\Delta\Theta$).

The benefit of using energy-efficient products was an important contributing factor leading to restraining household energy consumption demand. The findings illustrated that the growth in energy demand in the Greater Bangkok and Central regions could be decelerated by proliferating energy-efficient products. However, the energy efficiency effect and production structure effect had significantly large positive impacts on energy use increases in the Northern and Northeastern regions. One possible reason for this consumption behaviour is that in Thailand, the market prices of high energy-efficient products tend to be higher than prices for regular products. The survey market price of

AC, the leading energy consuming home appliance in Thailand, is illustrated in Appendix D. Under the same capacity, the 2010 and 2017 market prices of the higher EER air-conditioning system (such as that using inverter technology) was higher than the price of the regular split type air-conditioner (Label#5). Household incomes in Greater Bangkok and the Central and Southern regions were higher than in the Northern and Northeastern regions (Appendix A). Hence, buying the energy-efficient products of each household group can be implied to be influenced by the income level, and higher earning households were assessed as using higher energy efficiency goods than poorer households in Thailand. Current policies provide incentives for the industry to produce and market energy-efficient products. However, these products tend to be favoured and purchased by higher income groups on account of their higher prices. Therefore, policies should promote the use of long-term, energy-efficient products (e.g., AC, refrigerators, water heaters and stoves and ranges) in lower income households by means of subsidy programmes.

In this study, consumption structure, representing consumption behaviour, is shown to have a moderate to high impact on household energy consumption increases in Thailand. Therefore, modifying present consumption styles towards modes that promote energy savings may significantly decrease REC. Sukwan [27] indicated that energy-saving lifestyles, energy-saving attitudes and related practices were significantly correlated with lower electricity consumption for households within the sample cohort in the Bangkok metropolitan area. Nevertheless, even recently, Thai people still have a limited understanding with respect to energy-saving activities at home. They recognise only a few energy-saving methods as necessary, such as setting the AC temperature at 25 °C and switching from incandescent bulbs to energy efficient fluorescent tubes. Therefore, greater policy measures must be promoted to change people's energy-saving consciousness and behaviour patterns, starting with organising frequent and continuous workshops and promoting public awareness campaigns in institutes, communities and workplaces (to assess potential savings). Ehrhardt-Martinez [58] and Aldabas et al. [59] stated that receiving regular feedback from one's energy consumption patterns is an effective tool for inducing individuals to change their consumption behaviour. The consequences of these changes will yield environmental benefits and energy saving—facts that should be properly illustrated to people to motivate them to change their attitudes and energy use habits. Furthermore, full disclosure of knowledge, information and instructions is essential for providing a better understanding regarding how to efficiently use appliances. Household energy saving best practices should be provided. In addition, Simanaviciene et al. [60] mentioned that installing energy and emission metering devices may encourage people to save energy as well as to buy energy-efficient appliances and to more frequently turn off appliances when not being used.

Moreover, the expenditure effect is clearly the main factor for reducing energy demand in all regions, particularly the Northern and Northeastern regions, because the expenditure share of income for all household groups significantly decreased from 2000 to 2010. The household size effect is the offset factor for increases in energy demand of all five household groups because all household groups had smaller household sizes from 2000 to 2010.

Clearly, consumption characteristics are unique, and the previously described combination of influencing factors had different magnitudes of impacts on each household group, which was attributable to differences in economic and social factors. Therefore, a region-specific study of drivers of REC is necessary for policymakers. Our findings provide a better understanding of household energy consumption behaviour, characteristics and underlying driving factors that affect increases in energy for different demographic regions in Thailand. The findings could provide a reference for policymakers to conduct more effective energy-saving strategies to retrain future growth in residential energy demand.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

CPA	Classification of Products by Activity
DEDE	Department of Alternative Energy Development and Efficiency
EIA	Energy Information Administration
EPPO	Energy Policy and Planning Office
IDA	Index Decomposition Analysis
IEA	International Energy Agency
NESDB	National Economic and Social Development Board
NSO	National Statistics Office
REC	Residential Energy Consumption
SDA	Structural Decomposition Analysis

Appendix A

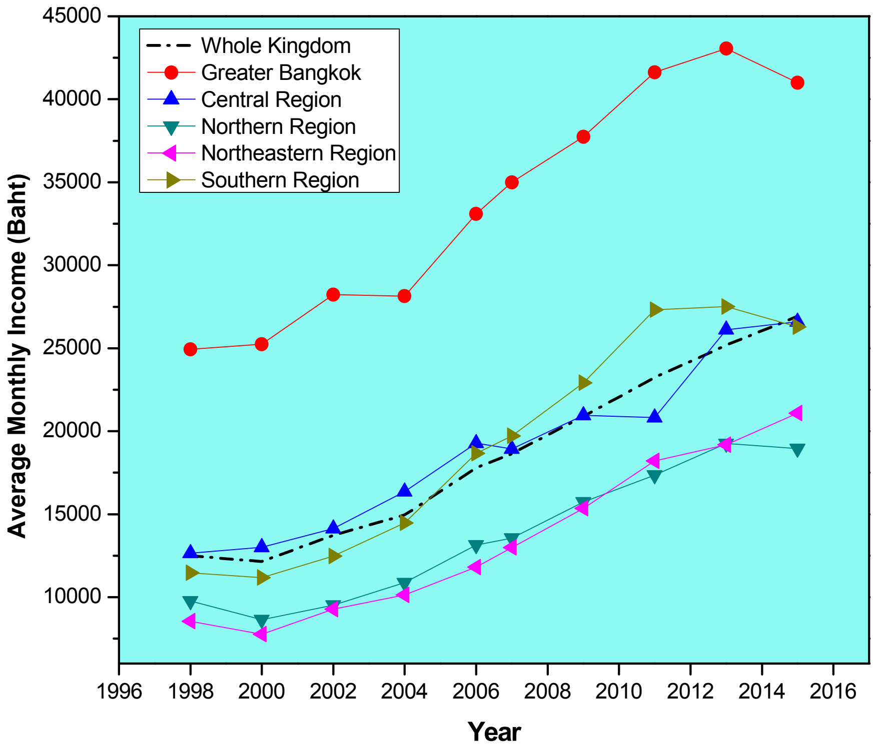

Figure A1. Average monthly income per household [57].

Table A1. The 2010 income by region using a linear regression (Unit: Baht).

	Entire Kingdom	Greater Bangkok	Central Region	Northern Region	Northeastern Region	Southern Region
Equation	Y = a + b*X					
a	9026.7	21,572	10,075	6655.1	4960	7594.2
b	1741.3	2224.5	1601.7	1278.3	1541.6	2110.7
R^2	0.978	0.947	0.951	0.946	0.955	0.940
Average 2010 income	22,086.45	38,255.75	22,087.75	16,242.45	16,522	23,424.45

Appendix B

Table A2. Key Population Indicators.

	Year	Greater Bangkok	Central Region	Northern Region	Northeastern Region	Southern Region	Data Source
Population (thousand)	2000	8813.9	11, 607.8	11,367.8	20,759.9	8057.5	[56]
	2010	12,795.1	13,693.4	11,656.0	18,966.1	8871.0	[56]
Number of households (thousand)	2000	2393.0	3109.8	3158.4	5019.7	1979.8	[56]
	2010	4520.9	4348.9	3771.5	5372.7	2509.5	[56]
Average household size	2000	3.7	3.7	3.6	4.1	4.1	(1)
	2010	2.8	3.1	3.1	3.5	3.5	(1)
Population Density (per sq. km.)	2000	1867	117	67	123	114	(2)
	2010	2710	138	69	112	125	(2)

(1) The average household size was obtained from Population divided by Number of households. (2) The population density was obtained from Population divided by region's areas from National Statistics Office (NSO).

Appendix C

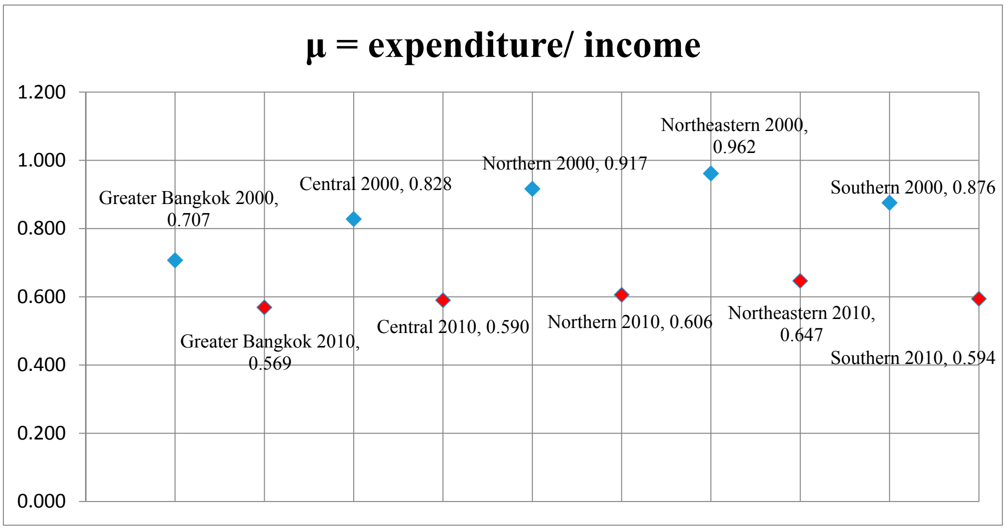

Figure A2. Expenditure per income shares of all household groups in 2000 and 2010.

Appendix D

Table A3. Market prices of air-conditioning systems in Thailand.

Type	Capacity (BTU)	Cost (Baht)	EER (BTU/Hr/W)	Data Source
		Year 2010		
Regular air-conditioning split type Label#5	18,000	20,000	11.2	[61]
Inverter system	18,000	25,000	12.0	[61]
Evaporative condensing system	18,000	29,000	15.5	[61]
		Year 2017		
Regular air-conditioning split type Label#5				
MITSUBISHI MS-GN18VF	18,000	28,800	13.1	(1)
DAIKIN ATM18MV2S	18,000	24,900	13.4	(1)
ELECTROLUX ESM18CRN-A1	18,000	27,000	12.2	(1)
Inverter system				
MITSUBISHI MSY-GN18VF	18,000	33,000	21.1	(1)
DAIKIN FTKM18NV2S	18,000	38,700	15.1	(1)
ELECTROLUX ESV18CRN-A1	18,000	33,900	18.1	(1)

(1) Home Product Center Public Company Limited. https://www.homepro.co.th/category/11259?q=search&b=&7318=16000-21000 (accessed on August 2017).

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