www.rericjournal.ait.ac.th

Assessment of Thailand's Energy Policy on CO_2 Emissions: Implication of National Energy Plans to Achieve NDC Target

Achiraya Chaichaloempreecha*, Puttipong Chunark*, and Bundit Limmeechokchai*,[1]

Abstract – *The industrial sector is one of the main energy-intensive sectors, and it accounted for 35.2% of total energy consumption in 2017. In terms of electricity consumption, the building sector was the largest electricity consuming sector, and it accounted for 57.4% of total electricity consumption in 2017. The objective of this paper is to assess the long-term energy policy in the building and the industrial sectors during 2005-2050 through a perspective of energy saving potentials and greenhouse gas (GHG) mitigation by using the Long-range Energy Alternative Planning system (LEAP). Results indicate that energy labeling and monetary incentive in the energy efficiency plan (EEP2015) and renewable energy plan (AEDP2015) are the most effective measures in the building and industrial sectors. This study discloses that plans are effective policies to reduce not only energy demand but also GHG emissions. Therefore, such reduction potentials can meet Thailand's Nationally Determined Contributions (NDC) target. In 2050, the deployment of biogas will significantly reduce GHG emissions in the residential sector. The GHG emission reduction from the non-metallic, papers and pulps, and chemical industries will be diminished by the carbon capture and storage (CCS) technology in 2030 onwards. This study also considers energy security by focusing on economic and environmental aspects.*

Keywords – *buildings and industries, GHG emissions, EEP2015 and AEDP2015 plans, LEAP model, Thailand NDC.*

1. INTRODUCTION

Climate change and global warming is currently a worldwide challenging responsibility. Greenhouse gases (GHG) significantly store heat in the earth's atmosphere as part of the GHG effect. Human activities are the most important action to contribute GHG effects [1]. Most GHG emissions are produced by the fossil fuel combustion such as automobiles, industries and electricity generation. Several impacts have been arisen since the increase of GHG emissions. These impacts affect the timing of seasonal events, changes in agricultural productivities and nutrition levels [2].

Thailand, as a developing country, is one of the fastest growing energy-intensive economies in Southeast Asia [3]. Thailand continuously requires energy for driving its economy. However, energy resources are limited and half of the required energy is imported [4]. Thailand consumes enormous energy and releases a large amount of GHG emissions, especially the energy sector [5]. The majority of GHG emissions in the energy sector arose from the fossil fuel combustion especially CO_2. Total CO_2 emissions accounted for 235.8 Mt-CO_{2eq} in 2017. Mostly the production of electricity and heat accounted for about 96.8 Mt-CO_{2eq} (41.1%) in 2017. CO_2 emissions from the transportation, and the manufacturing industry were 78.4 Mt-CO_{2eq} (33.3%) and 45.2 Mt-CO_{2eq} (19.2%), respectively. The building sector including residential and commercial sector emitted 6.7 Mt-CO_{2eq}, 2.8% of total CO_2 emissions from the energy sector [6].

In 2017, Thailand's total final energy consumption (TFEC) was 80.8 Mtoe, which increased by 1.0% compared to 2016 [6]. In the same year, among fuel types oil and petroleum products accounted for 50.1% of TFEC, followed by electricity, renewable energy, natural gas and coal (20.5%, 15.7%, 7.1%, and 6.6% of TFEC, respectively). In 2017, the transport sector was the largest energy consuming sector, and accounted for 40.0% of TFEC. The industrial sector was the second largest energy consuming sector. In the last decade, the industrial sector experienced a major revolution due to rapid economic development. It is one of energy intensive sectors. TFEC in the industrial sector was 28.5 Mtoe, and accounted for 35.2% of Thailand's TFEC in 2017 [6]. Fossil fuels, such as coal, oil, and natural gas, represented the majority of energy consumption. Most of the fossil fuel consumption was used for heating systems. The building sector, including both the residential and the commercial sectors, was the third largest energy consuming sector. In 2017, electricity is the main form of energy for end-use devices in this sector. Therefore, the sector had the highest share of Thailand's electricity consumption, 57.4% of TFEC in the building sector [6]. Because of the increase of energy demands in the building sector, GHG emissions increased. GHG emissions in the building sector was mainly contributed by the combustion of Liquefied petroleum gas (LPG). LPG was the main fossil fuel used in cooking and heating systems, and accounted for about 32.0% of total fossil fuel consumption in the building sector [6].

Traditional renewable energy (RE) including fuel wood, charcoal and paddy husk, was used for cooking devices in the residential sector. Many studies analyzed GHG mitigation measures on the global and national scale [7]-[9]. Full implementation of RE in both demand and supply side would substantially reduce the GHG

*Sirindhorn International Institute of Technology, Thammasat University, 99 Moo 18 Khlong Luang, Pathum Thani 12120, Thailand.

[1]Corresponding author;
Tel: +66-2-986-9009, Fax: +66-2-986-9112.
E-mail: bundit@siit.tu.ac.th

emissions, improve the energy security and create a large number of jobs in South Korea [10]. Zhang *et al.* [11] suggested that the technology development, the energy efficiency improvement and the optimizing of energy structure in the manufacturing industry were key measures to get a peak CO_2 emission in Beijing, China by 2020. Emodi *et al.* [12] found that the RE installation would be a significant measure to enhance the energy affordability, reliability and the GHG emissions reduction in the Australian's power sector. Currently, Thailand has limited studies on climate policies [13]. Pagnarith *et al.* [14] studied the effects of RE utilization and CO_2 mitigation in the power sectors in selected Greater Mekong Sub-region (GMS) countries. It provided several scenarios by using the Long-range Energy Alternatives Planning (LEAP) system. They concluded that the electricity generation from biomass power plants was expected to increase in 2030. Winyuchakrit *et al.* [15] used the Extended SnapShot Tool (ExSS), a macro-economic model, to estimate future energy demand and CO_2 emissions, and to present sustainable Thailand's low-carbon society (LCS) scenarios. They developed scenarios for forecasting energy demand and CO_2 emissions with and without climate policies intervention. An energy efficiency improvement and RE were suggested as significant CO_2 reduction measures in the industrial sector [15], [16]. The computable general equilibrium (CGE) model was applied to investigate the GHG reduction potential under emission trading scheme and carbon capture and storage (CCS) technology [17]. Selvakkumaran *et al.* [18] suggested that the 2^{nd} generation biomass and CCS were the mechanism to reach LCS in the industrial sector. RE would significantly reduce the GHG emissions under Thailand's Nationally Determined Contributions (NDC) [13]. Promjiraprawat *et al.* [19] assessed Thailand's energy policies and CO_2 emissions on electricity generation by RE and energy efficiency using the least-cost power generation expansion plans (PGEPs) model and a mathematical formulation of mix integration linear programing (MILP) model. These studies used the energy demand to predict CO_2 emissions [14],[15],[19]. Energy efficiency and RE are the main mechanism to diminish the GHG emissions. Therefore, the objective of this study is to evaluate the long-term energy policy in the building and the industrial sectors during 2005-2050 through perspectives of energy saving potentials and GHG mitigation by using LEAP model.

This paper is organized into six sections as follows. Section 1 is the introduction. Section 2 presents the Thailand's energy plans related to services sectors. Section 3 describes the methodological approach and scenarios' description which include the socio-economic information. Results and discussion are discussed in Section 4 while Section 5 provides the conclusions of the study and final remarks.

2. THAILAND'S ENERGY PLANS FOR SERVICE SECTORS

Thailand's economic growth prospects and the establishment of ASEAN Economic Community (AEC), were seen to have impacts on Thailand's energy consumption [20]. In 2015, Thailand's Ministry of Energy (MOE) developed energy master plans, which directly affect the reduction of TFEC and GHG emissions. They are Energy Efficiency Plan 2015-2036 (EEP2015), Alternative Energy Development Plan 2015-2036 (AEDP2015), and Thailand Power Development Plan 2015-2036 (PDP2015). These plans focus on energy security, economy and ecology issues. Thus, the plans considered fuel diversification to lessen the dependency on fossil fuels. Cost of power generation is a key parameter affecting Thailand's economy. Therefore, the generation cost should be maintained at an appropriate level, and energy efficiency improvement should be implemented. Reducing environmental and societal impacts should be considered through reducing CO_2 intensity [20]. In addition, Thailand formulated Thailand's Climate Change Master Plan 2012-2050 [21], providing a long-term framework for measures and actions. The plan was designed to achieve sustainable low carbon growth and climate change resilience by 2050. As mentioned earlier, this study focuses on CO_2 reduction in the service sectors, especially the building and industrial sectors. Therefore, policies presented in these plans are used in the scenarios.

2.1 Energy Efficiency Plan 2015-2036 (EEP2015)

Government foresaw that energy prices would be a major concern due to limited energy resources, environmental issues and climate change which are consequences of energy production and utilization. Increased energy costs will affect people's affordability and the country's economic competitiveness. To set a long-term energy efficiency plan, the EEP2015 was expected to reduce energy intensity by 30% in 2036 compared with 2010 level. The EEP2015 was projected to conserve 51,700 ktoe by 2030. The energy conservation will be undertaken in the transportation sector (30,213 ktoe), the industry sector (14,515 ktoe), commercial buildings and government buildings (4,819 ktoe), and residences (2,153 ktoe). The EEP2015 provided three strategies with ten measures. The compulsory strategy consisted of four measures including energy management in designated buildings and industries, building energy code (BEC), energy efficiency resource standard (EERS), and energy standard and energy labelling. The energy standard and energy labelling are high energy performance standards (HEPs) and minimum energy performance standards (MEPs). The voluntary strategy consisted of four measures: financial incentive, the implementation of light-emitting diode (LED) lights, the energy efficiency deployment in the transport sector, and the improvement of research and development in energy efficient technology. The complementary strategy includes human resources development and promotion of public awareness on energy conservation [22].

2.2 Alternative Energy Development Plan 2015-2036 (AEDP2015)

RE has been promoted to address global warming and climate change issues. Therefore, the Thai government desired to push forward the AEDP2015 in order to become a low-carbon country. The AEDP2015 considers the alternative energy and renewable utilization in three categories: electricity generation, thermal processes (particularly in the industrial and building sectors), and biofuel use in the transport sector. Thermal processes account for more than 50% of total alternative energy and RE promotion followed by biofuel (26.6%) and electricity (21.2%). RE promotion schemes were designed to strengthen the community, lessen the dependence on fossil fuels, and significant use of municipal solid waste (MSW) and agricultural waste. Therefore, the AEDP2015 plan intended to encourage use of MSW, biomass, and biogas for electricity generation as the top priority. The target of the AEDP2015 is to increase the portion of renewable power generation from 8% in 2014 to 20% of the total power requirement in 2036. This accounts for 19,684.4 MW. The target aligns with the PDP2015 which stated that the electricity generation from RE will be 15-20% by 2036 [20]. In addition, energy demand for heating systems is also an important concern for Thailand. The AEDP2015 suggests that the heat demand will be produced from biomass and biogas, fast growing trees, solar energy, and other alternative energy sources [23].

2.3 Thailand's Intended Nationally Determined Contributions

Thailand submitted its Intended Nationally Determined Contributions (INDCs) and relevant information to the United Nations Framework Convention on Climate Change (UNFCCC) in 2015. They prescribed that GHG emissions can be reduced by 20% from the BAU level by 2030, and up to 25% if the required support is received from international organizations [24]. In 2017, Thailand launched its NDC Roadmap to reduce 115.6 Mt-CO_{2eq}, which will account for a 20.8% reduction by 2030 compared to the BAU level [5]. GHG emission reductions can be obtained from the energy, waste, and industrial processes and product use (IPPU) sectors. The energy sector will reduce GHG emissions by about 113.0 Mt-CO_{2eq}. This reduction can be separated into 24.0 Mt-CO_{2eq} in the power sector, 43.0 Mt-CO_{2eq} in the industrial sector, 41.0 Mt-CO_{2eq} in the transport sector, 4.0 Mt-CO_{2eq} in the residential sector, and 1.0 Mt-CO_{2eq} in the commercial sector. The GHG mitigation in the waste sector and the IPPU sector accounts for 2 Mt-CO_{2eq} and 0.6 Mt-CO_{2eq}, respectively [13].

3. METHODOLOGY AND SCENARIO DESCRIPTION

3.1 LEAP Model

The GHG emissions and mitigations are analysed by using an end-use model, the Long range Energy Alternatives Planning system or LEAP. The model was developed by the Stockholm Environment Institute (SEI). LEAP is a tool for energy policy analysis and climate change mitigation assessment. It is an accounting framework, in which users can analyse both demand and supply sides [25]. It allows users to provide quantitative data of current and future energy demands. The LEAP model also supports users to create energy forecasted systems based on existing energy demand and supply data. In addition, the LEAP model also facilitates the creation of environmental scenarios. The model also allows users to compare different long-term scenarios and to assess results with different scenarios. Scenario analyses are regarded as the heart of the LEAP model since they offer a set of tools for analysing, updating and comparing different energy management activities. The scenarios in LEAP are based on detailed accounting of energy types consumed by production processes.

The demand module adopts the end-use driven approach in the model. Many researchers have applied the LEAP model to estimate energy demands and emissions [11], [26], [27]. In Thailand, LEAP was used to assess the energy saving potentials [28], and to forecast energy demand and corresponding emissions [29]. Theoretically, the assessment of energy demands is a multiplication between activity levels and energy intensity, whereas amounts of emissions are the product of energy demands and emission factors [30]. Emission factors are referred to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [31].

This study designed the model structure according to the energy information from Department of Alternative Energy Development and Efficiency (DEDE). In the residential sector, DEDE reported the energy use in three areas including Bangkok and nearby provinces called "Greater Bangkok", municipal area and rural area. The commercial buildings were divided into eight building types: offices, hotels, hospitals, department stores, schools, hypermarkets, condominiums and miscellaneous. The industrial sector was categorized into nine manufacturing industries, and construction and mining. Nine manufacturing industries consist of food and beverages, textile, wood and furniture, paper and pulp, chemical, non-metallic, basic metal, fabricated metal, and other industries [32]. The energy service flows of electricity and non-electricity in the residential building and the industrial sectors are illustrated in Figure 1.

3.2 Scenario Description

To consider the Thailand's energy policies, this study analyzes two timelines including medium-term (up to 2030) and long-term (up to 2050). Scenarios present alternative pathways to determine policies and technical frameworks. The scenarios are based on policies introduced by Thailand's government. Four scenarios are provided. The business-as-usual (BAU) scenario is a reference case without any policy instigation. To reduce the energy demand and GHG emissions, this study introduces three GHG mitigation scenarios (MIT scenarios). The scenarios include evaluation of policies implementation, deployment of energy efficient technologies, and new technologies. The first mitigation scenario (MIT1) scenario considers the implementation of the EEP2015 and the AEDP2015 plans. The MIT1 scenario and additional energy efficient appliances are considered in the second mitigation scenario (MIT2). The third mitigation scenario (MIT3) introduces a biogas technology in the residential sector and a carbon capture and storage (CCS) technology in the industrial sector together with all technologies in the MIT1 scenario (see Figure 2 to 4). The study period is 2005-2050 and the first mitigation year is 2011. The energy analysis is classified in terms of non-RE (including all fossil fuel combustions) and RE resources.

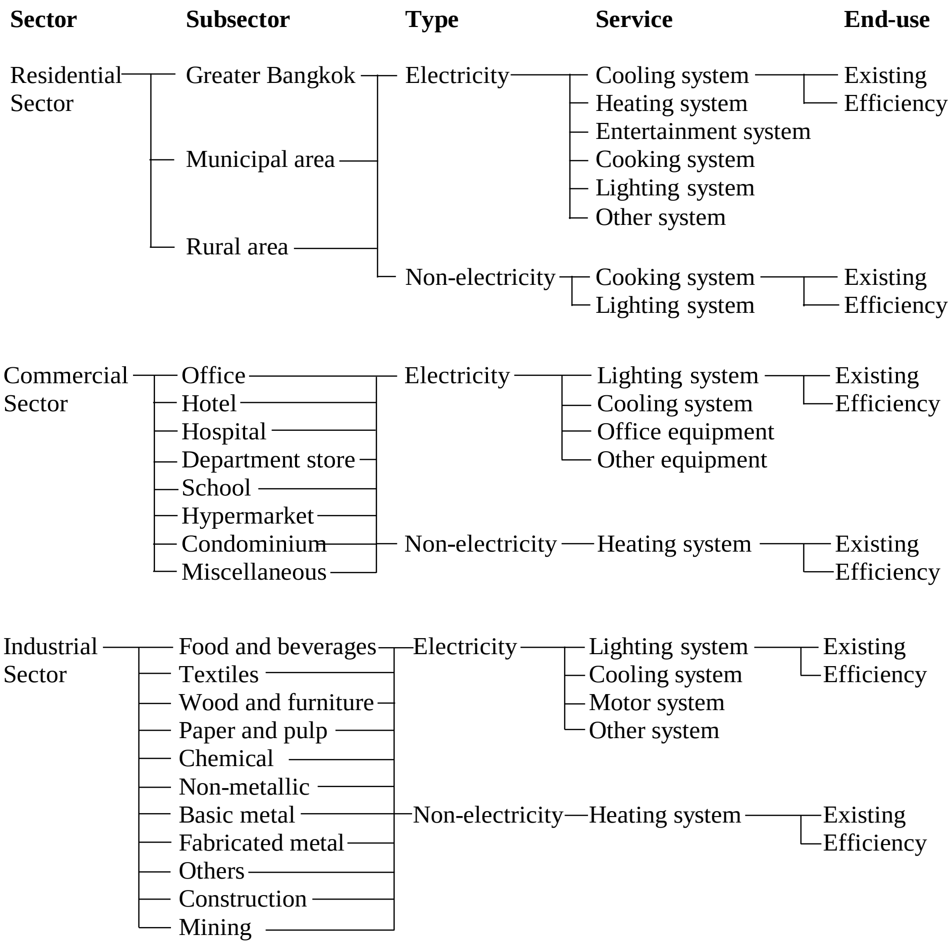

Fig. 1. Schematic diagram of energy services.

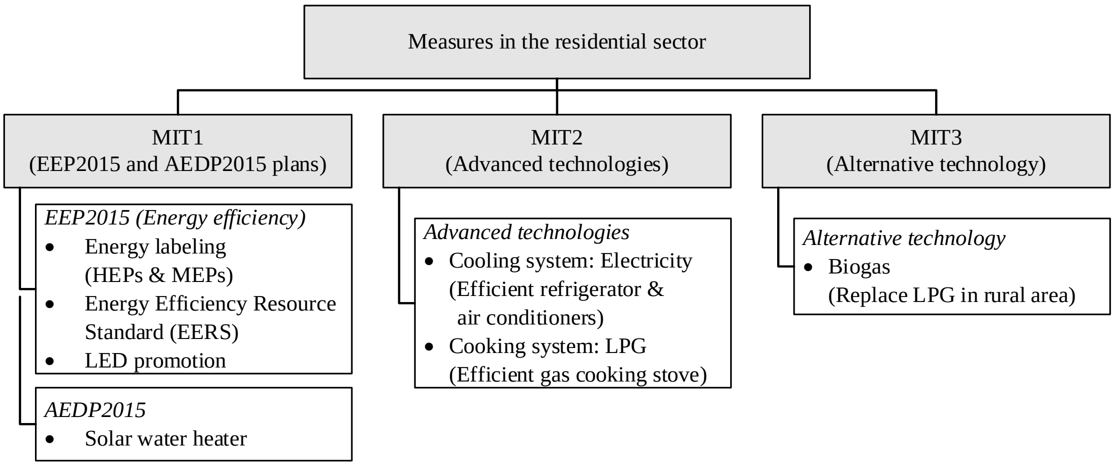

Fig. 2. Energy savings and GHG reduction measures in the residential sector.

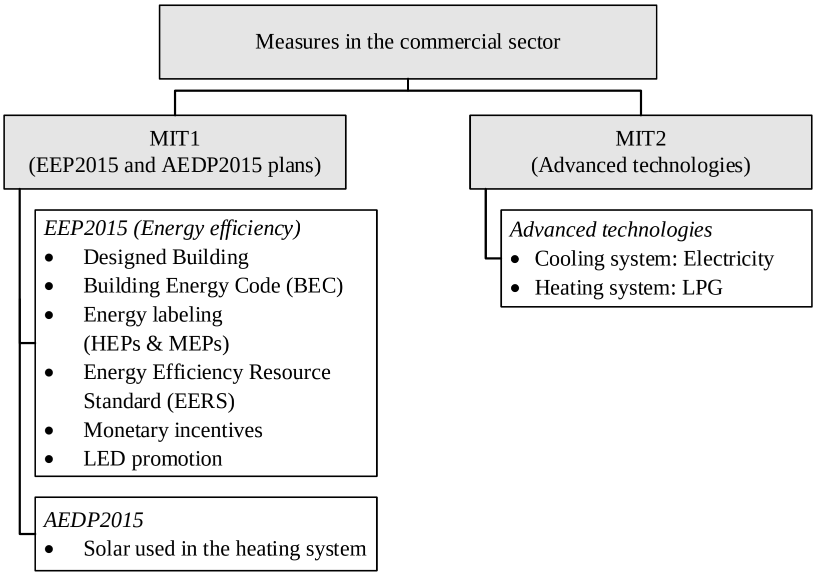

Fig. 3. Energy savings and GHG reduction measures in the commercial sector.

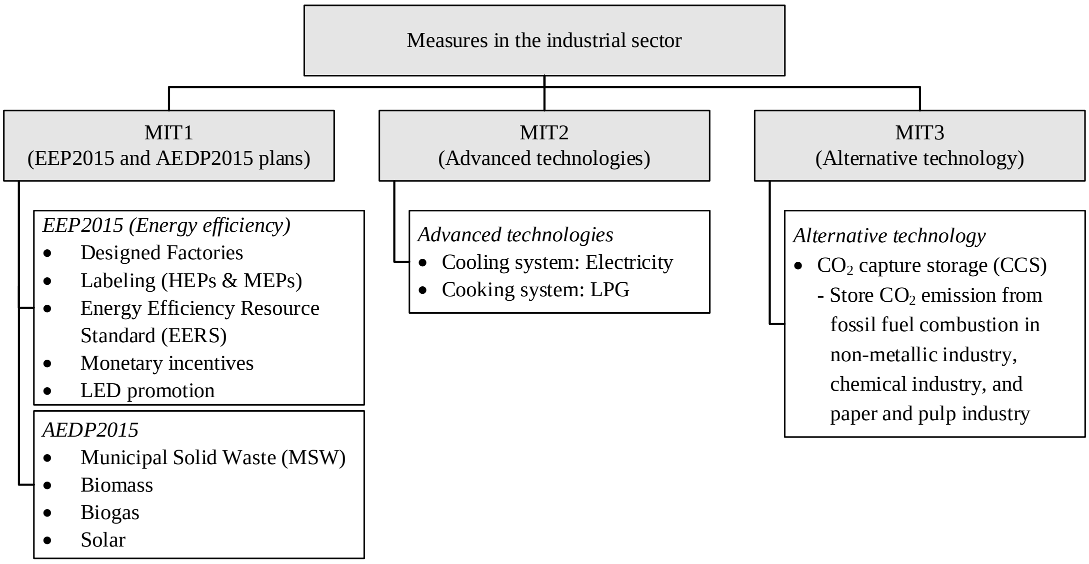

Fig. 4. Energy savings and GHG reduction measures in the industrial sector.

3.3 Socio-Economic Information

In this study, socio-economic information is used as a factor to estimate future energy demands. Changes of energy demand will affect the change in GHG emissions. Therefore, GHG emissions analysis in this study begins with the forecast of energy demand. Consequently, the analysis of the GHG emissions is performed for various fuel types related to emission factors of each fuel type [31]. RE is assumed to be a CO_2 neutral. However, it may emit other gases such as CH_4 and N_2O. Socio-economic data is collected during 1995-2014. Data includes population, gross domestic product (GDP), gross national product (GNP), and fuel prices (coal, natural gas, oil, and RE). These indicators are used as major factors to forecast future energy demand. Thailand's population in 1995-2014 was collected from the National Economic and Social Development Board (NESDB) [33]. The population increased from 59.46 million in 1995 to 65.12 million in 2014 with a compound annual growth rate (CAGR) increase of 0.48% per year. During 2015-2040, the population estimated by NESDB will increase moderately [34]. This study follows the growth rate of historical data (1995-2014) and estimated population by NESDB (2015-2040). Thai population increased from 62.42 million persons in 2005 to 65.12 million persons in 2014 or 0.47% annually. Based on the NESDB estimation, population will continuously increase with a CAGR of 0.16% annually during 2015-2026. Due to a lower birth rate and aging society, the population will decline at an average rate of 0.38% per year after 2026. GDP is also used to forecast energy demand in the residential and the commercial sectors. The historical data of GDP during 2005-2014 is collected from the NESDB. The historical trend revealed that GDP increased by 3.35% annually from 193 billion USD in 2005 to 260 billion USD in 2014 [35]. The estimated GDP growth during 2015-2036 was published by NESDB [20]. Table 1 presents the historical and estimated population and GDP.

Table 1. The historical and estimated parameters of the driven factors.

Factors	Historical data		CAGR	Estimated data			CAGR
	2005	2014	(%)	2015	2030	2050	(%)
Population (*1000 people*)	62,418	65,125	0.47	65,104	66,175	60,109	-0.23
GDP (*Million USD*)	193,387	260,111	3.35	270,515	494,715	1,044,047	3.93
Coal price *(USD/toe)*	16	23	4.11	19	26	41	2.22
Natural gas price *(USD/toe)*	8	7	-1.47	5	8	12	2.53
Cruel oil price *(USD/toe)*	390	704	6.78	371	767	1,439	3.95
Renewable energy price (*USD/toe*)	249	236	-0.59	223	267	296	0.81

Fuel prices are important factors affecting the changes in energy demand. Fuel prices applied in this study consider crude oil price, coal price, natural gas price and RE prices. The trend of coal price follows the World Bank [36]. The World Bank reported coal prices during 2001-2015 and forecasted coal prices during 2016-2025 [36]. The coal price will increase from 16 USD per tonne of crude oil equivalent (toe) in 2005 to 41 USD per toe in 2050 or a CAGR of 2.11% per year. Natural gas and crude oil prices and the estimated price trends are also collected [37]. Natural gas price is expected to increase from 8 USD per toe in 2005 to 12 USD per toe in 2050 or a CAGR of 0.91% per year. Crude oil price will increase from 390 USD per toe in 2005 to 1,439 USD per toe in 2050 or by a CAGR of 2.94% annually [38]. RE includes fuel wood, paddy husk, bagasse, agriculture waste, MSW, biomass, and biogas. The historical RE prices during 2002-2015 are obtained from the Energy Policy and Planning Office (EPPO) [39]. This study estimates the RE prices during 2016–2050 by the linear regression method. The average RE prices will increase from 249 USD per toe in 2005 to 296 USD per toe in 2050 with the growth rate of 0.38% per year.

3.4 Energy Demand Estimation

The historical energy demand has been collected from DEDE in 2005-2013 [32],[40],[41],[42]. Final energy demand and CO_2 emissions in 2030 are estimated by using the linear correlation between GDP, population and fuel prices. Then, it was calibrated to comply with Thailand's NDC in 2030. In the BAU scenario, this study estimated time-series data of the energy demand and CO_2 emissions between 2030 and 2050.

4. RESULTS AND DISCUSSIONS

4.1 Estimated Energy Demand and GHG Emission in the BAU Scenario

The total final energy demand will increase from 35.7 Mtoe in 2005 to 199.6 Mtoe in 2050 with an average growth rate of 3.9% per year. In addition, GHG emissions will increase from 120.8 Mt-CO_{2eq} in 2005 to 583.6 Mt-CO_{2eq} in 2050, a rate of 3.6% per year. More than half of the energy demand and GHG emissions will be dominated by the industrial sector. In the case of the building sector, the residential sector will require higher final energy demand than the commercial sector. LPG will be a main energy source in the commercial sector compared to the residential sector. Therefore, the GHG emissions are expected to be higher than those in the residential sector. Figure 5 presents the energy demand and GHG emissions in the BAU scenario.

Total final energy demand in the residential sector will increase from 9.0 Mtoe in 2005 to 53.4 Mtoe in 2050 with an average growth rate of 4.05% per year. Almost three quarters of final energy demand will be used in the rural area. The energy demand in the greater Bangkok area will be about 12%-14% of final energy demand in the residential sector. LPG and electricity will be the main fuels used in urban households. Biomass will play a vital role in the rural households and will account for 58% of final energy demand in the residential sector in 2050. Charcoal, wood and paddy husk will be major biomass resources. Half of the biomass demand will be charcoal. Electricity demand will account for 25% of final energy demand. For providing quality recipes, LPG has been preferred for cooking in urban areas. It will account for almost 17% of residential energy demand in 2050. Total GHG emissions will increase from 19.6 Mt-CO_{2eq} in 2005 to 102.6 Mt-CO_{2eq} in 2050 in the residential sector (increased by 9.2% annually). GHG emissions will increase from 9.5 Mt-CO_{2eq} in 2005 to 52.3 Mt-CO_{2eq} in 2050 in the rural area (an CAGR of 9.8% annually). Similarly, GHG emissions in the greater Bangkok area and the municipal area will increase with average annual growth rates of 8.5% and 8.9%, respectively, in 2050. More than 60% of households are in the rural area. Moreover, LPG and charcoal demand for cooking in the rural area will be significantly higher than that in greater Bangkok and the municipal area. Therefore, GHG emissions will be 52.3 Mt-CO_{2eq} in the rural area or 51.0% of total GHG emissions in the residential sector in 2050. This is the reason why the residential sector in rural area has the highest GHG emissions.

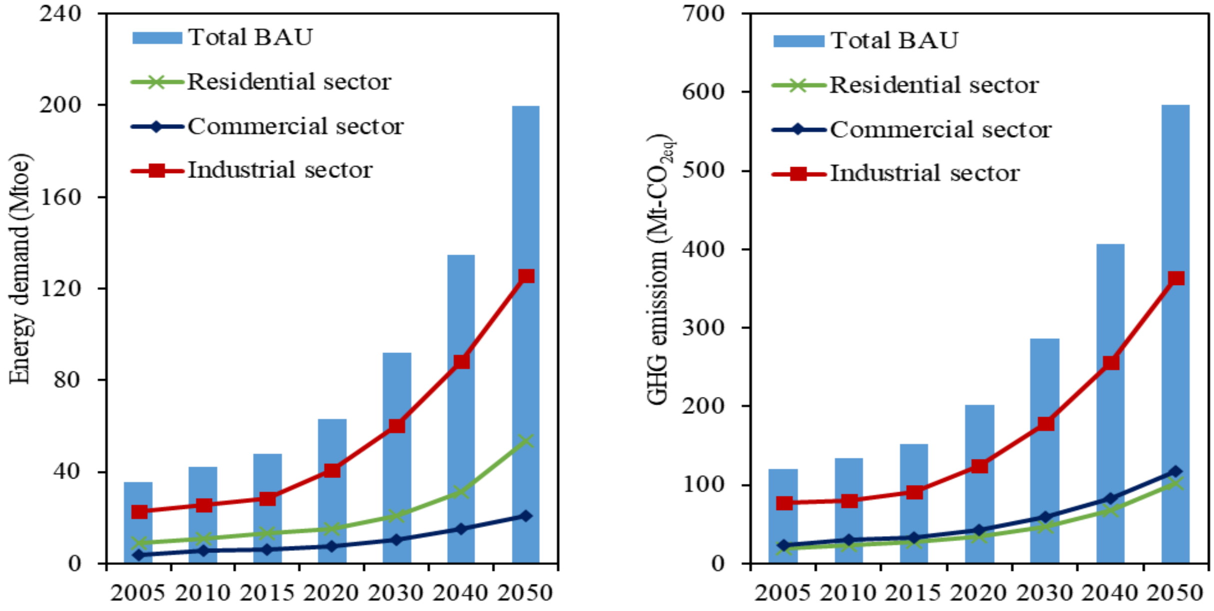

Fig. 5. (a) Energy demand and (b) GHG emissions in the BAU scenario

Total final energy demand in the commercial sector will increase from 3.8 Mtoe in 2005 to 20.7 Mtoe in 2050, with an average growth rate of 3.8% annually. The office building type will be the most energy-intensive building type, and will account for 32.8% of total final energy demand in the commercial sector, followed by hospitals, hotels and department stores (16%, 15%, and 12% of total energy demand), respectively. Schools, hypermarkets, and condominiums will consume 16% of total final energy demand in 2050. Electricity plays an essential role and accounted for 82% of total final energy demand in the commercial sector. Non-electricity energy, especially LPG, is consumed by heating and cooking systems. Due to the limitation of activity data in both heating and cooking systems, the energy use from both systems is integrated. LPG will account for 18% of the commercial sector's total final energy demand. The GHG emissions from electricity demand will be 12 times higher than LPG use. The GHG emissions from electricity will increase from 22.1 Mt-CO_{2eq} in 2005 to 108.3 Mt-CO_{2eq} in 2050 with an average growth rate of 8.5% annually. GHG emissions from LPG will emit 8.7 Mt-CO_{2eq} in 2050. In addition, when considering the GHG emissions by building types in 2050, office buildings will contribute the highest GHG emission in the commercial sector, 35% of total GHG emissions in the commercial sector, followed by hospitals and hotels (13.8% and 13.2%), respectively.

In the industrial sector, the energy demand will increase from 22.9 Mtoe in 2005 to 125.6 Mtoe in 2050 with a CAGR increase of 3.9% per year in the BAU scenario. Food and beverage and non-metallic industries will account for almost 60% of the industrial sector's energy demand in 2050. Thailand is the world's sixth largest sugar producer [43]. Almost three quarters of energy demand came from biomass. The reason is that bagasse is mostly used for electricity cogeneration in sugar factories. The food and beverage industry will be the largest energy demand industry. Its demand will be almost 32% of the industrial final energy demand in 2050. Petroleum products and electricity demand will be accounted for 93% of fossil fuels used in the food and beverage industry. The non-metallic industry, mainly the cement industry, will be the second largest energy consumer in the industrial sector in 2050 in the BAU scenario. Its energy demand will account for almost one third of the industrial sector energy demand in 2050. Almost 80% of non-RE demand will be dominated by coal. The chemical industry will be the third largest industry. It will account for more than one eighth of energy demand in the industrial sector.

Moreover, electricity will continuously be the most important energy for producing products and accounted for almost 58% of total final energy demand in the chemical industry in 2050. The fabricated metal industry will be the fourth largest energy user in the industrial sector. Electricity demand will be more than 50% of total energy demand in the fabricated metal industry in 2050. Presently, Thailand does not produce primary steel [44]. Hence, the energy consumed by the basic metal industry is insignificant. Unlike in industrialized countries, energy intensive industries such as cement, iron and steel, paper industries do not require a large proportion of Thailand's energy demand in the industrial sector [40]. In 2050, coal, including bituminous, anthracite, lignite, briquettes, and coke, will account for 23% of total energy demand, followed by electricity (19%), petroleum products including gasoline, kerosene, diesel, LPG, and fuel oil (19%) and natural gas (12%) in the industrial sector, respectively. RE sources including wood, agricultural wastes, bagasse, MSW, biomass, biogas will account for 27% of total final energy demand in the industrial sector in 2050. Most of GHG emissions will originate from the fossil fuel combustion. It will account for 224.1 Mt-CO_{2eq} or 61.6% of total GHG emissions in the industrial sector in 2050. Coal and oil products will emit GHG emissions about 97.0 Mt-CO_{2eq} (26.6% of total GHG emissions) and 85.8 Mt-

CO_{2eq} (23.6% of total GHG emissions) in 2050, respectively. The GHG emissions from electricity demand will be 140.0 Mt-CO_{2eq} or 38.4% of total GHG emissions in 2050. When classified by sub-industries, non-metallic industries will contribute the highest GHG emissions, which will account for 26.4% of total GHG emissions in the industrial sector in 2050. The second largest emissions source will be food and beverages industries which will contribute about 16.4% of total GHG emissions, followed by chemical industries which will contribute about 13.9% of total GHG emissions in the industrial sector.

4.2 Energy Savings and GHG Mitigation in the MIT Scenarios

Figure 6 illustrates the energy savings in the residential, the commercial and the industrial sectors. The green shade is represented measures of the EEP2015 in the MIT1 scenario. The yellow dot gives advanced technologies in the MIT2 scenario. The implementation of EEP2015 will be the most effective measure in terms of energy savings in the residential sector. The plan will mitigate energy demand by 1.8 Mtoe in 2050 in the MIT1 scenario. Advanced technologies (such as highly efficient air conditioners and refrigerators) will significantly reduce the energy demand (see yellow dot in Figure 6a). The energy demand will be reduced by 1.8 Mtoe in the MIT2 scenario in 2050. Energy labeling will be the most desirable measure in energy demand reduction (see Figure 6a). Such a measure will reduce energy demand by 42% of total energy savings. The promotion of LED lighting and EERS measures will slightly reduce the energy demand compared to the former measure in the MIT2 scenario. These measures will account for 6% and 2% of total energy savings, respectively, in 2050. Therefore, measures in the EEP2015 and advanced technologies will considerably reduce the electricity demand by about 50% of the total energy savings in the MIT2 scenario.

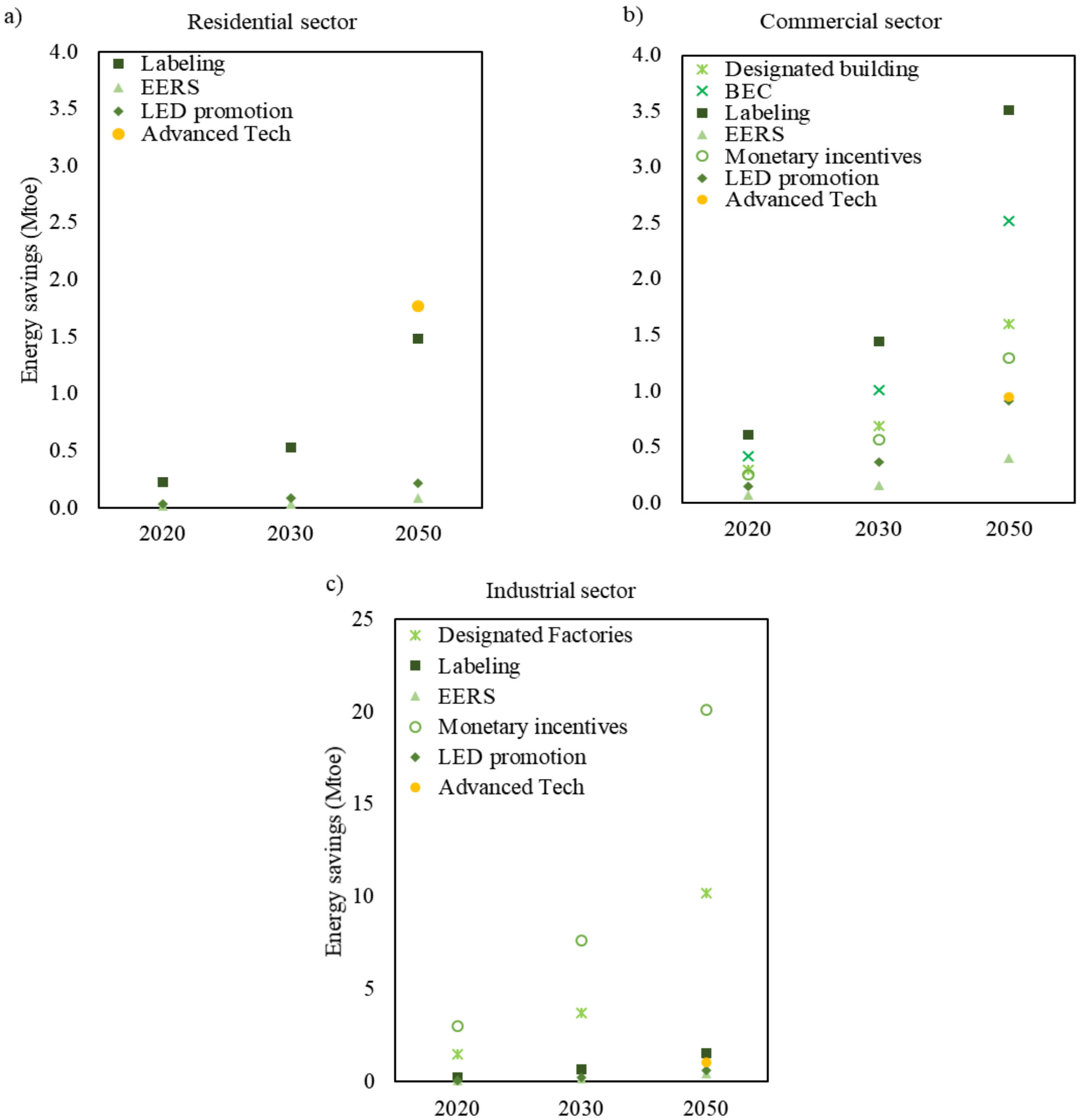

Fig. 6. Energy saving potentials in a) the residential, b) the commercial and c) the industrial sectors.

All six measures of the EEP2015 and the deployment of advanced technologies reveal the effectiveness in energy savings in the commercial sector (energy savings: 11.2 Mtoe in 2050). Similar to the residential sector, energy labeling will play an important role reducing energy demand by 31% of the total energy reduction. The Building Energy Code (BEC) and energy savings in designated buildings will achieve the energy savings target. Both measures will reduce energy demand by 37% of the total energy reduction. Monetary incentives to support energy efficiency improvement programs will reduce the energy demand by 12% of total energy reduction in buildings. The installation of LED and the EERS measures will insignificantly reduce energy demand. The measures will conserve the energy by 8% and 4% of total energy reduction, respectively. The implementation of advanced technologies will affect energy savings by 8% of total energy reduction in the MIT2 scenario in 2050 (See Figure 6b).

In the MIT2 scenario, five measures in the EEP2015 and advanced technologies will be implemented in the industrial sector. Energy demand will reduce by 34.0 Mtoe in 2050 compared to the energy demand level of the industrial sector in the BAU scenario. Monetary incentives will be the most important measure reducing energy demand. The measures will account for 59% of total energy reduction in the industrial sector. The second largest energy saving measure will be the energy saving measure in the designated factories. It will account for 30% of total energy reduction in the MIT2 scenario in 2050. Energy labeling, LED promotion, and EERS measures will reduce energy demand by 6% of total energy reduction in the industrial sector. Advanced technologies will reduce energy demand by 3% of total energy savings in the MIT2 scenario in 2050 (see Figure 6c).

According to the mentioned scenarios (see Section 3.2), GHG emissions will significantly be decreased compared to the BAU scenario in all sectors. The implementation of EEP2015 and advanced technologies will be the effective measures in terms of energy savings and GHG mitigation in the MIT1 and MIT2 scenarios, respectively. However, the implementation of AEDP2015 (MIT1) and biogas (MIT3) will affect only GHG mitigation. Figure 7 presents the GHG emissions in all scenarios. In 2030, GHG emissions will be 43.6 Mt-CO_{2eq} in the residential sector, 36.0 Mt-CO_{2eq} in the commercial sector, and 115.3 Mt-CO_{2eq} in the industrial sector in the MIT1 scenario. In addition, GHG emissions will be 93.6 Mt-CO_{2eq} in the residential sector, 59.2 Mt-CO_{2eq} in the commercial sector, and 201.6 Mt-CO_{2eq} in the industrial sector in 2050. GHG emissions will be 85.1 Mt-CO_{2eq} in the residential sector and 168.9 Mt-CO_{2eq} in the industrial sector in 2050 in the MIT3 scenario. The measures in the EEP2015 and AEDP2015 plans in the MIT1 scenario will reduce GHG emissions by about 3.5 Mt-CO_{2eq} in 2030 and 9.0 Mt-CO_{2eq} in 2050 in the residential sector (see Figure 8a). The rural area will mitigate the highest GHG emissions, and account for 4.1 Mt-CO_{2eq} in 2050. The second highest mitigation area will be in greater Bangkok area. In the commercial sector, the GHG mitigation will be about 23.9 Mt-CO_{2eq} in 2030 and 57.8 Mt-CO_{2eq} in 2050 as shown in Figure 8b. Most GHG mitigation will be in offices, which will account for 20.1 Mt-CO_{2eq} followed by hospitals and hotels, which will account for 8.3 Mt-CO_{2eq} and 8.1 Mt-CO_{2eq}, respectively. GHG emissions in the industrial sector will reduce 63.8 Mt-CO_{2eq} in 2030 and 162.5 Mt-CO_{2eq} in 2050 (see Figure 8c). Non-metallic industries will be the highest GHG mitigation accounting for 62.5 Mt-CO_{2eq} in 2050. The second largest GHG mitigation will be found in food and beverage industries and fabricated metal industries which will account for 24.6 Mt-CO_{2eq} and 17.1 Mt-CO_{2eq}, respectively, in 2050.

However, the measures in the EEP2015 and AEDP2015 plans applied in the MIT1 scenario will not satisfy the GHG emissions reduction target in the residential sector as announced in the Thailand INDC target [24]. There is a gap between the MIT1 scenario and INDC target by 0.5 Mt-CO_{2eq} in 2030 in the residential sector. The GHG reduction target in the residential sector will be 4 Mt-CO_{2eq} in 2030 [13]. Thailand's INDC target stated that only one million tonnes of CO_{2eq} will be reduced in the commercial sector by 2030. The commercial sector will successfully obtain the GHG reduction target in the MIT1 scenario in 2030. The GHG reduction potential estimated in the MIT1 scenario will be greater than that in the INDC target by 95.8% in 2030. As a result, Thailand potentially achieves the GHG reduction in the commercial sector over than that mentioned in the INDC target. Therefore, the GHG reduction potential in both the residential and the commercial sectors, combined as the building sector, will reach the INDC target. Monetary incentives on energy efficiency will be one of the most effective programs for the industrial sector in the MIT1 scenario. The incentives include energy service company (ESCO) funds, soft loans, revolving funds, joint ventures and grants [22]. All measures introduced in the industrial sector will greatly reduce the GHG emissions in the MIT1 scenario by 48.4% compared to the INDC target in 2030.

Measures in both the MIT2 and the MIT3 scenarios will be taken into the consideration after 2036. In 2050, the MIT2 and the MIT 3 scenarios will reduce GHG emissions compared to the MIT1 scenario by 2.2 Mt-CO_{2eq} and 8.5 Mt-CO_{2eq}, respectively, in the residential sector (see Figure 8a). Biogas will provide an essential role in the rural area in the MIT3 scenario. Thus, promoting the use of biogas to replace LPG will reduce the GHG emissions in the residential sector in 2050. The MIT2 scenario will mitigate GHG emissions by about 5.3 Mt-CO_{2eq} in 2050 in the commercial sector as illustrated in Figure 8b. GHG mitigation will be found mostly in offices, which will account for 2.0 Mt-CO_{2eq} followed by hotels (1.0 Mt-CO_{2eq}) and hospitals (0.8 Mt-CO_{2eq}). In the industrial sector, the MIT2 and the MIT3 scenarios will reduce GHG emissions by 4.9 Mt-CO_{2eq} and 31.7 Mt-CO_{2eq} in 2050, respectively (see Figure 8c). In the MIT2 scenarios, GHG mitigation will be in the fabricated metal industry, which will account for 1.0 Mt-CO_{2eq} followed by chemical industries and food and beverage industries. Their GHG emissions will be reduced by 1.0 Mt-CO_{2eq} and 0.8 Mt-CO_{2eq}, respectively, in 2050. The implementation of CCS technology in the MIT3 scenario will only be introduced in the paper and pulp, chemical, and non-metallic industries. Most of the GHG mitigation will be in non-metallic industries, which will reduce by 20.7 Mt-CO_{2eq} in the MIT3 scenario. Chemical and paper and pulp industries will reduce the GHG emissions by 6.8 Mt-CO_{2eq} and 4.3 Mt-CO_{2eq}, respectively, in 2050.

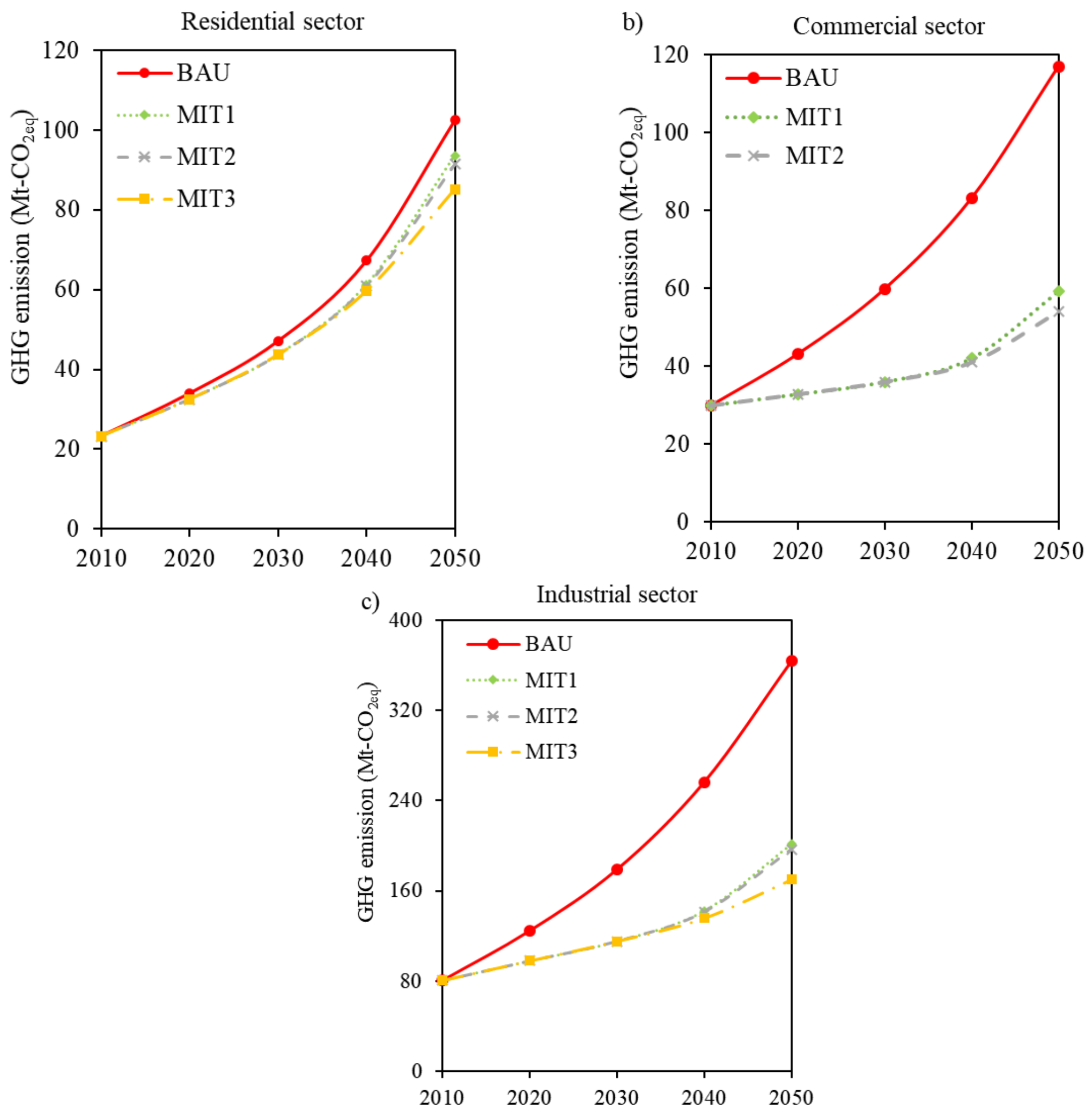

Fig. 7. GHG emissions in (a) the residential, (b) the commercial and (c) the industrial sectors.

4.3 Energy Security and Other Co-benefits of GHG Mitigation

In addition to the reduction of GHG emissions, Thailand will gain other co-benefits. Energy security, including its economic and environmental aspects, is considered. However, choices of analytical approach depend on the availability of the information. In this study, energy intensity is calculated. Environmental indicators are presented in terms of carbon emissions intensity and carbon emissions per capita in all sectors. Results of energy security and other co-benefits are presented in Table 2.

In the MIT1 scenario, energy intensity will be reduced by 1.3 toe/million USD in the residential sector (a 3.1% reduction compared with the BAU scenario in 2030). Similar to the energy intensity, carbon emission intensity and carbon emission per capita will be reduced by 6.9 kg-CO_{2eq}/thousand USD and 52.1 kg-CO_{2eq}/capita in 2030, respectively. In 2050, energy intensity will be reduced by 1.7 toe/million USD in the MIT1 scenario compared to the BAU scenario. In addition, energy intensity will be intensively reduced in the MIT2 scenario and will be accounted for 3.4 toe/million USD in 2050 compared to the BAU scenario. Carbon emission intensity and carbon emission per capita will be diminished by 8.6 kg-CO_{2eq}/thousand USD and by 149.1 kg-CO_{2eq}/capita in the MIT1 scenario compared with the BAU scenario, respectively. The deployment of advanced technologies will reduce the carbon emission intensity and the carbon emission per capita by 16.7 kg-CO_{2eq}/thousand USD and 290.3 kg-CO_{2eq}/capita compared with the BAU scenario, respectively. Biogas technology in the MIT3 scenario will reduce carbon emission intensity and carbon emission 10.6 kg-CO_{2eq}/thousand USD per capita and 185.2 kg-CO_{2eq}/per capita, respectively.

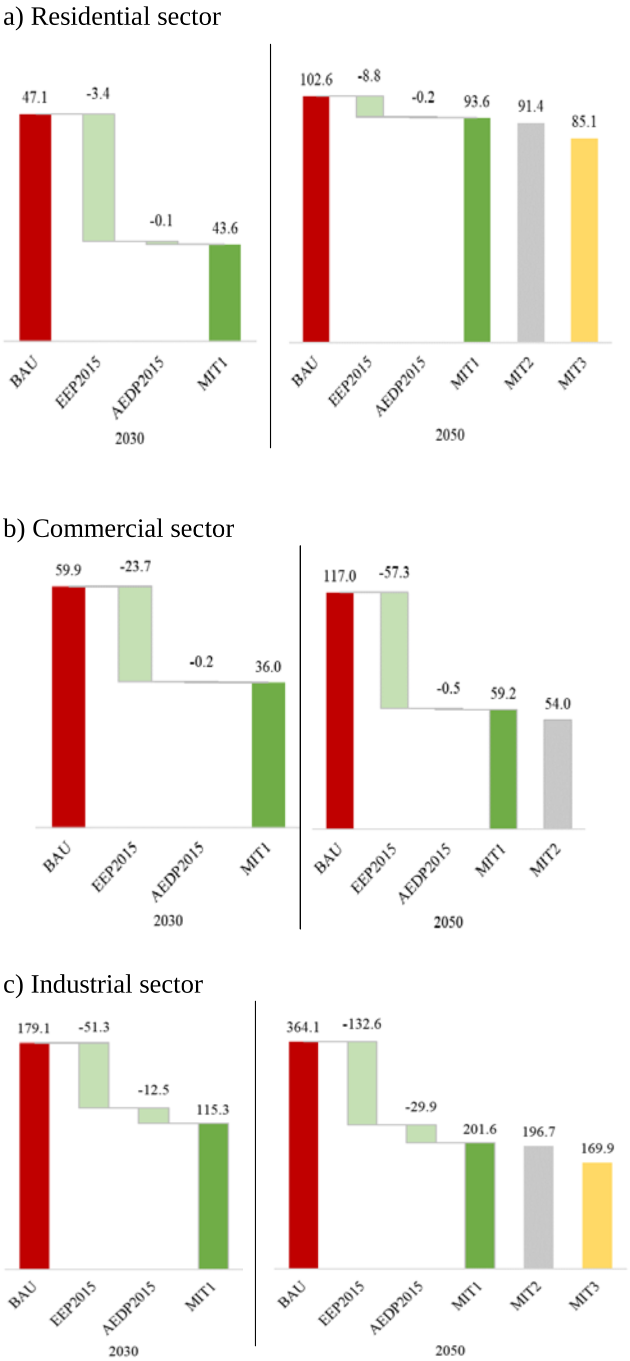

Fig. 8. GHG mitigation potential in a) the residential, b) the commercial and c) the industrial sectors by 2030 and 2050. The unit is Mt-CO_{2eq}.

In the MIT1 scenario, energy intensity will be reduced to 12.8 toe/million USD in 2030 in the commercial sector (39.6% reduction). Energy saving measures and technologies in the MIT1 and the MIT2 scenarios will substantially reduce the energy intensity. Energy intensity will be reduced by 9.7 toe/million USD and 10.6 toe/million USD in 2050 in the MIT1 and the MIT2 scenario, respectively. Emission intensity will be reduced by 55.1 kg-CO_{2eq}/thousand USD in 2050 in the MIT1 scenario, and 60.1 kg-CO_{2eq}/thousand USD in 2050 in the MIT2 scenario. Carbon emissions per capita will reduce by 960.5 kg-CO_{2eq}/per capita in 2050 in the MIT1 scenario, and 1,047.9 kg-CO_{2eq}/per capita in 2050 in the MIT2 scenario.

The implementation of energy policies in the MIT1 scenario will reduce energy intensity by 25.1 toe/million USD in 2030 in the industrial sector. Emission intensity and emission per capita will be reduced by 128.5 kg-CO_{2eq}/thousand USD and 963.9 kg-CO_{2eq}/per capita in 2030 compared with the BAU scenario. Energy intensity will reduce from 119.8 toe/million USD in the BAU scenario to 88.4 toe/million USD in the MIT1 scenario in 2050 and 87.4 in the MIT2 scenario in 2050. Emission intensity will be reduced by 155.0 kg-CO_{2eq}/thousand USD in the MIT1 scenario, 159.7 kg-CO_{2eq}/thousand USD in the MIT2 scenario, and 185.3 kg-CO_{2eq}/thousand USD in the MIT3 scenario compared with the BAU scenario. Similarly, emission per capita will be reduced by 2,703.2 kg-CO_{2eq}/capita in the MIT1 scenario, 2,784.2 kg-CO_{2eq}/capita in the MIT2 scenario, and 3,231.0 kg-CO_{2eq}/capita in the MIT3 scenario compared with 2050 in the BAU scenario.

Among energy policy measures, energy efficiency improvement is one of the main policy mechanisms to minimize energy use in the demand side. International Energy Agency (IEA) revealed that many countries introduced mandatory energy efficiency labeling for appliances [45]. Yilmaz *et al.* [46] analyzed the impact of energy efficiency labeling in Switzerland. Energy efficiency standards and labeling are effective instruments for achieving energy and CO_2 emission reduction. Currently, the Electricity Generating Authority of Thailand (EGAT) and Department of Alternative Energy Development and Efficiency (DEDE) launched the energy savings program for electricity and heat applicants called "Label No.5" [22]. The program was initiated since 1993 and focused on the appliances which consumed 70% of energy consumption [47]. In 2019, there are 27 energy efficient appliances (19 electricity appliances and 8 heat appliances) passed the efficiency standard [22]. This study reveals that the energy labeling is the most energy savings measure in the residential and the commercial sectors (see Figures 6a and 6b). This study suggests that policy makers should target at technical measures and social interventions (*e.g.* behavior change).

These techniques would lead to a low carbon lifestyle based on the concept of sufficiency. Policy makers should consider additional instruments to accelerate more stringent energy savings. Providing monetary incentives to make the efficient appliances more affordable for customer is recommended. The regulation redesign achieving energy labelling standard could be emphasized if both the incentives and sustainable environment are involved. In order to enhance the energy efficiency potential, the link between mandatory audits and minimum energy performance standards would need to be enacted, and related research and development (R and D) should be encouraged. Policy makers should enforce the commercial and government buildings to disclose the energy use activities in details, and to share responsibilities under the national climate target [48]. The policies should be targeted at the existing appliances by accelerating the rate of energy refurbishment [49]. The policy makers should determine the monetary incentive measure combined with tax exemption [48]. In this study, the monetary incentive will be the most important measure for reducing energy demand and GHG emission in the industrial sector. The measure promotes energy conservation by subsidizing investment for improving energy saving potentials in machineries, for example, standard operating policies and procedures, soft loan for energy conservation, ESCO revolving fund, tax incentive [22]. Stimulating the energy savings by imposing the polluter pays principle is suggested to be one of the economic instruments [48]. In addition, IPCC fifth assessment report (AR5) presented the sectoral policy instrument, subsidies are the important economic instrument especially in industrial and commercial sectors [50].

Table 2. Energy security and other co-benefits of GHG mitigation.

Year	2030		2050			
Scenario	BAU	MIT1	BAU	MIT1	MIT2	MIT3
Residential sector						
Energy intensity of GDP *(toe/million USD)*	42	40.7	50.9	49.2	47.5	-
Carbon emission intensity *(kg-CO_{2eq}/thousand USD)*	94.8	87.9	97.9	89.3	81.2	87.3
Carbon emission per capita *(kg-CO_{2eq}/capita)*	711.6	659.5	1,706.5	1,557.4	1,416.2	1,521.3
Commercial sector						
Energy intensity of GDP *(toe/million USD)*	21.2	12.8	19.7	10.0	9.1	-
Carbon emission intensity *(kg-CO_{2eq}/thousand USD)*	120.6	72.5	111.6	56.5	51.5	-
Carbon emission per capita *(kg-CO_{2eq}/capita)*	905.1	544.2	1,946.0	985.5	898.1	-
Industrial sector						
Energy intensity of GDP *(toe/million USD)*	121.7	96.6	119.8	88.4	87.4	-
Carbon emission intensity *(kg-CO_{2eq}/thousand USD)*	360.7	232.2	347.4	192.4	187.7	162.1
Carbon emission per capita *(kg-CO_{2eq}/capita)*	2,706.6	1,742.7	6,057.1	3,353.9	3,272.9	2,826.1

5. CONCLUSIONS

The objective of this study is to evaluate the long-term energy demand in the building sector and the industrial sector during 2005-2050 through the perspective of GHG mitigation potential by end-use approach. The GHG emission reductions in the building and the industrial sectors are analyzed by using the LEAP model. Policies considered in this study include the energy efficiency plan (EEP2015) and the alternative energy development plan (AEDP2015) of Thailand. Furthermore, this study also considers high efficiency technologies such as carbon capture and storage (CCS).

In the residential sector, total GHG mitigation will be 19.6 Mt-CO_{2eq} in 2050 which can be separated to 44.8% from the MIT1 scenario, 43.3% from the MIT2 scenario, and 11.1% from the MIT3 scenario. The highest GHG mitigation will be in the rural area followed by greater Bangkok and the municipal areas. GHG emissions will be reduced by 62.0 Mt-CO_{2eq} in the commercial sector which can be separated to 91.7% from the MIT1 scenario and 8.3% from the MIT2 scenario. Office buildings will reduce the most GHG emissions, followed by hospitals and hotels. Total GHG mitigation in the industrial sector will be 199.1 Mt-CO_{2eq} in 2050. The share of GHG reduction in the MIT1 scenario, the MIT2 scenario and the MIT3 scenario will share 81.6%, 2.4% and 16.0% of GHG mitigation, respectively.

This study confirms that the EEP2015 and the AEDP2015 plans in the MIT1 scenario will be effective plans to reduce not only energy demand but also GHG emissions in the building and the industrial sectors. Therefore, such reduction potentials will achieve the Thailand's INDC target. Advanced technologies in the MIT2 scenario will significantly reduce energy demand and GHG emissions. The deployment of biogas will significantly reduce the GHG emissions in the residential sector by 2050. CCS technologies will undoubtedly reduce GHG emissions from the non-metallic, papers and pulps and chemical industries by 2050. This study also analyses energy security, energy intensity, and carbon emission per capita. Results indicated that the implementation of energy policies and advanced technologies will substantially reduce emissions per capita. Emission intensity and emission per capita will be reduced in all scenarios, mostly in the MIT3 scenario due to the CCS technology in the industrial sector.

Results show that energy labeling will be the most desirable measure in energy demand reduction. However, the promotion of LED and EERS measures will slightly reduce the energy consumption. In addition, building energy code (BEC) and energy savings in designated buildings can significantly achieve the energy saving target in the commercial building in 2030. Monetary incentives will be an effective program to promote the energy efficiency improvement in the commercial and the industrial sectors. This paper also gives a clear policy implication. Policy makers should pay attention in energy labeling measure in the building sector and monetary incentive in the industrial sector. These effective measures could reduce energy demand and emissions. To induce the behavioral changes and energy technology innovation, the reinforcement of energy performance standards and the investment in research and development are recommended to accelerate the energy savings and emissions.

This study also shows that Thailand's NDC target in 2030 will be achieved by existing national energy plans. In addition, advance technologies need to be promoted and will help reducing substantial GHG emissions by 2050.

REFERENCES

[1] Intergovernmental Panel on Climate Change (IPCC), 2014. *Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change*. United Kingdom: Cambridge University Press.

[2] Cramer W., Yohe G.W., Auffhammer M., Huggel C., Molau U., Dias M.d.S., and Leemans R., 2014. *Detection and attribution of observed impacts, Climate Climate Change 2014: Impacts, Adaptation, and Vulnerability*. United Kingdom: Cambridge University Press.

[3] Shrestha R.M., Malla S., and Liyanage M.H., 2007. Scenario-based analyses of energy system development and its environmental implications in Thailand. *Energy Policy* 35(6): 3179-3193.

[4] Chunark P., 2014. *Impacts of Carbon Taxation and CO_2 Emission Reduction Targets in Thai Power Sector*. MS Thesis, ME-MS-2013-01. Sirindhorn International Institute of Technology, Thammasat University, Thailand.

[5] Office of Natural Resources and Environmental Policy and Planning (ONEP), 2018. *Thailand's third national communication*. Bangkok: ONEP.

[6] Department of Alternative Energy Development and Efficiency (DEDE), 2018. *Energy Balance of Thailand 2017*. Bangkok: DEDE.

[7] Park S., Lee S., Jeong S.J., Song H.-J., and Park J.-W., 2010. Assessment of CO_2 emissions and its reduction potential in the Korean petroleum refining industry using energy-environment models. *Energy* 35(6): 2419-2429.

[8] Pan L.J., Xie Y.B., and Li W., 2013. An analysis of emission reduction of chief air pollutants and greenhouse gases in Beijing based on the LEAP model. *Procedia Environmental Sciences* 18: 347-352.

[9] Ates S.A., 2015. Energy efficiency and CO_2 mitigation potential of the Turkish iron and steel industry using the LEAP (long-range energy alternatives planning) system. *Energy* 90: 417-428.

[10] Hong J.H., Kim J., Son W., Shin H., Kim N., Lee W.K., and Kim J., 2019. Long-term energy strategy scenarios for South Korea: Transition to a sustainable energy system. *Energy Policy* 127: 425-437.

[11] Zhang D., Liu G., Chen C., Zhang Y., Hao Y., and Casazza M., 2019. Medium-to-long-term coupled strategies for energy efficiency and greenhouse gas emissions reduction in Beijing (China). *Energy Policy* 127: 350-360.

[12] Emodi N.V., Chaiechi T., and Beg A.R.A., 2019. Are emission reduction policies effective under climate change conditions? A backcasting and exploratory scenario approach using the LEAP-OSeMOSYS Model. *Applied Energy* 236: 1183-1217.

[13] Chunark P., Limmeechokchai B., Fujimori S., and Masui T., 2017. Renewable energy achievements in CO_2 mitigation in Thailand's NDCs. *Renewable Energy* 114: 1294-1305.

[14] Pagnarith K. and B. Limmeechokchai. 2011. Renewable energy utilization and CO_2 mitigation in the power sector: A case study in selected GMS countries. *Songklanakarin Journal of Science and Technology* 33(3).

[15] Winyuchakrit P., Limmeechokchai B., Matsuoka Y., Gomi K., Kainuma M., Fujino J., and Suda M., 2011. Thailand's low-carbon scenario 2030: Analyses of demand side CO_2 mitigation options. *Energy for Sustainable Development* 15(4): 460-466.

[16] Winyuchakrit P., Limmeechokchai B., Matsuoka Y., Gomi K., Kainuma M., Fujino J., and Suda M., 2016. CO_2 mitigation in Thailand's low-carbon society: The potential of renewable energy. *Energy Sources, Part B: Economics, Planning, and Policy* 11(6): 553-561.

[17] Thepkhun P., Limmeechokchai B., Fujimori S., Masui T., and Shrestha R.M., 2013. Thailand's Low-Carbon Scenario 2050: The AIM/CGE analyses of CO_2 mitigation measures. *Energy Policy* 62: 561-572.

[18] Selvakkumaran S., Limmeechokchai B., Masui T., Hanaoka T., and Matsuoka Y., 2015. A quantitative analysis of Low Carbon Society (LCS) measures in Thai industrial sector. *Renewable and Sustainable Energy Reviews* 43: 178-195.

[19] Promjiraprawat K. and B. Limmeechokchai. 2012. Assessment of Thailand's energy policies and CO_2 emissions: analyses of energy efficiency measures and renewable power generation. *Energies* 5(8): 3074-3093.

[20] Energy Policy and Planning Office (EPPO), 2015. *Power Development Plan 2015–2036 (PDP2015)*. Bangkok: EPPO.

[21] Office of Natural Resources and Environmental Policy and Planning (ONEP), 2015. *Climate Change Master Plan 2015-2050*. Bangkok: ONEP.

[22] Energy Policy and Planning Office (EPPO), 2015. *Energy Efficiency plan 2015-2036 (EEP2015)*. Bangkok: EPPO.

[23] Energy Policy and Planning Office (EPPO), 2015. *Alternative energy devalopment plan 2015-3016 (AEDP2015)*. Bangkok: EPPO.

[24] United Nations Framework Convention on Climate Change (UNFCCC), 2015. *Thailand's Intended Nationally Determined Contribution (INDC)*

[25] Heaps C., 2008. An introduction to LEAP. *Stockholm Environment Institute*: 1-16.

[26] Nieves J., Aristizábal A., Dyner I., Báez O., and Ospina D., 2019. Energy demand and greenhouse gas emissions analysis in Colombia: A LEAP model application. *Energy* 169: 380-397.

[27] Beg A.R.A., 2019. A Techno-Economic and Environmental Analysis of Queensland's Transition Towards a Low Carbon Society. *Sustainability in Energy and Buildings 2018: Proceedings of the 10th International Conference in Sustainability on Energy and Buildings (SEB'18).* Springer.

[28] Limmeechokchai B. and P. Chaosuangaroen, 2006. Assessment of energy saving potential in the Thai residential sector: Long-range energy alternatives planning approach. *The 2nd Joint International Conference on "Sustainable Energy and Environment (SEE 2006).*

[29] Tanatvanit S., Limmeechokchai B., and Chungpaibulpatana S., 2003. Sustainable energy development strategies: implications of energy demand management and renewable energy in Thailand. *Renewable and Sustainable Energy Reviews* 7 (5): 367-395.

[30] Heaps C., 2012. Long-range energy alternatives planning (LEAP) system. *Somerville, MA, USA: Stockholm Environment Institute*.

[31] Intergovernmental Panel on Climate Change (IPCC), 2006. *2006 IPCC guidelines for national greenhouse gas inventories*.

[32] Department of Alternative Energy Development and Efficiency (DEDE), 2008. *Energy Balance of Thailand 2007*. Bangkok: DEDE.

[33] Office of The National Economic and Social Development Board (NESDB), 2016. *Thailand's population*. Bangkok: NESDB.

[34] Office of The National Economic and Social Development Board (NESDB), 2013. *Population projections for Thailand 2010-2040*. Bangkok: NESDB.

[35] Office of The National Economic and Social Development Board (NESDB), 2016. *National Income of Thailand 2014 chain volume measure*. Bangkok: NESDB.

[36] World Bank, 2016. *Coal Prices: Long Term Forecast to 2020*.

[37] World Bank, 2016. *Commodities Price Forecast*.

[38] World Bank, 2016. *Crude Oil Price Forecast: Long Term 2016 to 2025*.

[39] Energy Policy and Planning Office (EPPO), 2016. *Economic Data and Analysis*. Bangkok: EPPO.

[40] Department of Alternative Energy Development and Efficiency (DEDE), 2014. *Thailand energy statistics 2013*. Bangkok: DEDE.

[41] Department of Alternative Energy Development and Efficiency (DEDE), 2010. *Energy Balance of Thailand 2009*. Bangkok: DEDE.

[42] Department of Alternative Energy Development and Efficiency (DEDE), 2012. *Energy Balance of Thailand 2011*. Bangkok: DEDE.

[43] Thailand Board of Investment (BOI), 2013. *Thailand: Food Exports Soaring*. Bangkok: BOI.

[44] The Office of Industrial Economics (OIE), 2015. *Industrial Economic Conditions in 2015 and Outlook for 2016*. Bangkok: OIE.

[45] International Energy Agency (IEA), 2017. *Policy Pathway - Monitoring, Verification and Enforcement*. IEA.

[46] Yilmaz S., Majcen D., Heidari M., Mahmoodi J., Brosch T., and Patel M.K., 2019. Analysis of the impact of energy efficiency labelling and potential changes on electricity demand reduction of white goods using a stock model: The case of Switzerland. *Applied Energy* 239: 117-132. 2019/04/01/.

[47] Electricity Generating Authority of Thailand (EGAT). LabelNo5, Retrived 2018 from the Word Wide Web: http://labelno5.egat.co.th/new58/?taxonomy=language&term=en.

[48] Murphy L., Meijer F., and Visscher H., 2012. A qualitative evaluation of policy instruments used to improve energy performance of existing private dwellings in the Netherlands. *Energy Policy* 45: 459-468.

[49] Dongyan L., 2009. Fiscal and tax policy support for energy efficiency retrofit for existing residential buildings in China's northern heating region. *Energy Policy* 37(6): 2113-2118. 2009/06/01/.

[50] Intergovernmental Panel on Climate Change (IPCC), 2015. *Climate change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva, Switzerland: IPCC.