Household Energy Requirements and CO_2 Emissions In Thailand

Onicha Meangbua[1]

Abstract

This study employs energy input-output and structural decomposition analyses (SDA) to assess the overall role of economy-wide household consumption on energy-related CO_2 emissions in Thailand. Over the 1995-2015 period, findings indicate that household energy requirements and associated CO_2 emissions, constituted the second-largest contributor to emissions in Thailand, trailing only the export sector and there was a trend of continuously increase throughout the study period. The research considered the factors driving change using the SDA method through 3 driving factors: 1) Intensity Effect 2) Leontief Effect and 3) Final Demand Effect. It was found that the final demand effect, representing the economic context, was the primary driver of changes in energy-linked emissions (83.34%) in Thai households from 1990 to 2015. The Leontief effect (11.37%) and energy intensity effect (5.29%) also contributed to increased energy demand. Notably, the final demand effect was a significant factor in raising CO_2 emissions in Thai households. While technological advancements and intensity improvements reduced household CO_2 emissions, they were insufficient to counterbalance the emissions driven by final demand. In summary, this study underscores the crucial role of household consumption in driving energy-linked emissions in Thailand. It highlights the need for targeted policies to align consumption patterns with sustainability objectives and leverage technology for effective household carbon emissions reduction.

Keywords: Household Requirement; CO_2 Emissions; Energy Input - Output Analysis

Corresponding Author: Onicha Meangbua
E-mail: onicha33@tu.ac.th
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[1] Dr. in College of Interdisciplinary Studies, Thammasat University. E-mail: Onicha33@tu.ac.th

ความต้องการใช้พลังงานเชื่อมโยงกับการปลดปล่อยก๊าซ CO_2 ในภาคครัวเรือนของประเทศไทย

อรณิชา เมี่ยงบัว[1]

บทคัดย่อ

การวิเคราะห์ Energy Input-output analysis (EIO) ร่วมกับ Structure decomposition analysis (SDA) เป็นวิธีที่นำมาใช้เพื่ออธิบายบทบาทของใช้พลังงานและการปลดปล่อยก๊าซ CO_2 ที่เกิดจากภาคครัวเรือนในภาพรวมของประเทศไทย ในช่วงเวลาระหว่างปี พ.ศ. 2533 - 2558 ผลการศึกษาพบว่า ตั้งแต่ปี 2538 เป็นต้นมาความต้องการใช้พลังงานและปริมาณการปลดปล่อยก๊าซ CO_2 ที่เกิดจากการบริโภคในครัวเรือนมีสัดส่วนมากเป็นอันดับ 2 รองลงมาจากภาคการส่งออก และมีแนวโน้มเพิ่มขึ้นอย่างต่อเนื่องตลอดช่วงเวลาศึกษา เมื่อพิจารณาปัจจัยในการขับเคลื่อนการเปลี่ยนแปลงโดยวิธีการ SDA ผ่านปัจจัยขับเคลื่อน 3 ตัว คือ 1) Intensity Effect 2) Leontief Effect และ 3) Final Demand Effect พบว่าในปี พ.ศ. 2533 - 2558 ปัจจัยขับเคลื่อนการเพิ่มขึ้นของความต้องการใช้พลังงานและการปลดปล่อยก๊าซ CO_2 คือ Final Demand Effect ร้อยละ 83.34 ตามด้วย Leontief Effect ร้อยละ 11.37 และ Intensity Effect ร้อยละ 5.29 ของการเปลี่ยนแปลงทั้งหมดที่เกิดขึ้นตามลำดับ ทั้งนี้ Final Demand Effect เป็นปัจจัยที่มีอิทธิพลต่อการเพิ่มขึ้นของก๊าซ CO_2 ในขณะที่การพัฒนากระบวนการผลิตซึ่งสะท้อนผ่าน Leontief Effect และ Intensity Effect เป็นปัจจัยที่ทำให้การปลดปล่อยก๊าซ CO_2 ลดลง แม้การเพิ่มประสิทธิภาพการผลิตจะทำให้ก๊าซ CO_2 ลดลง แต่ไม่มากพอที่จะชดเชยการเพิ่มขึ้นของก๊าซ CO_2 ที่มาจากปัจจัยด้านความต้องการบริโภคขั้นสุดท้ายได้ จากผลการศึกษา ในครั้งนี้บ่งชี้ให้เห็นปัจจัยในการกำหนดความต้องการใช้พลังงานที่เชื่อมโยงต่อการปลดปล่อยก๊าซ CO_2 ระดับมหภาค ซึ่งเป็นข้อมูลสำคัญในการกำหนดนโยบายด้านสิ่งแวดล้อมของประเทศไทย

คำสำคัญ: การบริโภคในครัวเรือน; การปลดปล่อยก๊าซ CO_2; การวิเคราะห์ปัจจัยการผลิตและผลผลิตในหน่วยพลังงาน

ชื่อผู้ติดต่อบทความ: อรณิชา เมี่ยงบัว
E-mail: onicha33@tu.ac.th

[1] อาจารย์ประจำ วิทยาลัยสหวิทยาการ มหาวิทยาลัยธรรมศาสตร์ E-mail: onicha33@tu.ac.th

1. Introduction

Gross Domestic Product (GDP) is the most widely used measure for the overall size of an economy, and it is an indicator reflecting the country's economic growth. The components of GDP consist of private consumption, government expenditure, private investment, and net export (export minus import). Private consumption is the most critical component of GDP in many countries, specially developed countries such as The United States and many countries in the EU (Eurostat, 2023; Picardo, 2021; Amedeo, 2019).

In Thailand, economic growth has been increasing continuously since 1997 (except for some years when economic crises occurred, such as 1998, 2011, and the COVID-19 pandemic in 2020). Private consumption affected the changes in Thailand's GDP as the lowest before 1998, but this component has played an increasingly important role in GDP after 1998. Even though Thailand is the export country, the net export value (the subtraction of export and import value) is still lower than the value of private consumption expenditure (NESDB[a], 2023).

The research regarding the relationship between economics, energy, and emissions proved that economics and energy-linked emissions are interrelated (Mufutau Opeyemi Bello and Kean Siang Ch'ng, 2022). Therefore, reducing energy and emissions without obstructing economic growth is challenging. Sustainable production and consumption pattern are the ways to achieve the climate change goal at the country and global levels. The ongoing global debates on climate change and energy point to the fact that adaptation to more sustainable lifestyles is a significant need of the global community, which is crucial to reducing natural resource and emission reduction burdens. The prosperity and stability of economic development cannot be achieved without an increase in energy requirements. Therefore, it is essential to deeply understand the changes in energy requirements impacting emissions and its driving factor of them from a macro perspective. It is a challenge for policymakers to design the energy policy to achieve the environmental goal of global that is practical for people without obstructing the economy's growth at the same time.

Hence, this study will track the production process of goods and services in Thailand's economy through final demand to investigate the role of private or household consumption on energy requirements-linked CO_2 emissions. Moreover, to design effective energy policies to relieve the climate change problem, understanding the role of energy-related CO_2 emissions in private consumption and its crucial driving factor will be provided to comprehend the context of consumption changes impacting energy-linked CO_2 emissions from a macro perspective.

2. Research Objectives

2.1 To investigate the role of private consumption category on energy requirements-linked CO_2 emissions in Thailand.

2.2 To demonstrate the critical driving factor of household energy and CO_2 emission in Thailand.

3. Literature Review Conceptual Framework and Hypothesis

3.1 Literature Reviews

Household energy requirements and emissions research have been a well-liked topic recently. Different contexts and countries are using different methods in these studies (Chen et al., 2017; Chen et al., 2017; Zhang & Lahr, 2018; Zhang et al., 2016). Most research in early periods was done in the context of developed countries using input-output analysis. For example, the study of CO_2 emissions was in Australia, Denmark, Australia, Brazil, Denmark, Netherlands, Spain, New Zealand, Norway, and Japan, and in terms of energy requirements and related CO_2 in India, Greece, the USA, and France (Manfred, 1998; Kainuma et al., 2000; Wier et al., 2001; Lenzen et al., 2006; Kees & Konelis, 1995, Vringer & Blok, 1995; Peet et al., 1985; Herendeen, 1978; Papathanasopoulou, 2010; Roca & Serrano, 2007; Estiri, 2015; Belaïd, 2017; Pranay Kumar, et al., 2023). For developing countries, research about energy requirements and related CO_2 emissions was published in massive developing countries such as China over the past decade (Liu et al., 2018; Liu et al., 2021; Zhang et al., 2022; Li et al., 2021; Youmeng Wu et al., 2022).

Since the 1960s, Energy input-output analysis has been used to indicate energy requirements' role in the economy (E. Miller, 2012). EIO analysis aims to explore the energy requirement to satisfy the final demand in a particular economy. IO analysis is also put in to estimate the emission in the economy (Jinbo Zhang et al., 2022).

Accordingly, to recognize historical changes in economic, energy, and emissions indicator (driving factors of the changes of them), structural decomposition analysis (SDA) will be employed because it could decompose the driving forces factors affecting the changes in energy requirements-linked CO_2 emissions by using the IO framework. Furthermore, it also could pick out between a range of technological effects and final demand effects. This study has chosen a range of indicators based on the literature. Three selected indicators consist of 1) the energy intensity effect, 2) the technology effect, and 3) the final demand effect because these indicators are adequate to consider the driving force factor in the macro view (Cellura et al., 2012)

Table 1 Indicators of SDA from existing researches.

Country	Sector	Main influencing indicators
Taiwan (Chang et al., 2008)	Industrial	Final demand and Intensity
United States (Weber, 2009)	US economy	Growing population, household consumption, and economic structure
Chile (Muñoz & Hubacek, 2007)	Material consumption	Economic growth, material intensity, and category effect
Korea (Lim et al., 2009)	Industrial	Energy intensity, economic growth, and intermediate import
Brazil (Wachsmann et al., 2009)	Industrial and household	Wealth, population, sectors interrelations, direct energy intensity, and income per capita in household
Italy (Cellura et al., 2012)	Household consumption	Final demand
Spain (Llop ,2017)	Whole economy	Technological changes and structure changes
China (Xia et al, 2015)	Urban economy	Intensity structure, production linkage, and final demand
Thailand (Supasa et al., 2017)	Region	Number of households, Income per capita
China (Pu et al., 2018)	International trade	The sectoral effect, export scale
China (Yi Hu et al., 2017)	Municipal economy	Intensity, input-output structure, and final demand
India (Zhu et al, 2018)	Whole economy	Final demand and intensity
USA (Feng et al., 2021)	Residential	Weather feature, Building feature

Table 1 Indicators of SDA from existing researches. (Continued)

Country	Sector	Main influencing indicators
China (Meng el al, 2021)	Reginal economy	final demand and technological progress
China (Liu et al., 2021)	Residential	Occupant behavior
Brazil (Wiess de Abreu et al, 2021)	Household consumption	Energy Intensity Effect, Leontief Effect, household consumer basket or Basket Effect, Household expenditures or Activity Effect
China (Ji Guo et al., 2023)	Household consumption	Characteristics of Chinese households
USA (Pranay Kumar, et al., 2023)	Household	Energy efficiency and Energy curtailment
Asia-Pacific (Le Na Tran, et al.,2023)	Household consumption	Difference of countries such as temperature, urbanization

The previous research studied household consumption behavior impacting energy-linked emission using the SDA method to appraise the driving factors on energy requirement and related CO_2 emission from different perspectives. For Thailand, there is an analysis of the dominant factors on the energy-linked emission in final demand, but it only describes the output as the regions (Supasa et al., 2017). The deep knowledge of the key driving forces of household energy requirements -linked emissions in the whole perspective of Thailand is limited. Remarkably, it is challenging for the government to reduce emissions without threatening people's livelihoods and enhancing economic growth. Information is essential to design energy efficiency policies that accomplish economic and environmental targets.

3.2 Conceptual Framework

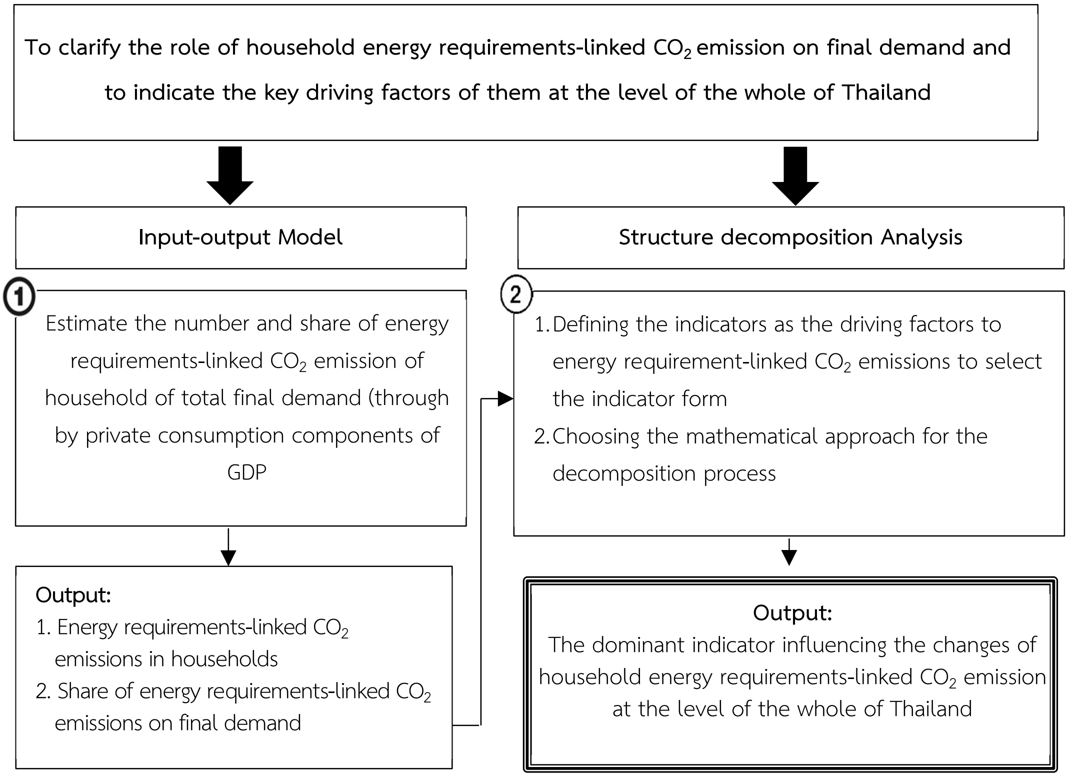


Figure 1: Conceptual Framework

3.3 Hypothesis

This study addresses the role of household consumption change on energy requirements-linked CO_2 emissions in Thailand. The period of this study follows the availability of input-output in Thailand, which is from 1990 to 2015 (NESDB[b], 2023). The assumptions consist of as follows.

1) Homogeneous goods and services in the same categories in each 58 sectors (Park & Heo, 2007)

2) Energy and CO_2 intensities as on average values.

3) The meaning of household consumption is domestic consumption, shown as private consumption in the I-O table (Kofoworola & S.H. Gheewala, 2008).

4. Research Methodology

The hybrid-unit IO model adjusts from the original input-output framework for a closed economy, i.e.,

$$x = Z_i + f \tag{1}$$

where matrix Z is the total interindustry transactions (dimension n X n),
vector x is the total output (length n),
vector f is the final demand (length n), and
n is the number of industries,

Therefore,

$$x^* = (I-A^*)^{-1}f^* = L^*f^* \tag{2}$$

where x^* is the vector of total industrial output,
$(I-A^*)^{-1}$ or L^* is the inverse Leontief matrix or total requirements matrix, and
f^* is the vector of final demand.

The total energy requirements of the economy (or matrix α) could calculate by adjusting from Equation 5, that is;

$$g = \alpha f^* \tag{3}$$

By detaching the matrix α, it is separated total energy output into two groups that are (1) changed by the final demand for energy products (h) and (2) changed by the other final demand for non-energy products (f_{non}).

Hence,

$$g = \alpha_\theta h + \alpha_\tau f_{non} \tag{4}$$

where α_θ and α_τ contain the energy and non-energy industries of matrix α, respectively represented in columns.

Moreover, the sub-matrices of the matrix are the same as the sub-matrices of L^* in the rows for energy industries that it presents in Equation 8.

$$\alpha = [\alpha_\theta \quad \alpha_\tau] = [L^*_\theta \quad L^*_\tau] \tag{5}$$

In fact, the L^*_θ and L^*_τ are taken out from the inverse Leontief matrix in hybrid-unit to estimate matrix α. It does not mean that the total non-energy requirements in the economy are excluded in Equation 4, but it means that these total non-energy requirements are indirectly described by α_θ and α_τ. Hence, the element of α interprets the energy effect of the process of producing both energy and non-energy products in the economy.

The estimation of CO_2 emissions emitted by final demand consumption is achieved by helping the emissions factor (from IPCC) transform the energy requirements into emissions.

The identification of crucial driving factors energy requirements and related CO_2 emission of household on final demand through private consumption components of GDP applied the SDA. There are three steps summarized in the following.

Step 1: defines the indicators to be examined and the periods for analyzing the driving forces. The accessible data is essential for determining the studied periods.

Step 2: is to select the indicator form. An indicator could represent the absolute value of the energy requirements and in intensity value of the energy requirements per unit of economic output. However, the literature on SDA concentrates only on assessing absolute changes in the variables.

Step 3: choose the mathematical approach and index to weigh driving factors for the decomposition process. The additive approach and completeness index would be selected in this study because the decomposition has no residual.

The indicators chosen in this article are based on literature consisting of the energy intensity effect (E'_{effect}), technology effect or Leontief effect (L_{effect}), and final demand effects ($Y_{f\text{-}effect}$). Sun's SDA approach indicates the changes in all indicators shown in Equations 6 and 7 to analyze in the context of energy and CO_2 emissions.

$$\Delta E = E'_{effect} + L_{effect} + Y_{f\text{-}effect}, \tag{6}$$

$$\Delta B = B'_{effect} + L_{effect} + Y_{f\text{-}effect}. \tag{7}$$

The first variable of Equation 6 shows the contribution of the energy intensity effect (E'_{effect}) to the changes in the energy requirements (ΔE). The value interpretation is that a negative value means energy efficiency improved in the economic sectors.

The first variable of Equation 7 shows the contribution of the emissions intensity effect (B'_{effect}) to the changes in the emissions (ΔB). The interpretation of the value is that a negative value means eco-efficiency improvement in the economy.

In the second variable of Equations 6 and 7, they show the contribution of the influencing factor that is called the "Leontief effect (L_{effect})" to the changes in energy requirements and emissions, respectively, that represent an intermediate input used for producing a product. The interpretation of the value is that a negative value means reduced use of intermediate input in the productive structure.

The last variable of Equations 6 and 7 shows the contribution of final demand ($Y_{f\text{-}effect}$) to the changes in energy requirements and emissions, respectively. The interpretation of the value is that a negative value means the variation of final demand impacting the reduction of energy requirements and emissions.

Following the Dietzenbacher and Los method, there are six equations to investigate the driving factors impacting the changes in each studied indicator: energy requirements and emissions. Equations 8-13 and 14-19 are developed following the above method to constructed to assess the driving factors influencing the changes in the energy requirements and emissions, respectively:

$$\Delta E_1 = (\Delta E' (I - A)_0 Y_{f0}) + (E'_t \Delta (I - A) Y_{f0}) + (E'_t (I - A)_t \Delta Y_f), \quad (8)$$

$$\Delta E_2 = (\Delta E' (I - A)_0 Y_{f0}) + (E'_t \Delta (I - A) Y_{ft}) + (E'_t (I - A)_t \Delta Y_f), \quad (9)$$

$$\Delta E_3 = (\Delta E' (I - A)_t Y_{f0}) + (E'_0 \Delta (I - A) Y_{f0}) + (E'_t (I - A)_t \Delta Y_f), \quad (10)$$

$$\Delta E_4 = (\Delta E' (I - A)_0 Y_{ft}) + (E'_t \Delta (I - A) Y_{ft}) + (E'_0 (I - A)_t \Delta Y_f), \quad (11)$$

$$\Delta E_5 = (\Delta E' (I - A)_t Y_{ft}) + (E'_0 \Delta (I - A) Y_{f0}) + (E'_0 (I - A)_t \Delta Y_f), \quad (12)$$

$$\Delta E_6 = (\Delta E' (I - A)_t Y_{ft}) + (E'_0 \Delta (I - A) Y_{ft}) + (E_{0t} (I - A)_0 \Delta Y_f), \quad (13)$$

$$\Delta B_1 = (\Delta B' (I - A)_0 Y_{f0}) + (B'_t \Delta (I - A) Y_{f0}) + (B'_t (I - A)_t \Delta Y_f), \quad (14)$$

$$\Delta B_2 = (\Delta B' (I - A)_0 Y_{f0}) + (B'_t \Delta (I - A) Y_{ft}) + (B'_t (I - A)_t \Delta Y_f), \quad (15)$$

$$\Delta B_3 = (\Delta B' (I - A)_t Y_{f0}) + (B'_0 \Delta (I - A) Y_{f0}) + (B'_t (I - A)_t \Delta Y_f), \quad (16)$$

$$\Delta B_4 = (\Delta B' (I - A)_0 Y_{ft}) + (B'_t \Delta (I - A) Y_{ft}) + (B'_0 (I - A)_t \Delta Y_f), \quad (17)$$

$$\Delta B_5 = (\Delta B' (I - A)_t Y_{ft}) + (B'_0 \Delta (I - A) Y_{f0}) + (B'_0 (I - A)_t \Delta Y_f), \quad (18)$$

$$\Delta B_6 = (\Delta B' (I - A)_t Y_{ft}) + (B'_0 \Delta (I - A) Y_{ft}) + (B_{0t} (I - A)_0 \Delta Y_f), \quad (19)$$

where the subscripts t is the period of present time,

the subscripts 0 is the period of previous time.

Summarily, the detail of each driving factor from the above equation could be explained as follows:

- E'_{effect} or intensity effect is the mean of the first items of Equation 8 to Equation 13 for the energy analysis and the first items of Equation 14 to Equation 19 for the environmental analysis;
- L_{effect} or Leontief effect is the mean of the second items of Equation 8 to Equation 13 for the energy analysis and the second items of Equation 14 to Equation 19 for the environmental analysis;
- $Y_{f\text{-}effect}$ or final demand effect is the mean of the third items of Equation 8 to Equation 13 for the energy analysis and Equation 14 to Equation 19 for the environmental analysis.

5. Results and discussion

5.1 Result

5.1.1 Share of household consumption in energy requirements of total final demand

Using the hybrid unit EIO, private consumption was the sector that dominated the energy changes requirements-linked CO_2 emissions on final demand from 1990 to 1995. After 1995, the export sector was the largest share of energy requirement and CO_2 emission in final demand, accounting for 40% of total energy requirements-linked CO_2 emissions consumed by final demand. The changes in energy requirements by components of final demand rely on the economic situation. After the Asian financial crisis (1998), export played a more and more critical role in shaping the economic growth of Thailand because the economics was recovering and also the economic policy has promoted exports. (Kungcharoen, 2010). It also affected the energy requirements change (See Table 2). However, from the consumption viewpoints, it is found that the private consumption is the main cause of energy requirements because the total energy satisfied in the export sector is the production goods and services for export that are not consumed in country.

Table 2 Total energy requirements by components on the final demand of Thailand, 1990-2010

Unit: PJ per year/Mt-CO_2

	1990	1995	2000	2005	2010	2015
Private consumption expenditure	600.21 (69)	816.06 (113)	890.7 (144)	972.22 (197)	1,155.96 (217)	1,267.33 (262.13)
Government Consumption expenditure	78.8 (11)	135.83 (20)	109.07 (20)	150.24 (31)	272.15 (54)	269.551 (56.59)
Investment	298.92 (50)	524.71 (57)	180.65 (16)	356.81 (21)	615.46 (47)	534.864 (25.32)
Export	268.05 (37)	506.76 (71)	905.27 (144)	1,093.45 (184)	1,561.72 (272)	1,819.259 (315.91)
Total	**1,245.98 (167)**	**1,983.36 (261)**	**2,085.69 (324)**	**2,572.72 (433)**	**3,605.29 (590)**	**3,891.00 (659.95)**

Note: ( ) are the CO_2 emission on the final demand (unit: Mt-CO_2)

The goods and services consumed by private households predominantly consist of energy-related items. It is noteworthy that among the top twenty energy - intensive goods and services consumed by households, a substantial portion comprises essential items necessary for daily living. Notably, the primary categories of consumption within households in Thailand are food and beverages, along with energy carriers. This pattern of consumption is a significant contributing factor to Thailand's status as a middle-income country. Additionally, when examining the energy-intensive components of private consumption, services such as restaurants and hotels category, as well as transportation category, emerge as prominent contributors to energy requirements. This prominence can be attributed to the direct utilization of energy sources, specifically electricity and petroleum, within these activities.

Furthermore, it is observed that the overall structure of energy requirements across various consumption categories remains relatively consistent throughout the study period. A comprehensive overview of the top twenty energy-intensive private consumption categories is provided in Table 3. On an annual average, the direct energy requirements for private consumption have exhibited an increase of approximately 9.06%, while the indirect energy requirements have seen an annual growth rate of 8.4%. It is indeed of considerable interest to examine the annual distribution of direct and indirect energy requirements. Our analysis reveals that, on an annual average growth, direct energy consumption constitutes only half the proportion of indirect energy consumption. However, when we shift our focus to the average changes observed throughout the study period, a nuanced perspective emerges. The empirical evidence suggests that direct energy demand exhibits a propensity for greater escalation when compared to indirect energy demand. This phenomenon can be attributed to shifts in consumer behavior characterized by a heightened reliance on assistive technologies and a corresponding surge in petroleum consumption for transportation purposes. Consequently, this discernible trend has culminated in an elevated average annual growth rate of direct energy utilization, surpassing that of indirect energy utilization. This persistent upward trajectory in both direct and indirect energy demands underscores the enduring trend of escalating energy consumption over time, as depicted in Figure 2.

The total CO_2 emissions on Thailand's final demand has increased continuously. The study revealed that the total CO_2 emission in 2015 was 3.80 times that of 1990. This trend confirms the CO_2 emissions for energy consumption by sector reported by Energy Policy and Planning Office (EPPO), which CO_2 emissions also increased approximately three times from 1990 (Energy Policy and Planning Office, 2022). Additionally, the largest share of CO_2 emissions on final demand was export (47%), followed by private consumption (40%), government (9%), and investment (4%), respectively, in 2015. Even though private consumption was the second most important contributor to CO_2 emission in Thailand after 1995, the energy requirements, both direct and indirect, for goods and services produced to satisfy the domestic consumption reflected through private consumption had increased continuously. The goods and services as CO_2-intensive consist with energy-intensive. Therefore, the top-three CO_2- intensive by category were petroleum products, electricity, and electricity, respectively.

The results reveal that private consumption has played a significant role in energy and emissions in Thailand over time, especially in the consumption-based aspect. The above changes in energy requirements-linked CO_2 emissions depend on economic and technological changes.

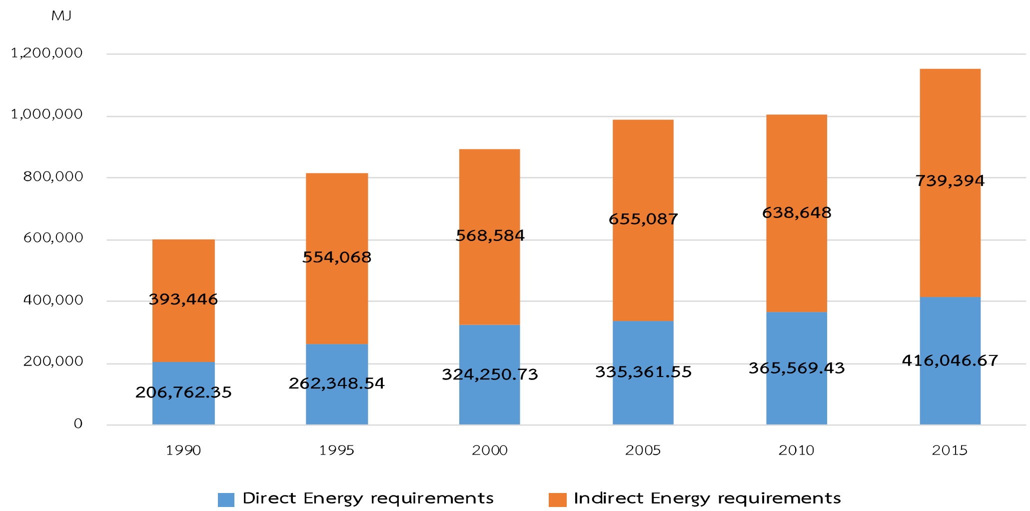


Figure 2: Direct and indirect energy requirements of final demand

Table 3 Top-twenty of energy-intensity in private consumption by category in Thailand, 1990-2015

Unit: PJ per year

Category	1990
Petroleum Refineries	105.81
Restaurants and Hotels	105.68
Transportation	95.29
Forestry	90.69
Electricity and Gas	43.41
Textile Products	41.59
Motor Vehicles and Repairing	19.15
Saw Mills and Wood Products	12.18
Rice and Other Grain Milling	9.39
Public Services	8.57
Vegetables and Fruits	7.68
Other Manufacturing Products	7.32
Processing and Presering of Foods	6.19
Slaughtering	6.17
Fishery	4.94
Other Chemical Products	4.51
Electrical Machinery and Apparatus	3.60
Other Services	3.26
Other Foods	3.11
Beverages	2.87

Category	1995
Petroleum Refineries	221.03
Restaurants and Hotels	115.63
Electricity and Gas	101.88
Transportation	95.60
Forestry	82.96
Textile Products	56.70
Motor Vehicles and Repairing	34.15
Public Services	12.07
Saw Mills and Wood Products	11.43
Other Manufacturing Products	8.46
Electrical Machinery and Apparatus	8.09
Other Chemical Products	7.62
Processing and Presering of Foods	6.23
Rice and Other Grain Milling	5.78
Banking and Insurance	5.59
Fishery	5.46
Building Construction	5.01
Slaughtering	4.75
Beverages	4.72
Vegetables and Fruits	4.13

Category	2000
Petroleum Refineries	273.47
Electricity and Gas	121.92
Transportation	120.87
Restaurants and Hotels	114.40
Forestry	68.86
Textile Products	46.42
Public Services	16.10
Other Chemical Products	14.78
Electrical Machinery and Apparatus	14.19
Processing and Presering of Foods	11.77
Saw Mills and Wood Products	11.65
Vegetables and Fruits	11.41
Motor Vehicles and Repairing	10.54
Other Manufacturing Products	8.65
Other Foods	6.95
Fishery	5.19
Real Estate	4.81
Rice and Other Grain Milling	4.70
Beverages	4.50
Leather Products	3.36

Category	2005
Petroleum Refineries	323.56
Electricity and Gas	161.99
Restaurants and Hotels	106.19
Transportation	100.24
Forestry	43.69
Saw Mills and Wood Products	41.00
Textile Products	40.50
Other Chemical Products	27.16
Motor Vehicles and Repairing	25.65
Vegetables and Fruits	20.96
Electrical Machinery and Apparatus	14.22
Public Services	10.49
Processing and Presering of Foods	10.36
Other Manufacturing Products	9.13
Beverages	8.11
Rice and Other Grain Milling	7.26
Other Services	6.28
Banking and Insurance	5.13
Real Estate	4.91
Other Foods	4.06

Table 3 Top-twenty of energy-intensity in private consumption by category in Thailand, 1990-2015 (Continued)

Unit: PJ per year

Category	1990
Petroleum Refineries	105.81
Restaurants and Hotels	105.68
Transportation	95.29
Forestry	90.69
Electricity and Gas	43.41
Textile Products	41.59
Motor Vehicles and Repairing	19.15
Saw Mills and Wood Products	12.18
Rice and Other Grain Milling	9.39
Public Services	8.57
Vegetables and Fruits	7.68
Other Manufacturing Products	7.32
Processing and Presering of Foods	6.19
Slaughtering	6.17
Fishery	4.94
Other Chemical Products	4.51
Electrical Machinery and Apparatus	3.60
Other Services	3.26
Other Foods	3.11
Beverages	2.87

Category	1995
Petroleum Refineries	221.03
Restaurants and Hotels	115.63
Electricity and Gas	101.88
Transportation	95.60
Forestry	82.96
Textile Products	56.70
Motor Vehicles and Repairing	34.15
Public Services	12.07
Saw Mills and Wood Products	11.43
Other Manufacturing Products	8.46
Electrical Machinery and Apparatus	8.09
Other Chemical Products	7.62
Processing and Presering of Foods	6.23
Rice and Other Grain Milling	5.78
Banking and Insurance	5.59
Fishery	5.46
Building Construction	5.01
Slaughtering	4.75
Beverages	4.72
Vegetables and Fruits	4.13

Category	2000
Petroleum Refineries	273.47
Electricity and Gas	121.92
Transportation	120.87
Restaurants and Hotels	114.40
Forestry	68.86
Textile Products	46.42
Public Services	16.10
Other Chemical Products	14.78
Electrical Machinery and Apparatus	14.19
Processing and Presering of Foods	11.77
Saw Mills and Wood Products	11.65
Vegetables and Fruits	11.41
Motor Vehicles and Repairing	10.54
Other Manufacturing Products	8.65
Other Foods	6.95
Fishery	5.19
Real Estate	4.81
Rice and Other Grain Milling	4.70
Beverages	4.50
Leather Products	3.36

Category	2005
Petroleum Refineries	323.56
Electricity and Gas	161.99
Restaurants and Hotels	106.19
Transportation	100.24
Forestry	43.69
Saw Mills and Wood Products	41.00
Textile Products	40.50
Other Chemical Products	27.16
Motor Vehicles and Repairing	25.65
Vegetables and Fruits	20.96
Electrical Machinery and Apparatus	14.22
Public Services	10.49
Processing and Presering of Foods	10.36
Other Manufacturing Products	9.13
Beverages	8.11
Rice and Other Grain Milling	7.26
Other Services	6.28
Banking and Insurance	5.13
Real Estate	4.91
Other Foods	4.06

Table 3 Top-twenty of energy-intensity in private consumption by category in Thailand, 1990-2015 (Continued)

Unit: PJ per year

Category	2010
Electricity and Gas	336.44
Petroleum Refineries	272.36
Transportation	166.76
Restaurants and Hotels	96.20
Saw Mills and Wood Products	41.33
Electrical Machinery and Apparatus	36.67
Motor Vehicles and Repairing	32.77
Other Services	27.39
Other Manufacturing Products	20.35
Textile Products	20.26
Vegetables and Fruits	14.47
Rice and Other Grain Milling	13.91
Public Services	12.93
Banking and Insurance	10.97
Beverages	10.87
Real Estate	9.58
Other Chemical Products	8.85
Processing and Presering of Foods	8.22
Other Foods	5.41
Slaughtering	5.23

Category	2015
Petroleum Refineries	152.12
Restaurants and Hotels	113.30
Forestry	100.50
Transportation	86.23
Textile Products	52.86
Electricity and Gas	23.90
Motor Vehicles and Repairing	20.71
Public Services	10.60
Other Chemical Products	6.94
Processing and Presering of Foods	6.91
Rice and Other Grain Milling	6.11
Saw Mills and Wood	5.95
Fishery	5.88
Vegetables and Fruits	5.65
Other Manufacturing Products	5.44
Slaughtering	5.16
Leather Products	3.44
Building Construction	3.07
Other Foods	2.96
Beverages	2.34

5.1.2 Influencing factors forcing the changes in energy requirements-linked CO_2 emissions in final demand

SDA was the tool to identify the influencing factors forcing the change in energy requirements and emissions of households through private consumption on final demand. This study has three major factors: 1) the final demand effect, 2) the Leontief effect, and 3) the intensity effect. The final demand effect means Thailand household final demand. The Leontief effect relates to the changes in the use of intermediate inputs in the productive structure. For energy intensity effect, it represents the improvement of energy efficiency in the economic sector. The results highlight that the rise in the total energy requirements from 1990 to 2015 is mainly due to driving factors such as the final demand effect (83.34% of the total effect), the Leontief effect (11.37% of the total effect), and the energy intensity effect (5.29% of total effect), respectively (see Figure 2). This result accords with several studies that final demand is the main contributor to the changes in energy requirements (Supasa et al., 2017; Cellura et al, 2012; Wachamann et al, 2009), but the result of this study differs from the study of change in energy output in Spain that the final demand is a negative contribution to energy (Llop, 2017) because of the difference of the life-style of population and economy situation.

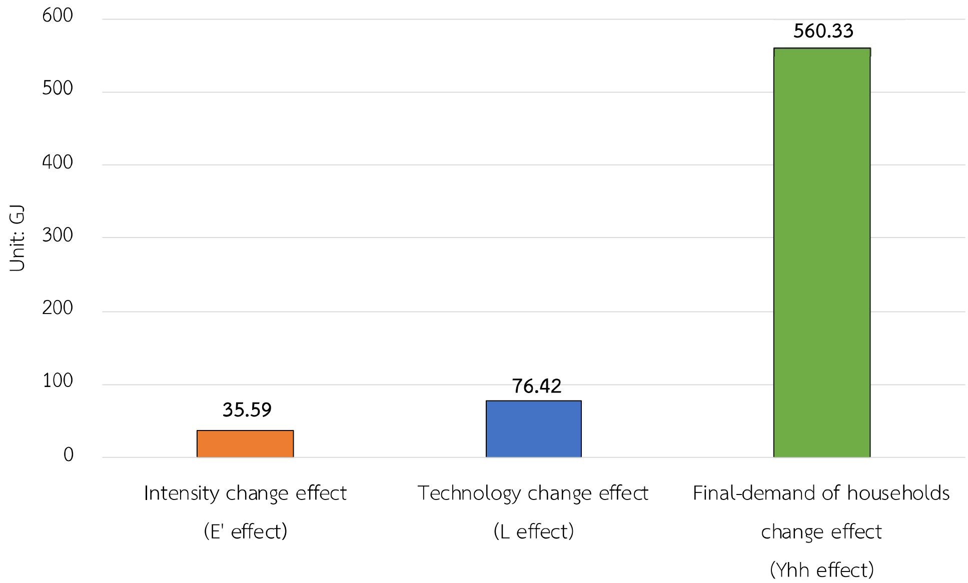
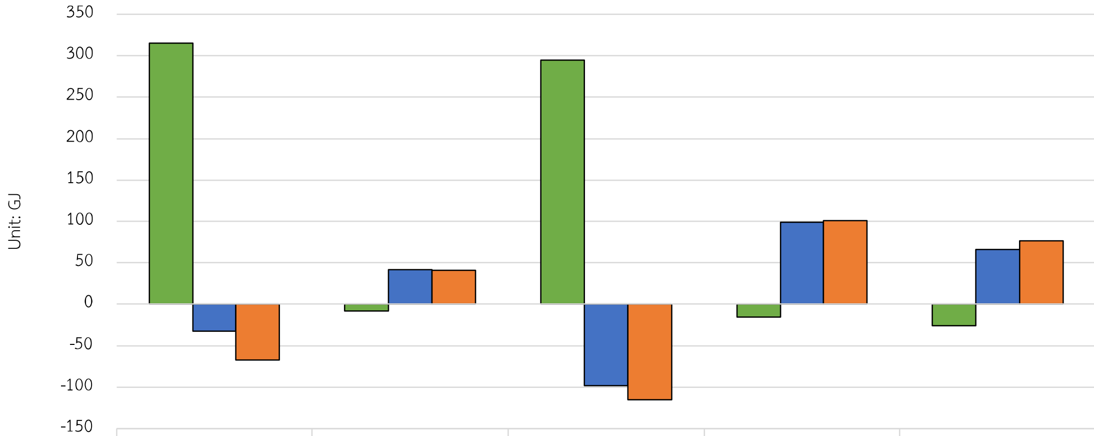


Figure 3: Structural decomposition analysis of total energy requirements, 1990 to 2015

Figure 3. illustrates the variation in energy requirements between two consecutive years from 1990 to 2015. In this respect, the final demand effect increased energy requirements in the 1990 - 1995 and 2000 - 2005 periods, and it decreased energy requirements in the 1995 - 2000, 2005 - 2010, and 2010 - 2015 periods, while the Leontief effect is adversely affecting with final demand that is it decreased energy requirements in 1990 - 1995 and 2000 - 2005, and it increased energy requirements in 1995 - 2000, 2005-2010 and 2010 - 2015. The energy intensity effect reduced energy requirements in 1990 - 1995 and 2000 - 2005; oppositely, it increased in 1995 - 2000, 2005 - 2010, and 2010 - 2015 (see Figure 4).



	1990-1995	1995-2000	2000-2005	2005-2010	2010-2015
Yhh effect	315.37	-7.65	294.26	-15.55	-26.105
L effect	-32.18	41.95	-97.88	98.69	65.84
E' effect	-67.34	40.35	-114.86	100.6	76.84

Figure 4: Structural decomposition analysis of total energy requirements between five consecutive years, 1990 to 2015

Due to the Sun's approach (1998) that allows for a sector-level analysis, the results of SDA at the sector level for the period (1990 to 2015) are presented in Table 4. The positive values in each sector point out that they do not use energy efficiently, while the negative values imply that these sectors are a reduction in energy requirements per unit of output. Almost half of the sectors are a reduction of energy requirements by intensity effect. It means the other half of the sectors are characterized by an increased intensity effect.

The energy and industrial sectors are increased in energy requirements by the technology effect. These sectors are characterized by increased technology input use per output unit. Meanwhile, the rest of the sectors, especially the agricultural sector, decreased energy requirements by the technological effect. The final - demand effect significantly affects the increase of energy requirements for all sectors, except forestry (decreasing by 3.79 PJ from 1990 to 2015) and leather products (decreasing by 3.8 times from 1990 to 2015) (see Figure 5).

SDA of CO_2 emissions, the CO_2 emissions on average, raised by 6.86% per annum from 1990 to 2015. The results of SDA showed in Figure 4. The final-demand effect is the most influencing factor on the variation of CO_2 emission in Thailand's households. The decline of CO_2 emissions in Thailand's households due to the intensity effect and technological effect could not be compensated for the increase of CO_2 emission by final demand. Similarly, to the SDA of energy requirements, the top-three sectors of the CO_2 intensive consisted of transportation (+68%), electrical machinery and apparatus (+33%), and other services (+19%). Considering the top-twenty sectors of the CO_2 intensive, most of them were the industrial and services sectors, while the agricultural sector was the insignificant CO_2 emitter from 1990 to 2010 (see Table 5).

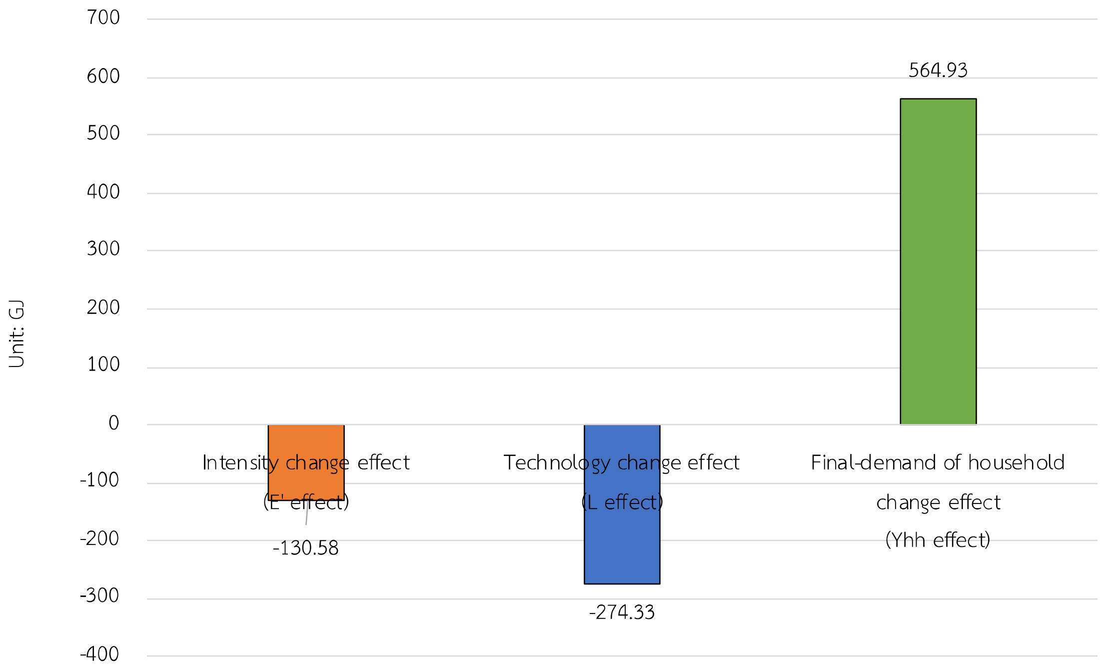


Figure 5: Structural decomposition analysis of total CO_2 emissions of the household, 1990 to 2015

The change in CO_2 emissions by the final-demand effect in households in Thailand is partially offset by the intensity effect and technology effect, especially in energy goods (excluding petroleum refinery) and industrial sectors. It implies that the agricultural sectors should be oriented toward the adoption of more eco-efficient technologies of production.

Table 4 Structural decomposition analysis of energy requirements by sector.

Sector	1990-2015 (unit: GJ)		
	Intensity change effect (E' effect)	Technology change effect (L effect)	Final-demand of households change effect (Yhh effect)
Forestry	1.29	-27.61	-4.92
Crude Oil and Coal	7.71	-0.94	59.45
Petroleum Refineries	19.28	-79.88	130.47
Electricity and Gas	-24.58	-46.69	165.63
Paddy	1.19	0.04	0.89
Maize	1.69	0.46	0.14
Cassava	1.63	0.34	0.22
Beans and Nuts	1.65	0.41	0.11
Vegetables and Fruits	3.33	0.18	2.63
Sugarcane	1.80	0.63	0.13
Rubber (Latex)	1.12	-0.53	0.06
Other Crops	-1.74	5.06	1.58
Livestock	-2.77	-6.07	4.21
Fishery	-0.75	4.91	0.30
Metal Ore	1.68	1.72	0.13
Non-Metal Ore	1.58	5.80	0.60
Slaughtering	-9.71	-13.77	6.99
Processing and Preserving of Foods	0.97	1.40	2.67
Rice and Other Grain Milling	1.02	-5.50	4.72
Sugar Refineries	0.88	2.60	0.55
Other Foods	0.06	-5.43	3.60
Animal Food	-1.40	2.50	1.19
Beverages	2.00	-8.67	5.42
Tobacco Processing and Products	1.35	-0.13	0.33

Table 4 Structural decomposition analysis of energy requirements by sector. (Continued)

Sector	1990-2015 (unit: GJ)		
	Intensity change effect (E' effect)	Technology change effect (L effect)	Final-demand of households change effect (Yhh effect)
Spinning, Weaving and Bleaching	-24.46	15.54	6.49
Textile Products	-17.94	-1.92	6.18
Paper and Paper Products	6.89	1.52	3.29
Printing and Publishing	1.61	-0.21	0.50
Basic Chemical Products	2.95	-24.63	2.82
Fertilizer and Pesticides	1.56	4.08	0.36
Other Chemical Products	2.57	11.83	2.73
Rubber Products	1.69	-3.47	1.67
Plastic Wares	3.92	-0.14	2.37
Cement and Concrete Products	0.44	3.16	0.72
Other Non-metallic Products	0.06	-7.47	3.27
Iron and Steel	-1.79	32.24	2.65
Non-ferrous Metal	1.15	-1.17	0.61
Fabricated Metal Products	1.94	-0.61	0.61
Industrial Machinery	1.77	1.63	0.80
Electrical Machinery and Apparatus	17.13	15.22	10.07
Motor Vehicles and Repairing	4.77	2.53	7.12
Other Transportation Equipment	1.86	-1.44	0.27
Leather Products	0.65	0.37	-0.48
Saw Mills and Wood Products	24.13	16.71	8.42
Other Manufacturing Products	-0.27	6.19	9.93
Water Works and Supply	0.72	0.06	0.71
Building Construction	-2.30	16.87	2.23
Public Works and Other Construction	-0.01	-0.18	0.03

Table 4 Structural decomposition analysis of energy requirements by sector. (Continued)

Sector	1990-2015 (unit: GJ)		
	Intensity change effect (E' effect)	Technology change effect (L effect)	Final-demand of households change effect (Yhh effect)
Trade	0.75	0.00	0.73
Restaurants and Hotels	-39.61	8.88	30.75
Transportation	13.21	30.66	39.10
Communication	2.93	0.97	1.24
Banking and Insurance	1.32	3.20	7.63
Real Estate	4.04	2.92	1.79
Business Services	4.83	1.96	2.95
Public Services	1.65	0.83	2.11
Other Services	8.61	-0.08	10.63
Unclassified	-0.46	109.53	2.92
△ Energy requirement total (GJ)	**35.59**	**76.42**	**560.32**

Table 5 Structural decomposition analysis of CO_2 emission by sector.

Sector	1990-1995 (unit: ton-CO_2)		
	Intensity change effect (E' effect)	Technology change effect (L effect)	Final-demand in household change effect (Yhh effect)
Forestry	-0.12	-0.01	-0.01
Crude Oil and Coal	11.73	-0.23	130.86
Petroleum Refineries	31.59	-23.10	266.31
Electricity and Gas	-52.86	-14.04	377.65
Paddy	0.56	0.01	1.48
Maize	-0.49	0.11	0.24
Cassava	-0.50	0.08	0.35

Table 5 Structural decomposition analysis of CO_2 emission by sector. (Continued)

Sector	1990-1995 (unit: ton-CO_2)		
	Intensity change effect (E' effect)	Technology change effect (L effect)	Final-demand in household change effect (Yhh effect)
Beans and Nuts	-0.63	0.10	0.20
Vegetables and Fruits	1.42	0.03	3.64
Sugarcane	-0.35	0.16	0.24
Rubber (Latex)	0.22	-0.13	0.10
Other Crops	-5.25	1.10	2.38
Livestock	-5.13	-1.17	5.59
Fishery	-4.48	1.29	0.56
Metal Ore	-0.61	0.46	0.24
Non-Metal Ore	-1.14	1.34	0.96
Slaughtering	-6.04	-1.72	6.80
Processing and Preserving of Foods	-0.92	0.32	4.24
Rice and Other Grain Milling	0.46	-1.42	8.43
Sugar Refineries	-0.63	0.50	0.72
Other Foods	-3.68	-1.37	6.29
Animal Food	-2.00	0.42	1.37
Beverages	0.61	-2.04	8.90
Tobacco Processing and Products	-0.63	-0.02	0.34
Spinning, Weaving and Bleaching	-55.52	4.55	13.22
Textile Products	-42.11	-0.55	12.38
Paper and Paper Products	-1.52	0.10	1.80
Printing and Publishing	-0.35	-0.04	0.58
Basic Chemical Products	3.40	-7.13	5.69
Fertilizer and Pesticides	0.51	0.38	0.38
Other Chemical Products	0.57	2.10	3.38

Table 5 Structural decomposition analysis of CO_2 emission by sector. (Continued)

Sector	1990-1995 (unit: ton-CO_2)		
	Intensity change effect (E' effect)	Technology change effect (L effect)	Final-demand in household change effect (Yhh effect)
Rubber Products	0.05	-0.45	1.51
Plastic Wares	4.11	-0.04	4.70
Cement and Concrete Products	-3.12	0.88	1.39
Other Non-metallic Products	-0.67	-1.11	3.39
Iron and Steel	-7.72	9.33	5.32
Non-ferrous Metal	0.09	-0.30	1.09
Fabricated Metal Products	-0.21	-0.20	1.00
Industrial Machinery	-0.72	0.43	1.47
Electrical Machinery and Apparatus	27.17	3.95	21.85
Motor Vehicles and Repairing	4.24	0.65	12.71
Other Transportation Equipment	0.81	-0.47	0.37
Leather Products	-1.53	0.07	-0.48
Saw Mills and Wood Products	-3.83	0.33	1.27
Other Manufacturing Products	-0.16	1.22	13.60
Water Works and Supply	-0.38	0.02	1.47
Building Construction	-4.56	2.18	1.99
Public Works and Other Construction	-0.03	-0.06	0.04
Trade	-0.05	0.00	1.37
Restaurants and Hotels	-26.54	1.90	45.33
Transportation	20.65	8.60	81.15
Communication	3.69	0.27	2.44
Banking and Insurance	-2.96	0.79	13.42
Real Estate	5.98	0.83	3.52
Business Services	4.38	0.44	4.76

Table 5 Structural decomposition analysis of CO_2 emission by sector. (Continued)

Sector	1990-1995 (unit: ton-CO_2)		
	Intensity change effect (E' effect)	Technology change effect (L effect)	Final-demand in household change effect (Yhh effect)
Public Services	-0.92	0.21	3.67
Other Services	8.41	-0.02	21.48
Unclassified	-0.09	0.36	3.46
△ CO_2 emissions total (ton-CO_2)	**-107.85**	**-10.12**	**1118.60**

6. Conclusion

This study carried out analyses to understand the role of private consumption in energy requirements and related CO_2 emissions through a hybrid energy input-output model and the structural decomposition analysis (SDA). The results provided important insights to clarify the role of consumption of households in the energy use and emissions from the macro perspective, which complimented analysis from the micro-level in previous chapters for 1990 - 2010. Further, the influence of the key driving forces was studied, which showed their relative influences on the changes in energy and emissions. The results indicate the finding of study as follows:

- The household consumption was the leading agent contributing to the energy requirement, for both the direct and indirect terms, and related CO_2 emissions. The contributors influencing the changes in energy requirements and related CO_2 emissions in private consumption or household consumption consist of intensity effect, technology effect, and final demand on household effect.

- The final demand of households is the important contributor influencing the change in energy requirements and related CO_2 emissions. It is a highlight that the economic condition effect on the purchasing power of people or consumer behavior is the significant driving factor to shape energy and emission in Thailand. However, the final demand for the household effect that usually increases energy requirements and related CO_2 emissions could not compensate for the effect of energy efficiency improvement and technology development both in sectoral level and the whole country.

7. Suggestions

7.1 Suggestion for Research

Structural Decomposition Analysis (SDA) stands as a critical tool for understanding the intricate relationships and influences within economic systems. The existing literature highlights various methodologies within SDA, each offering unique approaches for decomposing economic changes. However, there remains a need to further explore and compare these methodologies to better comprehend their relative advantages and limitations.

7.2 Suggestions for the Future Study

The Structural Decomposition Analysis (SDA) was conducted employing the methodologies advocated by Sun and Dietzenbacher (Dietzenbacher & Los, 1998; Sun, 1998). This model is distinguished by its comprehensive decomposition analysis devoid of a residual term. Subsequent research endeavors might opt for alternative SDA methodologies to contrast and assess the derived outcomes. Nonetheless, it is anticipated that significant variations in results are improbable. Prior studies have frequently demonstrated minor disparities between outcomes obtained through this method and those derived from more sophisticated methodologies such as the Logarithmic Mean Divisia Index.

7.3 Policy Suggestions

The household sector occupies a prominent position within the framework of both the Energy Efficiency Development Plan (2011-2030): EEDP (Ministry of energy, 2013) and the Alternative Energy Development Plan: AEDP (Energy Policy and Planning Office, 2018) each geared towards the overarching objective of enhancing energy efficiency and conservation. On the supply side, these plans aspire to achieve a target of 131,000 tons of oil equivalent (ktoe) in final energy consumption across all sectors by the year 2036. A pivotal component of these initiatives involves the establishment of the Energy Efficiency Resource Standard (EERS) for major energy corporations, with a view to encouraging the adoption of energy-saving practices among their household customers.

Concurrently, on the demand side, these plans advocate the implementation of mandatory energy efficiency labeling for consumer appliances, particularly those commonly utilized in residential settings such as refrigerators, air conditioners, and water heaters. Furthermore, supplementary programs will be instituted to disseminate awareness regarding energy conservation through multimedia channels. These operational strategies encompass endeavors like the promotion of LED lighting as a replacement for conventional lighting methods. The AEDP further advocates the promotion of self-consumption of energy within households, exemplified by the utilization of solar energy for rooftop installations and hot water systems (Energy Policy and Planning Office, 2018) However, it is worth noting that despite technological advancements, the phenomenon of the energy rebound effect has the potential to indirectly amplify energy consumption within households in cases where energy policies are deemed inefficient (Freire-Gonza'lez, Jaume & Ho Mun S., 2017; Supasa et al., 2017; Wang et al., 2021; Peng et al, 2023; Mizobuchi & Yamagami, 2022). The promotion of alternative energy sources in Thailand still faces numerous hurdles, particularly in relation to installation costs.

Given this context, our research findings underscore the imperative for Thai policymakers to accord household consumption due consideration as a pivotal element in the formulation of energy and climate mitigation policies and interventions. A comprehensive approach is indispensable, one that extends beyond conventional production-centric emissions considerations. In light of these findings, we offer the following recommendations to policymakers:

- Diversify Energy Policy Focus: Current energy policies predominantly prioritize technological enhancements, with limited emphasis on demand-side interventions. Policymakers should acknowledge the role of consumption and integrate it into the broader framework of environmental policy for climate change mitigation.

- Knowledge Dissemination: Existing energy policies lack concrete strategies for educating the populace about energy-saving practices and the reduction of high-energy and carbon-intensive products and services. Therefore, the government should consider incorporating energy-saving concepts into the educational curriculum, starting from elementary education and extending to higher levels, to instill an understanding of energy conservation across various categories.

- Integrated Policy Framework: Altering consumer behavior is a formidable challenge. To this end, the government should design a comprehensive policy framework that harmonizes energy policy, monetary policy, and fiscal policy to reshape consumption patterns, thereby reducing energy consumption and emissions within households. This could involve incentivizing the use of energy-efficient appliances through a combination of energy policy measures and financial support or offering tax refunds to households that opt for environmentally friendly products within the broader context of energy policy.

By adopting these recommendations, policymakers can foster a more sustainable and energy-efficient future for Thailand's residential sector while contributing to broader climate mitigation goals.

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ประวัติแนบท้ายบทความ

Name and Surname: Onicha Meangbua, Ph.D.

Highest Education: Ph.D. in Energy Policy, Planning and Economics, Asian Institute of Technology

University: Thammasat University

Field of Expertise: Energy Economics/ Agricultural Economics

Address: 2 Prachan Road, Phra Barom Maha Ratchawang, Phra Nakhon, Bangkok 10200, Thailand.

E-mail: onicha33@tu.ac.th