CO₂ MITIGATION IN POWER AND RESIDENTIAL SECTORS IN INDONESIA AND THAILAND: ANALYSIS OF RENEWABLE ENERGY AND ENERGY EFFICIENCY IMPROVEMENT

BY

TRI VICCA KUSUMADEWI

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
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APRIL 2016
Abstract

CO₂ MITIGATION IN POWER AND RESIDENTIAL SECTORS IN INDONESIA AND THAILAND: ANALYSIS OF RENEWABLE ENERGY AND ENERGY EFFICIENCY IMPROVEMENT

by

TRI VICCA KUSUMADEWI


Power generation is an important factory to produce electricity which it supply energy demand in each sector. The electricity production is undesirable emission and environmental effects. The existence of carbon emissions can lead to climate change. Since 1992, climate change was a global issue that started to be a topic of conversation in the world while the oil price has been increased. Indonesia and Thailand have undergone expansion in their energy system to keep up with rapid economic growth. In both countries, the power sector is the largest CO₂ emitting sector. CO₂ mitigation in the power and residential sectors will influence greatly on national emissions. Dependency on fossil fuel has improved as a potential renewable energy for CO₂ mitigation in both Indonesia and Thailand.

Thus, long-term energy planning of energy supply and energy security is required. In this study, the Long-range Energy Alternative Planning (LEAP) package is used to forecast future demand by developing energy-environment scenarios which
are the business as usual (BAU), the renewable energy and the optimization scenarios, while reduction CO₂ emissions during 2010-2050. This thesis also presents energy efficiency improvement and CO₂ mitigation in the residential sector between Indonesia and Thailand. This study applied the Demand Side Management (DSM) options to reduce CO₂ emissions in the residential sector by implementing energy efficiency improvements such as efficient lighting, cooking, cooling and entertainment devices.

The result shows that renewable energy scenario has high potential to mitigate CO₂ emissions than optimization scenario for both Indonesia and Thailand. In fact, renewable energy scenario has the highest mitigation potential where it has cumulative CO₂ emissions reduction during 2010-2050 by 18.4% in Indonesian power sector when compared with the BAU while the figure relevant to Thailand is 12.76%. On the other hand, the cost value in the optimization scenario is lower than renewable energy scenario in both countries.

In addition, in energy efficient devices in the residential sector show that energy saving in the energy efficiency scenario in Indonesia is higher than the case of Thailand, it will be about 31% and 22.5%, respectively. In terms of energy saving, CO₂ emissions have reduced, while energy security has been positively affected by the policy in both countries. The cumulative CO₂ emission reduction in the residential sector in Indonesia and Thailand will be about 21.15% and 13.58% when compared to the BAU scenario.

Thus, it can be seen that the renewable energy scenario, optimization scenario and energy efficiency scenario can improve the sustainability in both power and residential sectors while achieving a significant reduction in CO₂ mitigation.

**Keywords:** LEAP models, CO₂ mitigation, optimization, power sector, residential sector, renewable energy, energy efficiency, Indonesia, Thailand
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Chapter 1
Introduction

1.1 Background and rationale

Energy security has been a global issue since the beginning of the 1970’s when the first oil crises occurred. Since then many developing/developed countries have been solved and concerned about energy security. Most literature supposes that energy security implies only the security of supply, and also postulates that if a country is an energy secure it implies that the country is made available with energy it requires, at a price which does not affect its economic performance, and with the least environmental impact.

One of the critical issues is the growth of fossil fuel utilities, most countries have to revise the plans and improve the sustainability of energy supply by using alternative energy sources. The country should use domestic power generation from coal, oil, natural gas, geothermal, hydropower, and biomass. This power generation purpose is to supply electricity in industry, residential and commercial sectors.

The renewable energy development is continuing to be made as construction and development the power plant such as geothermal, solar, wind, and nuclear power plants. The domestic energy resources especially renewable energy resource is very useful to developed power generation system and reduced CO\textsubscript{2} emission. Based on the level of energy consumption in economic sectors, the largest contributor to CO\textsubscript{2} emissions is the power sector due to the fossil fuel used for power generation with high carbon contents such as coal, oil, and gas, as well as the high demand for electricity than with non-electricity. Utilization of renewable energy power plants such as geothermal, solar, wind and biomass power plants is limited. It takes a commitment of the government to increase the share of renewable energy in forms of the formulation of appropriate policies and regulations. Feed-in tariff policy is already implemented in many countries to promote renewable or alternative energy. In Indonesia, it was estimated that 86% of the power come from the conventional resource, 9% from hydropower, 5% from geothermal and other renewable energy
resources to generate electricity in 2010. In contrast to Indonesia, Thailand power mainly comes from natural gas, oil, and coal. Fossil fuel was estimated at 93%. Most of the renewable power generation comes from hydroelectricity. It shares 5%. Other renewable sources include biomass and biogas share almost 2%.

However, CO\textsubscript{2} emissions also come from households because the residential sector used fossil fuel such as liquefied petroleum gas (LPG), and kerosene to meet the energy demand. Energy demand in the residential sector is used for cooking, lighting, cooling, heating, entertainment and other activities. The fossil fuel usually used for cooking and lighting in the rural area. In the urban area, people mostly used electricity.

Electricity is a basic form of energy in all sectors. The electricity production results in undesirable emission and environmental effects. The existence of carbon emissions can lead to climate change. Since 1992, climate change to be a global issue that started to be a topic of conversation in the world. A presidential regulation of the republic of Indonesia, law No. 6/1994 was ratified by Indonesia government regarding the work of United Nations Climate Change on the convention of climate change. It needs to maintain a stable concentration of greenhouse gasses (GHGs) and objective of the convention GHGs in the atmosphere thus ensuring food security and sustainable development [1]. The meeting resulted in the Kyoto Protocol regulating GHGs emissions due to human activities so that its concentration in the atmosphere is stable and will not be harmful to the earth's climate system. This protocol contains an obligation for developed countries called Annex I countries to reduce emissions by 5% from 1990 levels during 2008-2012 [2]. While developing countries are entering into the Non-Annex I countries, they are not obliged to reduce emissions such as Indonesia and Thailand. In Asia, several countries developed low carbon Asia research projects. The project will run in accordance with the country regulation for an Asia and national action plan for reducing CO\textsubscript{2}.

Indonesia had income growth rate of 6.10 % in 2010 and the GDP per capita of 2990 US$. Indonesian population has increased to 237.42 million people and they are living in 60.93 million households. With the total population, around 58% of Indonesian lived on the Java’s island, where the capital city Jakarta is a big city in this island.
which is the center of Indonesian political, industrial, commercials and networking. The population growth rate decreased during 1990-2000 by 1.49% to 1.34% during 2000-2010. It is projected that Indonesia’s population will exceed 423 million by 2050. In 2010, total energy consumption in Indonesia was 555 Mtoe whereas the total CO$_2$ emission was accounted for 433.99 Mt CO$_2$ in the same year.

When compared to Indonesia, Thailand has GDP growth only 0.1% in 2011 and decreased from 7.8% in 2010 due to the extensive flooding during the latter half of 2011. The Thailand government forecast its economy to grow by 5.5% in 2012 in anticipation of post-flood reconstruction and higher domestic demand. Thailand population has 66.4 million people and they spread living in 22.77 million households in 2010. Thailand population growth was 0.3 % in 2010. The capital city is Bangkok, which is the Thailand’s political, industrial, commercial, and networking. In 2010, total energy consumption in Thailand was about 91.7 Mtoe and total CO$_2$ emission was accounted for 295.28 Mt-CO$_2$ emissions in the same year.

To protect the world, Indonesian President has made a note about the use of energy based on the Kyoto protocol, Japan. In the statement, Indonesia has a national action plan known as national appropriate mitigation action (NAMA) program for concern on the environment. The program will be run in accordance with government regulation as a national action plan to reduce GHG.

The national action plan regulation was prepared as Indonesia’s commitment to follow up the emission reduction plan, presented by President of Republic of Indonesia at Pittsburgh, the USA on September 2009. The Indonesia government established a target of GHG emission reduction of 26%. It will be reduced below the business as usual (BAU) scenario by 2020 [3]. The national action aims to reduce GHG emissions, particularly in forestry, agriculture, energy sector, industrial sector, transportation sector and to serve as a guide on investment relating to coordinated GHG emission reduction at national and regional levels.

Thailand is classified into two types of the national action plan, which are domestic and internationally supported national plans. The domestic plan is the unilateral national plans. Their financing and implementation supported by Thailand government as the countermeasure in mitigation action generally have low investment
cost, energy management, and energy efficiency improvement. The international plan involves high investment cost and advanced technology countermeasures [4].

For future development, the preparation of long-term electricity supply planning in Indonesia and Thailand are taken into account. This perspective would deeply look into the electricity supply planning and indigenous potential of renewable energy capacity that will be available to develop for the next 40 years. In addition to developing the domestic resources in Indonesia and Thailand for energy supply, they should also notice related impacts on the environment. In the residential sector, energy efficiency improvement technologies to reduce CO\textsubscript{2} emissions include lighting, cooking, cooling and entertainment appliances.

1.2 Objectives

The objective of this study is to develop an alternative energy scenario which is considered on both demand and supply sides. These alternative energy supplies include oil, coal, natural gas, geothermal, hydropower and biomass energies for power generation. There are three main objectives.

1. To propose sustainable development in the power and residential sectors in Indonesia and Thailand.
2. To analyze CO\textsubscript{2} emissions in the power and residential sectors.
3. To compare energy security between Indonesia and Thailand.

1.3 Scope of the study

Regarding the objective of this study, the scope of the study can be presented as follows,

1. All alternative energy sources available in Indonesia and Thailand have been analyzed to investigate the impact on electricity production.
2. Electricity demand forecasting has been based on power development plan in Indonesia and Thailand.
3. Sustainable development in the residential sector to estimate energy demand analysis and CO₂ emission in addition to CO₂ mitigation includes four proposed measures as follows, (1) efficient lighting devices, (2) efficient cooking devices, (3) efficient cooling devices, and (4) efficient entertainment devices.

4. Data on energy market have been obtained from Energy information Administration (EIA), International Energy Agency (IEA), World Bank, Ministry of Energy and Mineral Resources (MEMR) of Republic of Indonesia, Agency for Assessment and Application of Technology (BPPT) of Republic of Indonesia, National Electricity Company (PT. PLN Persero) Republic of Indonesia, Census and Statistic Department (BPS) of Republic of Indonesia, Electricity Generating Authority of Thailand (EGAT), Department of Alternative Energy Development and Efficiency of Thailand (DEDE), Census and Statistic Department of Thailand.

5. The planning time period for this study was from 2010-2050.

6. The analysis tool is the long-range energy alternative planning (LEAP) model.

1.4 Organization of the thesis report

The content of rest of the thesis is organized as follows, Chapter 2 presents the literature review, which presents the relevant information about Indonesia and Thailand, and presents the relevant work carried out; Chapter 3 presents the research methodology, which presents the models and scenarios; Chapter 4 presents the LEAP models; Chapter 5 presents the country background; Chapter 6 presents the results of Indonesia in the power and residential sectors; Chapter 7 presents the results of Thailand in the power and residential sectors; Chapter 8 presents the comparison result between Indonesia and Thailand; and Chapter 9 finally presents the conclusions.
Chapter 2
Literature Review

2.1 Energy and Carbon Emissions

Energy is an important thing for life. Many people use energy to fulfill their energy demand. Primary energy production and consumption increased because of increasing energy demand. Primary energy production includes oil, petroleum, natural gas, coal, and renewable energy such as paddy husk, coconuts cover, sugar cane, etc. Non-renewable energy sources are petroleum, coal, and natural gas. All are used in everyday life, in industry, and in power generation, and transportation. The threat that energy source will be depleted causing many scientists trying to find alternative energy sources. The renewable energy sources are currently being developed is biogas from animal manure, biomass, hydropower, geothermal, wind, and solar.

In 2010, total primary energy supply (TPES) in the world was 12,890.81 Mtoe while Indonesian total primary energy supply was 209.43 Mtoe. According to the international energy administrations (IEA) statistics [5], TPES in Indonesia is increased by 28% from its consumption in 2000. The Indonesian government estimates that TPES in 2050 will reach 1,000 Mtoe with the rapid growing economy as well as the energy consumption grows at around 7% per year. The dominant source of energy is oil accounted for 38% of the TPES in 2010 while the share of oil represented 35% in 2011. The Indonesian government has set a target to reduce the share of oil to 25% by 2025, 23% in 2030 and 20% in 2050. Natural gas also plays an important role, its share in TPES country represented 17% in 2011. According to the government plans, the consumption of natural gas is considered more than doubled from 35 Mtoe in 2010 to be 88 Mtoe in 2025. The share of coal was limited to be less than 9% until the early 2000s. However, coal consumption has increased. Its share reached 15% in 2011. This is expected to increase in medium and long-term due to its increasing consumption in power generation. Traditional biofuels and waste have become one of the dominant energy sources, representing 25% in 2011.
Due to the use of oil dominated in primary energy supply, the governments have plans and given priority to follow the key policies: minimizing the consumption of petroleum fuels, maximizing the utilization of renewable energy, optimizing the utilization of natural gas, arrangement of coal as the core of the national energy supply and regulation of nuclear energy as the last option. With regard to renewable energy, the Indonesian government considers geothermal and hydropower as renewable sources that are most important to be enhanced in power generation according to the high geothermal and hydro potential in Indonesia. Nuclear energy is considered as the last energy resource in its policy. There is no concrete plan to build nuclear power plants in Indonesia. The country would maintain subsidies on fossil fuels and electricity, spending about USD 18 billion just on fuel subsidies in 2012, which is accounted for nearly 20% of the governmental budget. The use of oil fuel continues to rise as well as a problem for their subsidized fuel prices. Production of crude oil continues to decline while demand needs growing will lead to an increase in imports crude oil and fuel. This presented a challenge as well opportunities to develop other energy sources as a substitute the oil fuel.

In 2010, primary energy supply in Thailand is around 117.43 Mtoe with a growth rate of 6.74% per year. The final energy consumption by sectors as transportation, industrial, residential and agriculture sector about 70,562 ktoe with a growth rate of 5.35% per year [6]. Three most energy consuming sectors are transportation, industry, and power, respectively. Energy consumption in this sector is very large because the majority is used petroleum.

The final energy supply in Indonesia is dominated by fossil fuel sources such as oil, natural gas, and coal which contribute up to 75% share of the final energy consumption. The government and the energy society concern that the fossil fuel sources would be reduced in the near future and increase in CO₂ emissions. On the other hand, renewable energy sources have not been optimized and improved due to its high production cost. Subsidy policy on fossil discourages the use of renewable energy fuel [7].

The utilization of renewable energy is still relatively minor. Several things that inhibit the development of renewable energy among others are high investment cost, minimal
incentives and the persistence of price subsidies for fuel. Financing system to encourage the development of renewable energy sources such as reduction of subsidies, feed-in tariff need to be developed and implemented. The use of fossil energy at current consumption levels will result in resources discharged quickly. This not only leads to dependence on oil but also increasing greenhouse gas emissions. CO₂ emission mitigation is the demanding challenge to reduce CO₂ emissions and others GHG gasses due to its high fossil energy consumption. Indonesia is the fourth biggest country in terms of population. Indonesia is also the candidate to become among the most important carbon emitters from energy consumption [8]. With the same case, Thailand also facing a challenge in energy-environment-economy development in the context of limited energy resources availability and global climate change. CO₂ emissions is generated from various sectors is not directly proportional to the total energy needs. In commercial, industrial, and transport sectors, which rely on fossil fuels, CO₂ emissions will be very high. While in the household sector the use of biomass results in lower CO₂ emissions because CO₂ emissions from biomass combustion are not taken into account at sustainable harvesting.

Based on primary energy demand, global CO₂ emissions were 31.7 Gt-CO₂ in 2012 [9]. It represents emissions increasing rate of 1.2% per year, about half of the average annual growth rate since 2000, and 4% less than in 2010. Emissions in non-Annex I countries increased by 3.8% while emissions in Annex I countries decreased by 1.5% in 2012. In absolute terms, global CO₂ emissions increased by 0.4 Gt-CO₂ in 2012, driven primarily by increased emissions from coal and oil in non-Annex I countries. Figure 2.1 present CO₂ emissions between Annex I and Non-Annex I countries [9].
Global GHG emissions in the atmosphere are carbon dioxide (CO$_2$), Methane (CH$_4$), Nitrous oxide (N$_2$O), and Fluorinated gasses. Fossil fuel utilization is the primary source of CO$_2$ emissions. Deforestation, improvement of soils, and other activities on land are important sources of CO$_2$ emissions. Agricultural activities, waste management, and energy use contribute to CH$_4$ emissions. Uses of fertilizer are the primary source of N$_2$O emissions. The industrial process, refrigeration, and air-conditioners contribute to F-gases emissions, which include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF$_6$) [10].

2.2 Low Carbon Society

The low carbon society (LCS) concept is the low carbon mitigation process. To shift towards a low-carbon country, mitigation efforts must occur across all countries in the world as decarbonising energy supplies of industrialized countries and developing countries in a low-carbon development path. The Kyoto Protocol is the first commitment of developed countries to reduce their domestic emissions about 5% relative to 1990 during 2008-2012.
All countries have to take action based on the carbon minimization in all sectors toward simpler lifestyles and coexistence with nature. In order to minimize CO$_2$ in all sectors, it has to utilize clean energy i.e. using renewable energy to replace fossil fuels and promoting a low-carbon lifestyle in the residential and commercial sectors such as energy efficiency improvement of appliances in green buildings and behavior change.

In Asia low-carbon research project, there are two LCS scenarios. The LCS for Japan is called Japan scenario and Japan local scenario [11]. Indonesia had LCS vision scenario 2050 especially for the energy sector, which includes associated actions and policies. The scenario developed about socio-economic, energy and associated carbon emissions.

The path of sustainability a low carbon economy is a minimum output of gas emissions in the economic system to improve the quality of life and removing poverty in order to protect the world for the present and future generations. The odds are in three areas with the great potential for energy efficiency, low carbon energy supply, and terrestrial carbon. Revealing the potential is a big challenge, but immediate actions through a strong framework of policies, technology innovations, and human consciousness will make it happen. The delay will lead to disaster.

The low carbon economy decision-making system is established and simulation models based on the analysis of the relations between the complex of low carbon economy and dynamic feedback system. The technical and policies have a significant impact on reducing carbon emissions that are to raise the level of consumption and enhance the social welfare. Industrial policies will reduce GHGs emission without changing the national economy [12].

There are several actions considered to reducing CO$_2$ emissions such as introducing clean energy in the residential and commercial sectors, low carbon lifestyle in the commercial and residential sectors, low carbon electricity in the power sector and low carbon fuels in industry and sustainable transportation [13]. In addition to policy initiatives, most of the above actions will still need policy measures to support the implementation of these actions. The actions to support the implementation of government plans are increasing the share of renewable energy and fuel switching from oil to natural gas in Indonesian electricity supply development plan (RUPTL). It
will lead to the formulation of the national master plan on energy efficiency, policies to support mass rapid transit development, diversification of fuels (CNG, LPG, biofuel, electricity) in the transport sector, monitoring, and control of local emission and combustion efficiency that has implication to CO₂ emissions.

In addition, the behavior of low carbon economy will be introduced to minimize the externality cost in the long-term electricity expansion planning. The hidden cost of a power plant in Indonesia and Thailand (using LEAP based on the Business as usual (BAU) scenario is found that the government plans to increase the use of coal in the power sector provides a significant increase in emissions. Climate and health damage also increase proportionally with increasing emissions. Then the damage is converted to the external effect monetary units or external cost. The LCS action is introduced and applied a comprehensively clean energy source, energy saving, and energy efficiency. It could reduce emission from the power plant and external cost.

The Thailand government plans to become a low carbon society in 2030 through increasing efficiency improvement in all economic sectors by using renewable energy and energy efficiency. Recent studies had examined the effect of energy use and GHG emission mitigation targets on economy and energy system using Computable General Equilibrium (CGE) model. The CGE model is the top-down energy model for analysis economic implications of climate change [14].

Indonesia is in the progress of conducting technical studies on low carbons development strategy. The progress made is emission reduction opportunities and policies in the manufacturing and industrial sector. The low carbon development options will prove clean environmental management, reduction of emissions, and energy efficiency is compatible objectives that are essential to the sustainability of the country development path [15].

2.2.1 CO₂ Mitigation

Indonesia and Thailand are non-Annex I countries in the Kyoto protocol. They have no responsibility to reduce GHG emissions. In both countries, CO₂ mitigation focuses
on reducing fossil fuels utilities such as in the power and residential sector switch to non-fossil fuels or renewable energy.

Mitigation conducted to obtain a certain level of emissions to replace the existing technologies with new technologies. Mitigation of emissions is an important effort in helping direct determination of activity that goes on decreasing GHG emissions. Technologies for greenhouse gas mitigation can be grouped into two categories: supply side and demand side. Actions on the supply side are using a more efficient conversion system, shifting from high carbon fuels to low carbon fuels, and increasing the use renewable energy. Actions on the demand side are demand side management (DSM), and the use of more efficient equipment.

One of the national plans to reduce CO$_2$ emission in Indonesia and Thailand called Nationally Appropriate Mitigation Action (NAMA). This NAMA program was established to reduce CO$_2$ emission in energy, residential, industry, and transportation. Developing countries contribute voluntary efforts in NAMA to reduce emissions within sustainable development context [16]. On January 2010, Indonesian had been submitted NAMA to UNFCCC. The CO$_2$ mitigation program including sustainable peatland management such as reduced CO$_2$ in the rate of deforestation and land degradation; promotion of energy efficiency such as in the residential, commercial, industrial, and transport sectors; development of alternative and renewable energy sources in the power sector; and shifting to low-emission modes in the transport sector.

In 2011, CO$_2$ emissions in Thai residential and building sectors are 7,222 kt-CO$_2$. It increased due to advanced technology in the power supply [17]. The analysis of low carbon scenario in the residential sector named “Thai style comfortable houses”. This study included efficiency improvement in lighting, heating, cooking, cooling, entertainment, and other devices [18].

CO$_2$ mitigation with advanced technology was applied in Indonesia. The focus of GHGs mitigation measures is to reduce consumption of fossil fuels. In the residential sector, the options were considered includes lighting, cooking, and cooling. The mitigation includes substitution of electronic ballast for conventional ballast, substitution of compact fluorescent lamp (CFLs) for incandescent light, substitution
of a solar home system for kerosene lamp, substitution of LPG stoves for kerosene stove, and substitution of efficient refrigerators and air conditioners [19].

In Switzerland, the GHG mitigation in the residential sector used reference building models. The model is established to describe the dynamics of energy-relevant properties of the residential building stock, starting at existing building stock in 2000. The heat demand per area stock is assumed to depend only on the year of the last renovation of the building [20]. Building technologies model has set target for energy efficiency improvement. Japan has an evaluation mitigation measures by energy efficiency to reduce CO$_2$ emission [21]. The end-use model was used to simulate nationwide energy consumption of the residential sector until 2025. The end-use model explicitly considers a change in technology and service levels. Energy demand for each activity depends on two factors: the level of activity and energy intensity. Recently there are many energy researches in Japan with the energy projection up to 2050.

Beijing used econometric models to forecast and analyze emission reduction. They analyzed possible effects of different policies on energy saving and emission reduction [22]. Under different scenarios, the emissions of pollutants will be reduced through increasing energy savings. Econometric models were used to estimating energy consumption and pollutant emissions.

To reduce CO$_2$ emission in the residential sector, the Middle East and North Africa (MENA) countries used renewable energy deployment simulation scenario in power generation [23].

Mexico’s National development plan using LEAP model to develop energy policy with the goal of low carbon strategies [24]. The plan provides a wide selection of the economic analysis of low-carbon for mitigation of greenhouse gas emissions in Latin America, the largest consuming fossil fuel country. The Copenhagen climate plan [25] was also examined by LEAP. It showed that the target is optimistic and the city will reduce CO$_2$ emissions by 20% between 2005 and 2015. The ultimate goal is to become the first carbon neutral capital in the world by 2025.
2.3 Co-benefits of Greenhouse Gases Mitigation

Co-benefits are the additional benefits that we get when we take action to control climate change, above and beyond the direct benefits of a more stable climate. Co-benefits are sometimes referred to as the multiple benefits or synergies and excluding the direct benefits of climate policy arising from a more stable climate.

Co-benefits of mitigation might be important decision criteria in analyzed by policymakers. The co-benefit approach is a strategy that aimed to capture both development and climate benefits in a single policy or measure. The terms of co-benefits appeared in the academic literature in the 1990s and generated wider interest around the time of the Third Assessment Report (AR3) of the Intergovernmental Panel on Climate Change (IPCC) published in 2001 [26]. The IPCC AR3 distinguished co-benefits or the intended positive side effects of a policy from ancillary benefits or unintended positive side effects.

Climate co-benefits refer to the global climate change benefits of development plans or sectoral policies and measures [27]. This view on co-benefits emerged in response to the belief that developing countries would focus on climate plans as well as its co-benefits.

Co-benefits of GHG mitigation can be defined as effects that are additional to direct reductions of GHG and impacts of climate change and have estimated to be large, relative to the costs of mitigation [28]. There are local air pollution benefits from pursuing greenhouse gases emissions mitigation policies, which lower the net costs of emission reductions and thereby may strengthen the incentives to participate in a global climate change mitigation agreement.

The large and diverse potential range of collateral benefits that can be attributed to climate change mitigation policies in addition to the direct benefits of avoided climate impact. In the process of controlling greenhouse gases other pollutants are also abated (SO\textsubscript{2}, NO\textsubscript{X}, and PM) [28]. Policy makers tend to look at issues such as climate change. If all the co-benefits are taken into account, there is usually a stronger case for climate action. For example, the health benefits of clean air can exceed the cost of climate action. In developed countries, the health benefits of low-carbon lifestyles are
greater than the benefits of avoided air pollution. Co-benefits may help to persuade the general public desire for climate action, especially those who do not accept that climate change is a serious problem. While the benefits of addressing climate change are difficult to measure, and may accrue especially for people in other countries and for future generations, the benefits of cleaning up the air in local town much quickly.

### 2.4 Energy Security

Energy security started after the oil shock in the beginning of the 1970’s. Energy security was associated with the effort to avoid oil supply disruption. The concept and definition of energy security continued to corporate environmental and social acceptability issues. (APERC, 2007), the definition of energy security as the ability of an economy to guarantee the availability of energy resources supply in a sustainable manner with energy price will not adversely affect the performance of the economy [29]. In the APERC report, there are three fundamental elements of energy security:

1. Physical energy security: the availability and accessibility of supply resources
2. Economic energy security: the affordability of resource acquisition and energy infrastructure development
3. Environment sustainability: the sustainable development and energy resources utility.

Definition of energy security by EIA [30] is the uninterrupted availability of energy sources at an affordable price and has many aspects. Long term energy security was the focus with economic developments and environmental needs and short-term energy security focus with the ability of the energy system. Some countries emphasize the sense of resilience and energy security as the availability of energy at affordable prices as the definition from EIA. Its definition is a difference because each country has its attention and different problems.

The general terms of energy security had been developed and can be divided into two terms. First, energy security is the availability of energy in sufficient quantities and at affordable prices. This understanding evolved in the period from the 1970s to 2000s. Secondly, energy security translates to a broader, namely sustainability of energy and
ease of access in the use of energy sources. An aspect of the environment is also a concern that the policy began to move to not only for new reserves of conventional energy but also to innovate clean and renewable energy utilization.

2.5 Energy Model

Energy models related with the energy system. Energy model has become the tool for energy system analysis. Energy model used for organizing data and providing a framework to investigate a variety of conditions energy systems such as energy economy interactions, energy policies, strategic changes and environmental impact mitigation action. Various energy models have been developed to assist in energy planning. The model is based on econometric many used to make projections of energy requirements, while for energy supply strategy, optimization techniques used by a certain objective function. Besides that, the recursive models are based on the equilibrium of demand and energy supply by adjusting pricing parameters.

Since the energy system forecasting and energy security were received paramount importance in the global energy regime, a number of energy models were developed in order to analyze alternative scenarios of energy systems [31]. Since then a variety of models were developed to accommodate different requirements that emerged due to changes in the global energy situation.

2.5.1 Accounting and Optimization Models

Energy accounting and optimization models are widely uses, software-based models. Optimization model typically uses linear programming to identify energy systems that provide the least-cost means of providing an exogenously specified demand for energy services. Optimization is performed under constraints such as efficiency, availability of technology, energy demand and supply data, emissions, cost, etc. Energy accounting framework describes the energy system, costs, and environmental impacts. Accounting framework is simple, transparent and flexible, lower data requirement, capable of examining issues that go beyond technology choice. It may be hard to cost and especially useful in capacity building applications.
Market allocation (MARKAL) is one of example software for energy optimization model. The Technology Assessment and Development Agency of Republic of Indonesia (BPPT) was using MARKAL to forecast the energy system. BPPT developed the database system, which also incorporated the output from MARKAL ASEAN for the regional gas market with assumed that there is no coal import. The result is identified the optimal national energy mix under least cost consideration. MARKAL was used to forecast CO$_2$ emission mitigation during 1995 to 2025 [32]. The mitigation scenario was analyzed to investigate the impact of limiting future CO$_2$ emission from the energy system. The focus of mitigation is to reduce fossil fuel utilization and change to non-fossil fuels (renewable energy) for the residential, the industrial, the commercial and the power sectors.

The accounting models such as MEDEE, Model for Analysis of Energy Demand (MAED) and Long-range energy alternative planning (LEAP) are popular tools. These tools are the model for long-term energy demand evaluation. MEDEE and MAED models were developed initially by Chateau and Lapillonne (1978) [33]. MEDEE and MAED designed to evaluate the long-term energy demand of a country, in combination with a scenario description of the main aspects of the country's social, economic, and technological evolution. MAED described above is essentially derived from the MEDEE model. Thus, the modeling approach remains the same but the development of the two products has taken different paths in the recent times.

MAED follows the end-use demand forecasting steps typical for an engineering economic model. It depends on the systematic development of consistent scenarios for the demand forecasts considered by socio-economic and technological factors. Through scenarios, MAED specifically captures structural changes and evolution in the end-use demand markets and does not use pricing and elasticity information for the inter-fuel substitution as is common in the econometric tradition.

Computable General Equilibrium (CGE) model was developed by Robinson and El-Said. The model is divided into five blocks as follows, the price, quantity, the reception, expenditure and the boundaries of the macro-economy system. CGE can be applied to analyze the impact of electricity tariff hikes to the household sector. In, addition, development of CO$_2$ mitigation in Thailand with Asia-pacific integrated
model (AIM) and computable general equilibrium (CGE) was a developed method with socio-economic assumptions [14]. The models deal with all payments recorded in the socio accounting matrix, which has been modified from input-output table and relevant data. In this models, the structure consist of four blocks i.e. production, income distribution, expenditure, and market. The AIM/CGE model can be categorized as a recursive dynamic model. The model access capital, labor, and technological improvement through total factor productivity and autonomous energy efficiency improvement factors.

In most cases, basic conceptual frameworks of these models were formulated using theoretical and analytical methods. LEAP includes a technology and environmental database that provides information on the technical characteristics, costs, and environmental impacts of hundreds of energy technologies. The quantitative data included in this database is automatically incorporated into LEAP. The database also includes information on the availability, appropriateness, and cost-effectiveness of these technologies.

LEAP can be used to forecast and analyze demand of certain energy type. The analysis of gas energy development was forecasted by LEAP in Bangladesh [34]. In this publication, the result indicates that logistic estimation produced more accurate in energy forecasting but use the linear approach is a better way to do this forecasting.

In electricity system, LEAP analyzes and forecast the expansion plan in the generating system. For example power generation in Java-Madura-Bali Indonesia [35]. This paper explains the expansion of power plant based on user-defined capacity addition. Then LEAP calculates endogenously the need of power plant capacity to meet the demand of electricity used three scenarios.

In Java-Madura-Bali Indonesia, LEAP was used to analyze optimization plan by developing geothermal and hydropower potential [36]. The electricity forecasting plan analyzed by calculating the addition of power plant capacity is based on the optimization calculation. The optimization module is a built-in tool in LEAP software and based on the least-cost system in power plant expansion. Thus, LEAP tries to find the minimum combined cost of power plant expansion and their capacity to meet the demand of electricity in the scenarios.
Chapter 3
Methodology

This study of energy planning and policies starts from the forecast of energy demand in Business as usual (BAU) scenario. Then, energy supply to meet the demand is estimated. The power generation system is optimized with renewable energy resources in the LEAP model. In the residential sector, LEAP is used to analyze energy efficiency improvement of appliances. The methodology of this research study can be best described by the flow diagram given in Figure 3.1:

Data Sources:
Statistical Reports
Research Papers
Official Government Plans and Online Data

Data collection

Energy models for power generation
Formulate renewable energy scenario
Energy consumption
CO₂ emissions and other emissions
Cost of Energy
Conclusion

Energy models for residential sector
Formulate energy efficiency scenario

Figure 3.1. Flow diagram of the research methodology.
The major steps of the methodology include data collection, scenario development, energy modeling and analysis, final energy consumption and CO₂ emissions, which are pointed out in the flow diagram.

3.1 Data Collection

This section presents the list of socio-economic, residential and power sector data and sources from which they were collected. They are given separately for Indonesia and Thailand in following sub-sections.

3.1.1 Local sources - Indonesia

The necessary data needed for the research to be undertaken various sources and government of Indonesia. Data required for modeling the Indonesia power and residential sector was mainly from a national report published by Ministry of Energy and Mineral Resources (MEMR) of Republic of Indonesia and other government departments. In addition, some power plants and residential energy consumption data were collected from research papers. The required data are as follows:

- Socio-economic data
  1. World bank – population and GDP database
  2. Census and Statistic Department of Indonesia – population growth database and electricity used

- Sector-specific data
  1. Ministry of Energy and Mineral Resources (MEMR) of Republic of Indonesia – energy sector database
  2. National Electricity Company (PT. PLN Persero) of Indonesia – power plants and electricity data
  3. PT. Pembangkit Jawa-Bali and PT. Indonesia Power – power plant data and electricity data
  4. BPPT – publication power and residential energy used data and Indonesian energy policy planning
  5. Published papers – power and residential data
6. Energy information Administration (EIA) – energy and CO₂ emission database
7. International Energy Agency (IEA) – energy and CO₂ emission database
8. IPCC (2006) – CO₂ emission factors of fuels

3.1.2 Local sources - Thailand

Data required for modeling Thailand power and residential sectors were mainly from a national report published by Department of Alternative Energy Development and Efficiency (DEDE) Thailand and other government institutes. In addition, some power plant and residential energy consumption data were collected from published research papers. The required data are as follows:

- Socio-economic data
  1. World bank – population and GDP database
- Sector-specific data
  1. Department of Alternative Energy Development and Efficiency (DEDE) Thailand – energy sector database
  2. Electricity Generating Authority of Thailand (EGAT) – power plant and electricity database
  3. Technology database for low carbon Thailand toward 2050 – power plant data and energy service in the residential sector
  4. Published thesis reports – power and residential data
  5. Energy information Administration (EIA) – energy and CO₂ emission database
  6. International Energy Agency (IEA) – energy and CO₂ emission database

3.2 Scenario development

In this study, two scenarios were carried out. They are business as usual (BAU) scenario and countermeasure (CM) scenario.
3.2.1 BAU scenario

In the BAU scenario, energy demand and energy supply are estimated and forecasted as traditional planning approach and frozen technologies. In this study, the business as usual scenario starts from 2010 as the base year. Energy system will be modeled without any policy interventions. First, energy system of the base year 2010 will be modeled using the reported data and then existing energy consumption trends will be projected till the end of the planning period which is 2050. The BAU scenario may include projections up to 2050 for the economic development (e.g., income, access to improve water sources), energy demand and supply, land use, and carbon emissions. The efficiencies and availability factors of power generation technologies for Indonesia are shown in Table 3.1 and in Table 3.2 for Thailand.

Table 3.1. Efficiency and availability factor of power generation in Indonesia

<table>
<thead>
<tr>
<th>Power generation</th>
<th>Efficiency</th>
<th>Availability factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydropower</td>
<td>100 %(^1)</td>
<td>96.39%(^1)</td>
</tr>
<tr>
<td>Steam power</td>
<td>40.25 %(^1)</td>
<td>82.88%(^1)</td>
</tr>
<tr>
<td>Combine cycle power</td>
<td>46.05 %(^1)</td>
<td>89.67%(^1)</td>
</tr>
<tr>
<td>Gas turbine power</td>
<td>23.99 %(^1)</td>
<td>87.86%(^1)</td>
</tr>
<tr>
<td>Diesel power</td>
<td>65 %(^2)</td>
<td>60.94%(^2)</td>
</tr>
<tr>
<td>Geothermal power</td>
<td>100 %(^2)</td>
<td>93.04%(^2)</td>
</tr>
<tr>
<td>Solar power</td>
<td>100 %(^3)</td>
<td>99%(^3)</td>
</tr>
<tr>
<td>Wind power</td>
<td>100 %(^3)</td>
<td>98%(^3)</td>
</tr>
<tr>
<td>Gas engine power</td>
<td>29.64 %(^3)</td>
<td>85%(^3)</td>
</tr>
</tbody>
</table>

Sources: 
\(^1\)PT. Pembangkit Jawa- Bali (PJB) [37]  
\(^2\)PT. Indonesia Power (IP) [38]  
\(^3\)Technology Database for low carbon Thailand [39]
Table 3.2. Efficiency and availability factor of power generation in Thailand

<table>
<thead>
<tr>
<th>Power generation</th>
<th>Efficiency</th>
<th>Availability factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cogeneration power</td>
<td>31%(^1)</td>
<td>89.52%(^1)</td>
</tr>
<tr>
<td>Hydropower</td>
<td>100%(^1)</td>
<td>98%(^1)</td>
</tr>
<tr>
<td>Solar power</td>
<td>100%(^1)</td>
<td>99%(^1)</td>
</tr>
<tr>
<td>Steam power</td>
<td>40.25%(^1)</td>
<td>90%(^1)</td>
</tr>
<tr>
<td>Wind power</td>
<td>100%(^1)</td>
<td>98%(^1)</td>
</tr>
<tr>
<td>Combine cycle power</td>
<td>46.05%(^1)</td>
<td>85%(^1)</td>
</tr>
<tr>
<td>Gas turbine power</td>
<td>23.99%(^1)</td>
<td>75%(^1)</td>
</tr>
<tr>
<td>Gas engine power</td>
<td>29.64%(^1)</td>
<td>85%(^1)</td>
</tr>
<tr>
<td>Municipal solid waste (MSW)</td>
<td>28%(^2)</td>
<td>70%(^2)</td>
</tr>
</tbody>
</table>

Sources: \(^1\) Technology Data base for low carbon Thailand [39] \(^2\) VGB power tech

3.2.2 Countermeasure scenarios

This sub-section explains scenarios development in the power and residential sectors. In the power sector, there are two CO\(_2\) emission mitigation scenarios, namely renewable scenario and optimization scenario. In the residential sector, CO\(_2\) mitigation is with energy efficiency improvement based on energy service appliances utilization. Energy savings were developed to analyze CO\(_2\) mitigation potential of those policies in Indonesia and Thailand, and their impacts on the power and residential sectors. Separated sector of scenarios was formulated for each policy. Table 3.3 provides the scenarios development description in the power and residential sectors.
Table 3.3. Scenario development description

<table>
<thead>
<tr>
<th>Sector</th>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>Renewable energy</td>
<td>Renewable energy scenario considers renewable energy utilization for the power plant to reduce cost and CO$_2$ emissions.</td>
</tr>
<tr>
<td></td>
<td>Optimization</td>
<td>In optimization scenario for power generation system, the model uses assumptions of capacity endogenous of power plants. The potential power plans include renewable energy technologies to reduce CO$_2$.</td>
</tr>
<tr>
<td>Residential</td>
<td>Efficiency</td>
<td>Efficiency improvement scenario in the residential sector in the urban area. This scenario increased the efficiency of appliances of energy service in the residential sector such as lighting, cooking, cooling and entertainment devices.</td>
</tr>
</tbody>
</table>

3.3 Energy models

As mentioned in the scope of the study, the LEAP is the energy modeling tool for this study. For both Indonesia and Thailand cases, modeling time was selected from 2010-2050. The base year is 2010. This sub-section provides the details of scenarios that will be modeled to analyze energy saving and carbon emission reduction potential of selected energy sectors between Indonesia and Thailand. Each sector will be analyzed for its low carbon potential of existing and new mitigation measures and CO$_2$ emission reduction potential will also be examined.

3.3.1 Power Sector

The power sector is modeled by using LEAP. This study develops scenarios thru LEAP for analyses of power plants with the low cost and low CO$_2$ emissions. Basic
modeling steps in the LEAP tool are provided by the flow diagram given in Figure 3.2.

For both countries, the base year is 2010. The planning horizon expands until 2050. Firstly, the business as usual (BAU) scenario is a reference scenario. The power generation systems include steam power plants, combined cycle power plants, diesel power plants, gas turbine power plants, gas engine power plants, hydropower, solar power plants, wind power plants, geothermal power plants and waste power plants. The energy conversion between the power plants considered in the model and their input and output, for Indonesia shown in Figure 3.3, and for Thailand is shown in Figure 3.4.
Figure 3.3. Electrical energy conversion in Indonesia.
Figure 3.4. Electrical energy conversion in Thailand.
Based on the economic perspective, the technology mix was selected in the BAU scenario. In the renewable energy scenario, the solution is based on country plans and in optimization scenario it is based on low-cost energy system. Efficient technologies, such as hydropower, geothermal power, solar power and wind power will be added in this scenario.

**Renewable Energy Scenario**

The objective of this scenario is to reduce electricity generation cost and CO₂ emission when compared with the BAU scenario. Renewable power plants are considered as fixed system and dispatched up to the limit of maximum availability and given a priority to renewable energy power plants according to the country plans. In the renewable energy scenario, the endogenous capacity is added. Table 3.4 presents additional endogenous capacity of renewable energy scenario.

<table>
<thead>
<tr>
<th>Type</th>
<th>Additional size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geothermal power</td>
<td>50 MW¹</td>
</tr>
<tr>
<td>Hydropower</td>
<td>50 MW</td>
</tr>
<tr>
<td>Wind power</td>
<td>5 MW</td>
</tr>
<tr>
<td>Solar power</td>
<td>5 MW</td>
</tr>
<tr>
<td>Steam power</td>
<td>300 MW¹</td>
</tr>
<tr>
<td>Combine cycle</td>
<td>300 MW¹</td>
</tr>
<tr>
<td>Gas turbine</td>
<td>100 MW¹</td>
</tr>
</tbody>
</table>

Source: ¹[35]

**Optimization scenario**

Linier programming usually use for optimization models to identify energy system that provides the least cost manner to provide exogenous demand for energy service.
Optimization scenario has constraints such as availability of technology, supply energy be equal to energy demand, limited emissions, maximum capacity added, etc.

### 3.3.2 Model for residential sector

The residential sector is divided by two subsectors, and by area. The subsectors are urban and rural areas. Each sub-sector consists of 4 service categories which are lighting, cooking, cooling and entertainment. The services are provided by each service categories shown in Figure 3.5. This study considers the CO₂ mitigation potential in the residential sector. The model will select between the types of appliances in order to satisfy the service demand and minimize the energy use of a scenario including energy efficiency improvement.

**Energy efficiency improvement**

In the residential sector, the energy efficiency improvement is the replacement of existing technology energy devices with higher efficiency based on the data currently available on the market. The four mitigations include in the scenarios are efficient lighting devices, efficient cooking devices, efficient cooling devices and efficient entertainment devices. Each service category in the residential sector is composed of several services. The details are shown in Figure 3.5. The lists of technology appliances are shown in Figures 3.6 to 3.11.
Figure 3.5. The structure of energy services in the residential sector.
Figure 3.6. Energy flows in the lighting devices.

Figure 3.7. Energy flows in the cooling devices.
Figure 3.8. Energy flows in the cooking devices.
Figure 3.9. Energy flows in the entertainment system.

End-Use devices

Electricity → TV CRT → Television
Electricity → TV LCD
Electricity → TV LED
Electricity → Radio
Electricity → Video
Electricity → Computer

Figure 3.10. Energy flows in the heating system.

End-Use devices

Electricity → Water heater → Water heating
Electricity → Iron → Ironing

Figure 3.11. Energy flows in the other devices.

End-Use devices

Electricity → Washing machine → Washing
Electricity → Water pump → Water pumping
Electricity → Other devices → Others
The proposed efficient technologies are to acquire energy saving and CO₂ mitigation during 2010-2050. Regarding the proposed penetration rates of particular technology as follows:

**Lighting devices**

Lighting is the most important device to reduce energy use in the residential sector. This study proposed the utilization of light emitting diode (LED) lamp to replace compact fluorescent lamps (CFLs), and CFLs to replace fluorescent lamp (FL) and incandescent lamp (IL). The options considered include:

- In 2030, the conventional lighting appliances are fully replacing
- Within 2030 and 2050, CFLs would share 40% and 70% of total lighting activities.
- Within 2030 and 2050, LED would share 40% and 80% of total lighting activities.

**Cooking devices**

In 2030, the conventional cooking appliances are fully replacing with more efficient appliances.

**Cooling devices**

Refrigerator and air conditioner are important cooling devices used in the cooling system. Their electricity use is growing rapidly. This study proposed high-efficiency cooling devices to replace conventional devices. The options considered include:

- Improvement of refrigeration performance.
- Improvement of air conditioning (AC) efficiency, in the cooling system.

**Entertainment devices**

In the residential sector, television is the most used devices as entertainment. The television utilization considered reducing energy use. This study proposed more efficient appliances to replace conventional appliances such as light emitting diode (LED) television to replace liquid crystal display (LCD), cathode ray tube (CRT), and plasma display panel (PDP) television. The option to reduce energy use in an efficient
entertainment system is the conventional television. In this study, the entertainment devices are fully replaced with more efficient appliances by 2030.
LEAP (Long-range Energy Alternatives Planning) is a tool that can be used to create the model of energy system where can trace energy consumption, energy production and energy resource extraction in all sectors of an economy. LEAP is a widely used software tool for energy policy analysis and climate change mitigation assessment. LEAP was originally created in 1980 for the Kenya project, and then developed by Stockholm Environment Institute (SEI) [40]. In 2011, LEAP has included the optimization calculation for power generation system.

LEAP is performed business as usual scenario (BAU) by describes the development of an energy system without any additional energy or climate policies implemented. LEAP model simulated the behavior of consumers and producers under energy price, income, gross domestic product (GDP), technologies, policies, population, etc. The model tends to be complex and data intensive. In addition, the behavioral relationship can be controversial to parameterize and forecast energy scenario in future. LEAP facilitates medium to long term modeling of different emissions scenarios as well as comparison and analysis of these scenarios to assess their energy requirements, environmental impacts, and social costs and benefits. Different reduction policies or options may be modeled separately or as part of an integrated framework. LEAP can be used as a database for baseline and historical data; as a forecasting tool for modeling future energy supply and demand; and as an analysis tool that can compare options and feed into target-setting and strategic plan development. LEAP can be applied in the local, national and regional system. [41] Its scenarios are based on comprehensive accounting under range assumption.

LEAP can perform multiple types of analysis, including demand analysis which is end-use energy consuming activities models analysis, transformation analysis which is the conversion and transportation of energy from its extraction through its final consumption, models analysis, resource analysis which is a dynamic database of the resources used to fuel the activities in the demand category, and environmental
analysis which models environmental loadings such as GHG or pollutant emissions for all devices in the demand analysis and all fuels in the transformation analysis. Cost-benefit analysis capabilities (based on the social cost of resources) are included, as are non-energy related effects (waste and refrigeration equipment emissions). LEAP calculation flow diagram [41] is presented in Figure 4.1.

![LEAP Calculation Flow Diagram](image)

Figure 4.1. LEAP calculation flow diagram.

The reserve margin is defined before the addition of endogenous capacity as follow:

\[ RM_{BA} = \frac{(MC_{BA} - PR)}{PR} \]  \[\text{Eq. 4.1}\]
Where,

\( RM_{BA} \): reserve margin before additions

\( MC_{BA} \): module capacity before additions (total of (capacity \( \times \) capacity value)) in MW

Endogenous capacity values are used to reflect existing capacity as well as planned capacity additions and retirements. The endogenous capacity before addition required is calculated as follow:

\[ EC_{BA} = (PRM - RM_{BA}) \times PR \]  \[\text{Eq. 4.2}\]

The planning reserve margin is used by LEAP to decide automatically when to add additional endogenous capacity. The LEAP will add sufficient additional capacity to maintain the planning reserve margin on or above the set values. Planning reserve margin [42] is defined as follows:

\[ PRM = \frac{(MC-PL)}{PL} \times 100\% \]  \[\text{Eq. 4.3}\]

Where,

PRM: planning reserve margin (%)

MC: module capacity (total of (capacity \( \times \) capacity value)) in MW

PL: peak load (MW)

Exogenous capacity values are used to reflect existing capacity as well as planned capacity additions and retirements while endogenous capacity values are those which are internally calculated by LEAP in order to maintain a minimum planning reserve margin. Peak system requirements on the module are calculated as functions of the total energy requirement and the system load factor.

\[ PR = \frac{ER}{LF \times 8760} \]  \[\text{Eq. 4.4}\]

Where,

PR: peak requirement (MW)

ER: energy requirement (MW hours)

LF: load factor
Therefore, endogenous capacity additions are calculated for each process by cycling through the processes listed on the endogenous capacity. In each year, the capacity will continue to be added in the specified amount until the amount is greater than equal to the endogenous capacity additions required.

Energy demand projection has two mains energy planning based on econometric and end-use (engineering model). Econometric model based on econometric activities and end-use model based on technological changes [43]. Energy consumption forecasted by econometric model could be referred as a dependent variable where GDP and population be selected as an explanatory variable. An econometric model would have the form as follow:

\[ D_i(t) = a + \sum_{j}^{m} b_{i,j} \cdot X_{i,j}(t) \]  

[Eq. 4.5]

Where,

\( D_i(t) \): energy consumption in sector \( i \) at time period \( t \)

\( a \): constant

\( b_{i,j} \): the coefficient to be determined for sector \( i \) and exploratory variable \( j \)

\( X_{i,j}(t) \): the level of activity for explanatory variable \( j \)

Since the econometric model provides the explicit relationship between dependent variable and explanatory variable, it might have help in understanding why changed of energy consumption is occurring.

In the end-use model, energy demand for each activity of the product depends on two factors: activity level and energy intensity. A summation of all the product activity accounted to the total energy demand. So, the total energy demand in each sector can be expressed by:

\[ E = \sum_{i=1}^{n} Q_i \cdot I_i \]  

[Eq. 4.6]

Where,

\( E \): Total energy use

\( Q_i \): Quantity of energy service \( i \)
\( I_i \): Energy use per unit of energy service \( i \)

The energy use per unit of energy service \( i \) can be reduced by technology energy efficiency improvement. The quantity of energy service \( Q_i \) depends on several factors, including the population, the share using the end-use service, and the extent of use of each service. Therefore, the quantity of energy service \( i \) as follow:

\[
Q_i = N_i \cdot P_i \cdot M_i \quad \text{[Eq. 4.7]}
\]

Where,

\( Q_i \): quantity of energy service \( i \)

\( N_i \): number of customers eligible for end-use \( i \)

\( P_i \): penetration (total units/total customers) of end-use service \( i \) (can be > 100%)

\( M_i \): magnitude or extent of use of end-use service \( i \)

The total of electricity demand in the residential sector is the summary of the electricity demand of household end-use services such as cooking, lighting, cooling, heating, television use, electric devices, etc. The electricity demand in the residential sector can be defined as follow:

\[
E_R = \sum_{i=1}^{n} E_{R_i} \quad \text{[Eq. 4.8]}
\]

Where,

\( E_R \): residential energy use

\( i \): end-use devices

Each end-use can have a specific expression followed by substituting from the equation 4.6, 4.7 and 4.8. The electricity consumption in residential sector following projection equation:

\[
E_{R_i} = N_i \cdot P_i \cdot M_i \cdot I_i \quad \text{[Eq. 4.9]}
\]

Where,

\( E_{R_i} \): residential energy consumption for end-use \( i \)

\( N_i \): the total number of households with end-use \( i \)
$P_i$: the penetration levels of appliances for end-use $i$

$M_i$: the number of hours. Degree-days or frequency of use for energy service $i$

$I_i$: the intensity of the end-use $i$

Residential energy requirements vary across income classes. Eq. 4.10 can also be derived for each income class. In this case, the total residential energy demand would be given as:

$$E_R = \sum_{i=1}^{n} R_{i,j}$$  \hspace{1cm} \text{[Eq. 4.10]}

Where,

$i$: end-use

$j$: income class

However, LEAP can be considered as the suitable tool to analyze the environmental impact of Thailand and Indonesian energy system. LEAP is developed to analyze GHG emission mitigation options in the world. LEAP capable of analyzing the emission gasses varying such as CO, CO$_2$, CH$_4$, NO$_x$, SO$_2$, and F-gasses, etc. LEAP has been used for Thailand and Indonesia energy system analysis in previously studies.
Chapter 5
Country Background

5.1 Indonesia socio-economic and Energy data

In the Southeast region, Indonesia is a large archipelago country which has almost 17,508 large and small islands, and about 6,000 islands, of which are uninhabited, which spread around the equator and has a tropical climate. The position of Indonesia is located at 6° North latitude to 11° South latitude of 95° to 141° East longitude. Indonesia has a unique geographical position and strategic [44]. It can be seen from Indonesia’s geographical location between two oceans, the Indian Ocean, and the Pacific Ocean. Geographical location of Indonesia is between two continents: Asia and Australia/Oceania.

The official census in 2010 recording the population of Indonesia was 237,424,363 people living spread in Sumatra, Java, Kalimantan, Sulawesi, Maluku and Irian Jaya islands. The population density is accounted by 123.76 people per square kilometer (323.05 per square mile). In Indonesia, around 58% of total population people live on Java islands, the most populous island in the world [45]. Indonesia had an income growth rate of 3.5 % in 2010 and the GDP of 539.352 Billion US$, lower 5.72 percent than the growth rate in the previous quarter.

5.1.1 Primary and Final energy consumption

Fossil fuel is the main fuel energy supply in Indonesia. Although Indonesia has a big potential of renewable energy playing a great role in the energy supply, Indonesia still heavily depends on fossil fuels. Provision of basic energy demand of renewable energy is an appropriate option with relatively many islands in Indonesia especially isolated islands and regions. The government of Indonesia projects the primary energy supply with the share of renewable energy growing at a current rate of 4.3% to 17% in 2025, with renewable energy playing an increasingly important role, particularly for geothermal power and biofuels [46].
The first form of energy found in nature which has not undergone any energy conversion or transformation process called primary energy. Primary energy actually is the energy contained in the raw fuels, and other forms of energy that are received as input to the system. Primary energy can be non-renewable energy or fossil fuel as oil, natural gas, coal and renewable as geothermal, water, solar, the wind, biomass, etc. The primary energy consumption of Indonesia can be shown in Figure 5.1. The primary energy shares by oil/petroleum: 30%, coal: 22%, natural gas: 19%, and biomass (including renewable energy): 29% [5].

Figure 5.1. Total Indonesian primary energy consumption in 2011.

The form of energy that is available to the user with the energy conversion and transformation process of primary energy called final energy. The final forms of energy are including gasoline or diesel, jet kerosene, fuel oil, purified coal, briquette, ceramic & cement, purified natural gas, LPG, LNG, electricity, mechanical energy, etc. The final energy consumption by type during 2000-2011 can be shown in Table 5.1 [45].
The shares of final energy consumption by types and by sectors can be shown in Figure 5.2 and 5.3. Shares of final energy consumption by types in 2011 were 47.6% for crude oil, 20.7% for natural gas, 18.95% for coal, and 12.8% for electricity. Power generation was produced by hydropower, geothermal, gas turbine, combined cycle, steam power, diesel and renewable energy. Shares of energy consumption by sectors were 42.91% for the industrial sector, 11.60% for the household sector, 4.44% for the commercial sector, 37.68% for the transportation sector, and others.
In 2011, the final energy consumption by sectors in Indonesia was accounted for 43% for industry, followed by transportation (38%), households (12%), commercial buildings (4%), and others (3%).
5.1.2 Energy consumption in the residential sector in Indonesia

Electricity in the residential sector is mainly used for lighting, space air conditioning, and other electronic equipment while thermal energy is used for cooking. Currently, domestic energy demand, excluding biomass, is dominated by electricity, followed by LPG and kerosene. The government projection is expected to be different from current conditions due to subsidy policy on LPG and kerosene. In the residential sector, energy demand mainly comes from petroleum products such as LPG and kerosene [3].

Energy demand in the residential sector is still dominated by the use of biomass because most of the Indonesian households are in a rural area with low purchasing power. Residential energy consumption, besides kerosene and outside the biomass in the last 11 years has increased each year. In terms of growth, type of household energy experience rapid growth is LPG, electricity and natural gas growing at the annual average of 17%, 7%, and 3%. The type of energy experiencing decreasing need is kerosene (decreasing at an average of 15% per year). LPG demand in the future is expected to continue to increase because it is promoted by government.

Uses of fossil fuels increase CO₂ emissions. Therefore, the action of CO₂ mitigation in the residential sector considered in this study includes replacement of conventional appliances with efficient electronic appliances. The actions include the replacement of conventional fluorescent lamps with the efficient electric lamps, substitution of compact fluorescent lamps incandescent lamps, substitution of solar home system for kerosene lamps, improving refrigeration efficiency, improving the efficiency of air conditioning system, and substitution of kerosene stove to LPG and natural gas stove [47].

5.1.3 Indonesia power sector

Electricity generation in Indonesia is under state authority and conduct by PLN. In 2011, electricity was generated by 183,419 GigaWatt hours (GWh) from PLN 142.74 GWh and Independent Power Producer (IPP) 40,679 GWh [48]. Indonesia has estimates installed capacity in 2011 by 44 GW and electricity generation by 192
billion kWh according to BPS (main statistic organization in Indonesia) [5]. Energy International Agency (EIA) estimates that 86% of power comes from the conventional resource, 9% comes from hydropower, 5% comes from geothermal power and remaining from other renewable energy resources (see Figure 5.4).

Until now, energy sources in the power sector in Indonesia is dominated by coal, gas and oil, both owned by PLN and private or IPP [48]. The role of renewable energy is limited to geothermal and hydropower, while the use of solar power, wind power and biomass are still very small. The total electricity generation by renewable energy in 2011 was 21.8 TWh or about 12% of the total electricity supply. Coal-fired, gas and oil became the foundation of PLN in electricity generation, and accounted for 80% of the total electricity generation. The rest is contributed by renewable generation and purchased power.

![Figure 5.4. Electricity generation of EIA in 2011.](image)

The government of the Republic of Indonesia has taken a commitment to increase the share of renewable energy uses in the form of the formulation of appropriate policies and regulations. This regulation is one of the actions to reduce CO₂ emission resulting from the fossil fuel uses. The Government has issued various regulations to encourage utilization of renewable energy. The feed-in tariff policy is already implemented in many countries to promote renewable or alternative energy. The feed-in tariff is a
policy mechanism imposition of tariffs designed to encourage the use of renewable energy sources.

The electrification ratio in Indonesia reached approximately 72.95% in 2011. The electrification ratio indicates a high-level comparison of the number of people who use electricity with a total population of a region or country. The electrification ratio is highly correlated with the level of economic development in a region. Indonesia including in the ranks of countries with an electrification ratio is below world average, Project Steam Power (power plant) finally became the government's solution to increasing the national electrification ratio which increased national economic growth. On the other hand, the 1st project is filled with the use of fossil fuel i.e. coal which is not quite friendly to the environment. With their commitment to the use of renewable energy, the government wants to increase the use of geothermal in the 2nd project. The power generation by sources in Indonesia can be seen in Figure 5.5.

![Power generation by sources in Indonesia in 2011.](image)

The actual sales of PLN's powers in 2011 were 157.99 TWh, and growing at a rate of 6.5% over the last ten years [49]. From the customer side of the electricity, in the same year, 94% of total electricity sales recorded sold for the residential, industrial and commercial sector.
By the end of the first quarter of 2011, the residential sector was the largest electricity consumer at the consumption of 15248.77 GWh, followed by the industry (13063.96 GWh), business customers (6726.23 GWh), and others (2358.98 GWh). The share of electricity consumption by sector can be seen in Figure 5.6.

![Electricity consumption by sectors in 2011.](image)

The optimization electricity production for electricity supply is based on the renewable energy power generation from geothermal and hydropower [36]. The developed scenarios are based on Gross Regional Domestic Product, population and electricity intensity.

### 5.1.4 Emissions

GHG emissions will cause global warming to causing climate change. It requires in an integrated and consistent handling of both producers and energy consumer. To be able to perform precise handling and effectively the necessary data availability greenhouse gas emissions of the energy sector in more detail based on various types of energy used. The increase in GHG emissions can be reduced if the use of renewable energy can be maximized. Indonesia is one of the CO₂ emitters in the world. It generated emissions by 1.79 Gt-CO₂ in 2005. The emissions mainly come from forest fuels, agriculture, industry, and waste incineration [1]. In 2011, total CO₂ emissions come from fuels combustion and fugitive emissions, and accounted 511 million tons CO₂.
equivalent [50]. In 2011, the refinery produces 12.84 million tons of CO₂ emissions and 25.27 million tons of fugitive emissions, or 2.54% and 5.0% of the national total CO₂ emissions, respectively. CO₂ emissions produced by various sectors are not directly aligned with the total energy demand. Three largest emitters of CO₂ emissions in Indonesia come from power plants, the transportation, and industry because most of the energy demand used premium gasoline and diesel. Then CO₂ emission will be high. CO₂ emissions from the residential, commercial, and other sectors are relatively limited due to the low consumption of fossil energy. While the residential sector which uses biomass, the CO₂ emissions will be low because emission from biomass is not taken into account. CO₂ emissions that taken into account include oil refinery sector and fugitive emissions from the production and distribution of fossil energy. CO₂ emissions calculations are carried out in accordance methodologies under the 2006 IPCC guidelines. In the preparation of an inventory of GHG emissions, the IPCC encourages the use of data which is based on the publication of official government institutions. CO₂ emissions by sectors in Indonesia in 2011 are presented in Figure 5.7.

Figure 5.7. CO₂ emissions by sectors in Indonesia in 2011.
5.2 Thailand socio-economic and energy data

Thailand is the largest country under the Mekong river with a total area of approximately 513,000 km\(^2\), with a population around 65 million. The population rose with an average annual growth rate of 1.12% during 1981-2005 [51]. The capital city is Bangkok, where the political, industrial, commercial and cultural centers there. Thailand is the country in the center between Cambodia, Laos, Myanmar and Malaysia.

Thailand is the second largest economy in the Association of South East Asian Nations (ASEAN) [51]. Thailand experienced rapid economic growth between 1985 and 1996 to the newly industrialized country and a major exporter. Manufacturing, agriculture, and tourism are leading economic sector. GDP of Thailand grew only 0.1% year over year in 2011, decreasing from high growth of 7.8% in 2010 due to the global economic recession and extensive flooding during the latter half of 2011. The Thailand government expected the economy to grow by 5.5% in 2012 after the post-flood reconstruction and higher domestic demand [52].

5.2.1 Primary and final energy consumption

More than 80% of total energy consumption in Thailand used primary energy consumption from fossil fuels. In 2010, oil was accounted for 39% of total energy consumption. Thailand mainly consumed oil for the transport sector and industrial sector. The condition of energy consumption has undergone changed, the use of natural gas has been replaced by high oil demand. Solid biomass and waste have comprised approximately 16% of total energy consumption. Most of the biomass feedstock derived from sugarcane, rice husk, bagasse, wood waste, palm residue, and are used in the residential and manufacturing sectors. In order to develop clean energy, Thailand promotes biomass for heat and electricity generation [6]. As a robust Nation based on agriculture, a by-product of agricultural such as rice, sugar, palm oil, timber and another agricultural commodity of Thailand is the greatest potential to produce electricity from biomass.
Table 5.2. Primary commercial energy production in Thailand

<table>
<thead>
<tr>
<th>Year</th>
<th>Hydro</th>
<th>Lignite</th>
<th>Natural Gas</th>
<th>Condensate</th>
<th>Crude oil</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>1,305</td>
<td>5,184</td>
<td>17,519</td>
<td>2,378</td>
<td>2,899</td>
<td>29,285</td>
</tr>
<tr>
<td>2001</td>
<td>1,368</td>
<td>5,640</td>
<td>17,039</td>
<td>2,355</td>
<td>3,090</td>
<td>29,492</td>
</tr>
<tr>
<td>2002</td>
<td>1,632</td>
<td>5,689</td>
<td>17,812</td>
<td>2,440</td>
<td>3,771</td>
<td>31,344</td>
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<tr>
<td>2003</td>
<td>1,597</td>
<td>5,254</td>
<td>18,627</td>
<td>2,846</td>
<td>4,807</td>
<td>33,131</td>
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<tr>
<td>2004</td>
<td>1,306</td>
<td>5,610</td>
<td>19,402</td>
<td>3,106</td>
<td>4,280</td>
<td>33,704</td>
</tr>
<tr>
<td>2005</td>
<td>1,256</td>
<td>5,983</td>
<td>20,554</td>
<td>3,156</td>
<td>5,684</td>
<td>36,633</td>
</tr>
<tr>
<td>2006</td>
<td>1,761</td>
<td>5,336</td>
<td>21,100</td>
<td>3,418</td>
<td>6,435</td>
<td>38,050</td>
</tr>
<tr>
<td>2007</td>
<td>1,764</td>
<td>4,912</td>
<td>22,553</td>
<td>3,581</td>
<td>6,716</td>
<td>39,526</td>
</tr>
<tr>
<td>2008</td>
<td>1,540</td>
<td>4,793</td>
<td>24,984</td>
<td>3,867</td>
<td>7,203</td>
<td>42,387</td>
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<td>2009</td>
<td>1,543</td>
<td>4,715</td>
<td>26,819</td>
<td>3,811</td>
<td>7,688</td>
<td>44,576</td>
</tr>
<tr>
<td>2010</td>
<td>1,185</td>
<td>4,950</td>
<td>31,484</td>
<td>4,026</td>
<td>7,644</td>
<td>49,289</td>
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<tr>
<td>2011</td>
<td>1,758</td>
<td>5,992</td>
<td>32,116</td>
<td>3,822</td>
<td>6,987</td>
<td>50,675</td>
</tr>
</tbody>
</table>

In 2011, the production of primary commercial energy can be shown in Figure 5.8.

Figure 5.8. Thailand primary commercial energy production in 2011.
In 2011, in the primary energy production, natural gas is the highest produced by 63% of total energy production. Following the chart of Thailand primary energy production, crude oil was produced by 14%, lignite by 12%, condensate by 8%, and hydro by 3%. Primary energy consumption can be shown in Table 5.3 and Figure 5.9.

Table 5.3. Primary Energy consumption in Thailand

<table>
<thead>
<tr>
<th></th>
<th>Hydro/import electricity</th>
<th>Lignite</th>
<th>Natural gas</th>
<th>Petroleum</th>
<th>Imported coal</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>2000</td>
<td>1,560</td>
<td>5,274</td>
<td>18,997</td>
<td>28,967</td>
<td>2,611</td>
<td>57,409</td>
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<td>2001</td>
<td>1,616</td>
<td>5,691</td>
<td>21,488</td>
<td>27,964</td>
<td>3,087</td>
<td>59,846</td>
</tr>
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<td>2002</td>
<td>1,874</td>
<td>5,872</td>
<td>23,344</td>
<td>29,403</td>
<td>3,495</td>
<td>63,988</td>
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<tr>
<td>2003</td>
<td>1,811</td>
<td>5,129</td>
<td>24,776</td>
<td>31,123</td>
<td>4,438</td>
<td>67,277</td>
</tr>
<tr>
<td>2004</td>
<td>1,596</td>
<td>6,007</td>
<td>25,931</td>
<td>34,361</td>
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<td>28,240</td>
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<td>2007</td>
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<td>80,044</td>
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<tr>
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<td>1,780</td>
<td>5,077</td>
<td>32,426</td>
<td>31,714</td>
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<td>80,971</td>
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<td>2009</td>
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<td>32,075</td>
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<td>82,974</td>
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<td>39,136</td>
<td>32,563</td>
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<td>88,981</td>
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<td>2011</td>
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<td>5,113</td>
<td>40,438</td>
<td>33,631</td>
<td>10,194</td>
<td>92,055</td>
</tr>
</tbody>
</table>

Figure 5.9. Thailand primary energy consumption in 2011.
In Thailand primary commercial energy consumption, petroleum was consumed by 36%, natural gas and liquid petroleum gas by 44%, lignite by 6%, imported electricity by 3% and imported coal by 11%. The total final energy commercial consumption in Thailand during 2000-2011 is presented in Table 5.4. Figure 5.10 presents the share of final energy consumption in Thailand in 2011. Petroleum product is the main source of energy (55%), followed by electricity (21%), natural gas (12%) and solid fossil fuels (12%) [6].

Figure 5.10. Thailand final energy consumption in 2011.
### Table 5.4. Thailand final energy commercial consumption

<table>
<thead>
<tr>
<th>Year</th>
<th>Solid fossil fuel</th>
<th>Petroleum Product</th>
<th>Total</th>
<th>Electric</th>
<th>NG in Industry</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coal</td>
<td>Lignite</td>
<td>Total</td>
<td>Premium</td>
<td>Regular</td>
<td>JP</td>
</tr>
<tr>
<td>2000</td>
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<td>1,776</td>
<td>3,058</td>
<td>2,127</td>
<td>2,553</td>
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</tr>
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<td>1,791</td>
<td>3,416</td>
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<tr>
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<td>1,995</td>
<td>2,148</td>
<td>4,143</td>
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<td>3,235</td>
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<td>1,313</td>
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<td>2,298</td>
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<td>2005</td>
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<td>6,189</td>
<td>2,750</td>
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<tr>
<td>2006</td>
<td>4,535</td>
<td>1,449</td>
<td>5,984</td>
<td>3,198</td>
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<td>2007</td>
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<td>2008</td>
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<td>4,303</td>
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<td>3,212</td>
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<tr>
<td>2010</td>
<td>7,047</td>
<td>962</td>
<td>8,009</td>
<td>4,781</td>
<td>2,166</td>
<td>3,360</td>
</tr>
<tr>
<td>2011</td>
<td>6,347</td>
<td>862</td>
<td>7,209</td>
<td>5,153</td>
<td>1,784</td>
<td>3,678</td>
</tr>
</tbody>
</table>

1 Including Power Generation from SPP
2 Preliminary data
3 Excluding LPG and Propane used as Feedstock in Petrochemical Industries
The final energy consumption by sector in Thailand is presented in Figure 5.11. In 2011, final energy consumed by petrochemical was accounted for 35%, followed by households (32%), transportation (24%), industries (8%) and others (1%).

![Figure 5.11. Thailand final energy consumption by sector in 2011.](image)

### 5.2.2 Energy consumption in the residential sector

Electricity in the residential sector is mainly used for lighting, cooling, cooking, heating and other equipment. In the residential sector energy consumption was 11,040 ktoe and accounted for 15.6% of final energy consumption in 2011. The rural area is the most energy consuming area, accounted for 76.7% of final energy consumption in the residential sector in 2011, followed by the greater Bangkok (14.1%), and municipal area (9.2%). The traditional renewable energy is the main fuel in the residential sector, accounted 56.3% of total energy consumption in the residential sector. The electricity consumption was 25.4% and consumption of petroleum products was 18.3% [6].

### 5.2.3 Thailand power sector

The electricity generating authority of Thailand (EGAT) is the power generation state-owned company and single electric transmission provider, which is accounted
for almost half of the power generation in the country [53]. Independent power producers (IPP) make up more than 35% of the generation mix. EGAT sells and transmits electricity to two authority wholesale distribution, the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA).

Thailand has an estimated installed capacity of 32.4 gigawatts (GW) in 2011. Natural gas-fired generation consists of more than 60% of the capacity mix, with coal and renewable energy. Thailand net electricity generation increased from about 90 TWh in 2000 to more than 152 TWh in 2011. The majority of renewable power generation from hydropower plants is 5% or more than 8 TWh, other renewable sources including biomass and biogas consist of almost 2% in 2011. To meet electricity demand, Thailand imports electricity from Laos to cover the shortfall. Therefore, other power plants should be built with three requirements: stability of production, environmentally friendly, and reasonable investment. 70% of electricity is generated by EGAT derived from natural gas that was obtained from the 22 natural gas wells offshore of the Gulf of Thailand. Although natural gas production increased, the natural gas requirement in the country is insufficient, forcing Thailand to import 25% of natural gas from Myanmar.

Thailand electricity generation by the resource in 2011 can be shown in Figure 5.12. [54]

Figure 5.12. Thailand electricity generation by source in 2011.
As the power sector share of natural gas has declined over the past decade [55], gas separation facilities are the second largest gas consumer group rising about 21% of the gas market in 2011. Since 1992, Thailand has plans to develop renewable energy while reducing energy dependence from outside. Minister of Energy plans to produce electricity from renewable energy around 25% of the total electricity output of the country for 10 years. Renewable energy target in 2014 will be boosted by 51% in 2021. The renewable energy in question includes biomass, biogas, solar, wind, hydropower and waste.

Government incentives granted to investors in order to encourage the use of renewable energy. Solar and wind energy potential is huge, but budgetary constraints and technology led to the beneficiary less than the maximum. Biomass potential is very promising as a source of energy is currently the largest as a consequence of the successful export of agricultural products to foreign countries. Waste agricultural products derived from wood, chaff/straw, leaves/bagasse, palm oil, corn cobs, and other agricultural products. Biogas derived from solid organic waste from municipal waste / agricultural products and liquid organic waste also deserves developed.

In addition, the Thai government would provide incentive and a special tax for renewable energy development so that investors will interest in renewable energy. Ministry energy has also initiated a feed-in tariff system for electricity generation. The feed-in tariff is a policy mechanism imposition of tariffs designed to encourage the use of renewable energy sources.

Electricity was mainly consumed by industries for 46%, followed by residential (22%), business (16%), small general service (10%), government and non-profit (3%), free of charge (2%), other (1%), and agriculture (less than 1%) (see Figure 5.13)
5.2.4 CO₂ emissions in Thailand

Generally, according to Intergovernmental Panel on Climate Change (IPCC) guidelines 2006 activities which generate GHG emissions consist of four parts, namely energy-based emissions, emissions from the production process and the use of products, land-based emissions, and emissions from waste. In 2011, CO₂ emissions mainly come from fuel combustion (37%), Transportation (30%), agriculture (22%), industrial process (7%) and waste management (7%) [56]. It is clear that CO₂ emissions in Thailand mostly come from fossil-fuel combustion.
Chapter 6
Results - Indonesia

This chapter presents modeling results obtained from LEAP. Results include energy consumption and CO₂ mitigation in Indonesia power and residential sector.

6.1 Power Sector

Results are presented of installed capacity, electricity share by plant type, cost analysis, and CO₂ emission mitigation.

6.1.1 BAU Scenario

In regards to Indonesia power sector, Figure 6.1 shows installed capacity in selected years in the BAU scenario. During the time span, total installed capacity in 2050 will increase 5.2 times when compared to the base year. In the base year, electricity generation was about 146,509.4 GWh. During the time span, total electricity will increase 8 times from the base year. Figure 6.2 shows total electricity demand in the BAU scenario.

![Figure 6.1. Installed capacity in BAU scenario in Indonesia.](image-url)
In the base year, 38.24% of the electricity generation came from steam power plants and 11.18% came from gas power plants. This share has increased further towards the end year since consumption of electricity demands change significantly with high growth rates of the steam power plant. Almost 86% of power generation comes from fossil fuel, 11% of hydropower and 3% of renewable energy. The capacity mix in the BAU scenario is shown in Figure 6.3.
In 2050, the capacity shares of steam power generate electricity by 118,618 MW (67.37%), gas turbine 38,236 MW (21.72%), combine cycle 8,481 MW (4.82%), diesel power 5,471 MW (3.11%), hydropower 3,880.8 MW (2.20%), geothermal 1,209 MW (0.69%), and gas engine 169 MW (0.1%), respectively.

6.1.1. Renewable energy scenario

Figure 6.4 shows the capacity mix in the renewable energy scenario. In 2050, steam power plants will have the highest amount of power capacity by 62,881.5 MW and share by 38.75% of total electricity generation. The second biggest power generation is the combined cycle plants with capacity of 49,790.3 MW (28.30%), followed by gas turbine plants: 21,521.6 MW (12.23%), geothermal plants: 10,242.8 MW (5.82%), hydropower plants: 9,783.9 MW (5.56%), wind power plants: 7,950.9 MW (4.52%), solar power plants: 7,501.2 MW (4.26%), diesel plants: 6,069.9 MW (3.45%) and gas engine: 169.5 MW (0.1%).

![Capacity mix (% share) vs. Years](image)

Figure 6.4. Capacity mixes in the renewable energy scenario in Indonesia.

In the renewable scenario, the growth of renewable energy power plant will help to reduce conventional power generation. In 2050, the steam power generation capacity
reduced by 47% when compared to the BAU scenario. In addition, the growth of renewable energy power plants which include wind, solar, and geothermal power plants had increased. In the same year, geothermal capacity will increase 9 times and hydropower will increase 2.84 times when compared with BAU scenario, respectively.

6.1.2 Optimization scenario

In the optimization scenario, the capacity of steam power will increase up to 10.5% when compared with BAU scenario. The capacity mix in optimization scenario is presented in Figure 6.5.

![Figure 6.5. Capacity mixes in the optimization scenario in Indonesia.](image)

The capacity requirement will increase to 272,577 MW in 2050, which is about 8-time increase when compared with the base year. Steam powers will have the highest amount of power generation capacity by 131,111 MW and shared by 48.1% of total electricity generation. The second largest power generation comes from gas turbine plants: 86,792 MW (31.84%), followed by combined cycle plants: 12,280 MW.
(4.51%), diesel plants: 10,090 MW (3.70%), hydropower plants: by 10,000 MW (3.67%), geothermal plants: 10,000 MW (3.67%), solar power plants: 6,000 MW (2.2%), wind power plants: 6,000 MW (2.2%), and gas engine power plants: 302 MW (0.11%). In the optimization scenario Indonesia still highly consumed coal, natural gas, and oil compared with renewable energy scenario while the renewable energy power plants will increase rapidly.

6.1.3 Cost analysis

In regards to Indonesian power generation plant, table 6.1 shows the total cost in each scenario which was analyzed by LEAP in the base year and selected eight years including the end year in the BAU scenario. During the considered time span, the total cost will increase about 21 times when compared with the base year.

Table 6.1. Total cost in all scenarios in Indonesia

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Total Cost (Trillion U.S. Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>BAU</td>
<td>12.3</td>
</tr>
<tr>
<td>Renewable</td>
<td>12.3</td>
</tr>
<tr>
<td>Optimization</td>
<td>12.3</td>
</tr>
<tr>
<td>Total</td>
<td>36.9</td>
</tr>
</tbody>
</table>

In 2050, the optimization scenario shows the highest cost when compared with the other scenario. The amount of total cost of power generation in renewable energy scenario is 289.8 trillion USD. The BAU scenario has cost about 261.7 trillion USD and the optimization scenario about 124.3 trillion USD. In the optimization scenario, total cost of production will decrease to 137.4 trillion USD (52.5%). In the renewable
energy scenario, the total cost of production will increase by 10.7% when compared to the BAU scenario, respectively.

### 6.1.4 Emissions

The purpose of this study is to present optimized power generation and minimized CO$_2$ emissions for the long term electricity generation planning in Indonesia. The total emissions were calculated by using the emission factors from Intergovernmental Panel on Climate Change (IPCC) [13].

The total CO$_2$ emission of each scenario is illustrated in Figure 6.6. In the BAU scenario, the CO$_2$ emission will increase up to 1041.3 million tons of CO$_2$ equivalent in 2050.

![Figure 6.6. Total CO$_2$ emission in all scenarios in power sector in Indonesia.](image)

In 2015, CO$_2$ emission will be reduced significantly in the renewable scenario approximately 280.1 million tons CO$_2$ emission will be reduced when compared to the BAU scenario. It is because of substitution of renewable energy sources for fossil fuels. CO$_2$ emission in the optimization scenario is the same level as in the renewable energy scenario. In 2050 CO$_2$ emission will be reduced by 133.2 million tons of CO$_2$
equivalent in the optimization scenario. CO$_2$ emission in the renewable and optimization scenarios will be reduced by 27% and 13%, respectively when compared to the BAU scenario.

Table 6.2 provides the cumulative emission of air pollutants in the BAU and counter-measure scenarios. Air pollutant CO$_2$ biogenic, CO, NO$_x$, and SO$_x$ are selected for the analysis. CO$_2$ biogenic emission is from biomass for the steam power plant. CO, NO$_x$, SO$_x$ emissions come from biomass, oil, natural gas, coal and diesel fuels.

Table 6.2. Other emissions in all scenarios in Indonesia

<table>
<thead>
<tr>
<th>Emission</th>
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<th>2030</th>
<th>2040</th>
<th>2050</th>
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<tr>
<td>BAU scenario</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$ biogenic</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
<td>1</td>
<td>1.8</td>
</tr>
<tr>
<td>CO</td>
<td>0</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>0.3</td>
<td>0.6</td>
<td>1</td>
<td>1.7</td>
<td>2.8</td>
</tr>
<tr>
<td>SO$_x$</td>
<td>1</td>
<td>1.5</td>
<td>3.5</td>
<td>6.7</td>
<td>7.2</td>
</tr>
<tr>
<td>Renewable scenario</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$ biogenic</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.6</td>
<td>1</td>
</tr>
<tr>
<td>CO</td>
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<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>NO$_x$</td>
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<td>0.6</td>
<td>0.9</td>
<td>1.4</td>
<td>2.2</td>
</tr>
<tr>
<td>SO$_x$</td>
<td>1</td>
<td>1.6</td>
<td>2.4</td>
<td>4.1</td>
<td>7</td>
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<tr>
<td>Optimization scenario</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO$_2$ biogenic</td>
<td>0.1</td>
<td>0.4</td>
<td>0.5</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>CO</td>
<td>0</td>
<td>0.1</td>
<td>0.4</td>
<td>0.8</td>
<td>1.8</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>0.3</td>
<td>0.9</td>
<td>1.8</td>
<td>3.7</td>
<td>7.3</td>
</tr>
<tr>
<td>SO$_x$</td>
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<td>2.4</td>
<td>3.4</td>
<td>4.5</td>
<td>4.5</td>
</tr>
</tbody>
</table>

According to the results, it can be seen that GHG mitigation actions can considerably reduce local air pollutant emissions. In the renewable scenario, a cumulative reduction of CO$_2$ biogenic, CO, NO$_x$, and SO$_x$ will be 36.11%, 14.29%, 15.63%, and 19.1%, respectively, when compared with the BAU scenario in 2050. Similarly, optimization
scenario also shows more considerable CO\textsubscript{2} mitigation, however, CO and NO\textsubscript{x} emissions had increased by 4.4 times and 2.19 times, respectively.

### 6.2 Residential Sector

In the residential sector, results are presented of total energy demand, fuel mix by appliance utilization, and CO\textsubscript{2} emission mitigation. Results of residential sector in the BAU scenario are compared with the energy efficiency scenario.

#### 6.2.1 Total energy demands in Indonesian residential sector

The residential sector is the third-largest sector which consumed energy after the industrial and transportation sector. Currently, the share of energy demand in the residential sector (except biomass) reached 13.4\%, while the shares of the industrial sector and transport sectors are 48\% and 30\% respectively (BPPT, 2010). Electricity consumption in the residential sector is for lighting, air conditioning, and other equipment while thermal energy is for cooking. Thermal energy mainly comes from burning kerosene, LPG, natural gas and wood in suburban and rural for cooking purpose.

The Indonesia energy demand in the BAU scenario will increase from 18,134.7 ktoe in the base year to 36,020.5 ktoe in 2050. In 2050, energy demand will increase about 2 times when compared with the base year. Trends of energy demand in the residential sector between the BAU and energy efficiency scenarios are presented in Figure 6.7.
In the energy efficiency scenario, the growth rate of energy demand is will be lower than the BAU scenario due to energy conservation efforts, particularly in the electricity consumption. In energy efficiency scenario, energy demand will be reduced by 31% when compared to the BAU scenario.

Figure 6.7. Total energy demands in the residential sector in Indonesia.

Figure 6.8. Technology mixes in Indonesian residential sector
The BPPT (The Assessment and Application Technology Agency) project in Indonesia has provided a roadmap of energy saving technologies such as substitution of LPG for kerosene, gas and efficient electric appliances [11]. Removal of kerosene and incandescent lamp with high efficient lighting appliances such as CFLs, LED, and improved air conditioners, refrigerators and TV, all of these will save energy by 25% in 2030 when compared with the BAU.

In the energy efficiency scenario, energy savings will be about 31% when compared with the BAU in 2050. Energy consumption in the conventional cooking and lighting devices will decrease because substitution of efficient devices such as biomass, kerosene, and wood for fossil fuels. Energy saving from cooking will be about 5502.9 ktoe in 2050. Total energy saving during 2010-2050 will be about 33%. The energy saving from lighting to replace lamp to the efficient lamp as well as CFLs and LED lamp will be about 52%. In energy efficiency scenario, shares of CFLs and LED lamp will be about 52% and 48%, respectively.

The energy efficiency scenario shows that shares of electricity, LPG, and natural gas will increase in 2050 (see Figure 6.9). In terms of growth, type of energy in the residential sector is experiencing rapid growth in LPG, electricity, and biogas. The type of energy is decreased consumption of kerosene, wood, and biomass. In
Indonesia during 2010-2050, the electricity consumption will increase by 43.82% when compared to the BAU scenario. In the energy efficiency scenario, the electricity consumption will decrease about 2,699 ktoe because of substitution of efficient devices when compared with the BAU. The consumption of LPG rapidly increases while kerosene consumption decreases as a result of fuel substitution program of the government.

**6.2.2 CO₂ Emissions in the residential sector**

GHG emissions had become an important parameter in national development in various sectors, including the energy sector. This projection has been carried out on the calculation of GHG emission trend in the energy sector, especially carbon dioxide (Figure 6.10).

![Figure 6.10. CO₂ emission in the residential sector in Indonesia.](image)

In the BAU scenario, energy demand in Indonesia comes from cooking, cooling, entertainment, and lighting devices. CO₂ emissions of electrified and non-electrified residential are accounted for 12,525.7 kt-CO₂ in 2010 and is expected to increase to 33,777.7 kt-CO₂ in 2050. CO₂ emissions will increase by 2.7 times during 2010-2050 in the BAU scenario. In the energy efficiency scenario, in 2050 CO₂ emissions will
increase by 2 times (from 12,525.7 kt-CO\textsubscript{2} to 25,978.6 kt-CO\textsubscript{2}). The cumulative CO\textsubscript{2} emissions reduction during 2010-2050 will be about 21% when compared to the BAU scenario.
Chapter 7
Results – Thailand

This chapter presents future energy consumption and CO\textsubscript{2} mitigation in Thailand power and residential sector.

7.1 Power sector

Results are presented of electric installed capacity, electricity share by plant types, cost analysis, and CO\textsubscript{2} emission mitigation.

7.1.1 BAU scenario

Figure 7.1 shows installed capacity in selected years in the BAU scenario. During 2010-2050, total installed capacity in Thailand will increase by 3.8 times from the base year. Electricity consumption was about 149,301 GWh in the base year. In 2050, total electricity consumption will increase to 722,283 GWh, and it is accounted for 4.8 times increase. Figure 7.2 shows total electricity demand in the BAU scenario.
In the base year, 51.72% of the electricity generation came from combined power plants, while 26.31% came from steam power plants. In terms of the generation mix, power generation mainly comes from fossil fuels (88%), hydropower (11%), and renewable energy (1%). The percent share capacity mix in the BAU scenario is shown in Figure 7.3.
In 2050, the required capacity will be 117,913 MW. Capacity mix in 2050 will be steam plants 73,585 MW (62.41%), gas turbine 22,209 MW (18.84%), combine cycle 16,091 (13.65%), hydro 3,488.1 MW (2.96%), cogeneration 2,427 MW (2.06%), gas engine 90 MW (0.08%), and MSW 12.5 MW (0.01%), respectively.

### 7.1.2 Renewable energy scenario

Figure 7.4 shows the capacity mix in the renewable scenario. In 2050, the capacity requirement will be 117,810 MW. Combine cycle generation will be the highest share of 49,578 MW (42.24% of total electricity generation). The second largest power generation shared comes from steam power plants 34,285 MW (29.10%), followed by gas turbine power plants 9,509 MW (8.07%), hydropower plants 7,838 MW (6.25%), MSW plants 4,362.5 MW (3.7%), solar power plants 4,357 MW (3.7%), wind power plants 3,953 MW (3.36%), cogeneration plants 3,613.5 MW (3.07%), and gas engine plants 134 MW (0.11%).

![Figure 7.4](image-url)  
**Figure 7.4.** Capacity mixes in the renewable energy scenario in Thailand.

In the renewable scenario, increasing renewable energy power plants will result in decreasing conventional power plants.
7.1.3 Optimization scenario

The capacity mix in the optimization scenario can show in Figure 7.5.

![Figure 7.5. Capacity mixes in the optimization scenario in Thailand.](image)

In 2050, the capacity grows up to 158,015 MW, 5.7 times increased when compared with the base year. Gas turbine will be the highest amount of power generation capacity by 50,000 MW and shared by 31.64% of total electricity generation. The second largest power generation comes from hydropower with capacity of 24,556 MW (share of 15.54%), followed by combined cycle plants: 23,957 MW (15.16%), steam power plants: 20,000 MW (12.66%), cogeneration plants: 18,367 MW (11.62%), solar power plants: 10,000 MW (6.33%), wind power plants: 9,000 MW (5.70%), MSW plants: 2,000 MW (1.27%), and gas engine power plants: 134 MW (0.08%). In the optimization scenario, Thailand still highly consumed coal, natural gas, and oil when compared with renewable energy scenario, however, shares of hydropower and renewable energy power generation will be increasing largely.
7.1.4 Cost analysis

Table 7.1 presents the total cost in each scenario, which was analyzed by LEAP in selected years in the BAU scenario.

Table 7.1. Total cost in all scenarios in Thailand

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Total cost (Trillion U.S. Dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>BAU</td>
<td>7.7</td>
</tr>
<tr>
<td>Renewable</td>
<td>7.7</td>
</tr>
<tr>
<td>Optimization</td>
<td>7.7</td>
</tr>
<tr>
<td>Total</td>
<td>23.0</td>
</tr>
</tbody>
</table>

In 2050, the renewable energy scenario shows the highest cost when compared with the other scenarios. The amount of total cost of power generation in the optimization scenario is 18.8 trillion USD, followed by the BAU scenario (29.4 trillion USD) and renewable energy scenario (35.4 trillion USD). In the optimization scenario, the total cost will decrease by 36%. However, the total cost of the renewable energy will increase by 20.4% when compared to the BAU scenario, respectively.

7.1.5 CO2 Emissions

The total CO2 emission is illustrated in Figure 7.6. In the BAU scenario, the CO2 emission will increase up to 532.7 million tons of CO2 equivalent in 2050. Electricity generation mainly comes from steam power plant, gas turbine plant and combine cycle plant. CO2 emission is reduced significantly in the renewable scenario, approximately 134.2 million tons CO2 reduction when compared to the BAU scenario. It occurs to develop a renewable scenario to reduce steam power plants and it means to reduce coal utilization. In 2050 CO2 emission will be reduced by 50
million tons of CO$_2$ equivalent in the optimization scenario. CO$_2$ emission in the
renewable and optimization scenarios will be reduced by 25.19% and 9.38 % when
compared to the BAU scenario, respectively.

![Figure 7.6. CO$_2$ emission in all scenarios in the power sector in Thailand.](image)

Table 7.2 provides the cumulative emission of air pollutants in the BAU and counter-
measure scenarios. Air pollutants of CO$_2$ biogenic, CO, NO$_x$, and SO$_x$ are assessed.
CO$_2$ biogenic emission is from biomass combustion in steam power plants. CO, NO$_x$, 
SO$_x$ emissions come from biomass, oil, natural gas, coal and diesel combustion.
Table 7.2. Other gas emissions in all scenarios in Thailand

<table>
<thead>
<tr>
<th>Emission</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BAU scenario</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ biogenic</td>
<td>3.9</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>CO</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.1</td>
<td>0.2</td>
<td>0.5</td>
<td>0.9</td>
<td>1.6</td>
</tr>
<tr>
<td>SOₓ</td>
<td>0.5</td>
<td>0.7</td>
<td>1.6</td>
<td>3.1</td>
<td>5.6</td>
</tr>
<tr>
<td><strong>Renewable scenario</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ biogenic</td>
<td>3.9</td>
<td>0.7</td>
<td>1.9</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>CO</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>SOₓ</td>
<td>0.5</td>
<td>0.6</td>
<td>1.1</td>
<td>2</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>Optimization scenario</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ biogenic</td>
<td>3.9</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>CO</td>
<td>0</td>
<td>0.1</td>
<td>0.4</td>
<td>0.8</td>
<td>1</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.7</td>
<td>1.3</td>
</tr>
<tr>
<td>SOₓ</td>
<td>0.5</td>
<td>0.7</td>
<td>1.5</td>
<td>2.8</td>
<td>4.5</td>
</tr>
</tbody>
</table>

According to the results, it can be seen that GHG mitigation actions considerably reduce local air pollutant emissions. In the renewable scenario has cumulatively reduced CO₂ Biogenic, CO, NOₓ, and SOₓ by 25.89%, 100%, 45.45% and 41.7%, respectively. Similarly, optimization scenario also shows considerable mitigation. In 2050, the CO emission will increase by 11 times and NOₓ emissions will increase by 82%, CO₂ biogenic and SOₓ will increase by 21.6% and 13%, respectively.

### 7.2 Residential sector

This section presents results of residential sector in Indonesia. Results are presented of total energy demand, fuel mix by appliances, and CO₂ mitigation.
7.2.1 Total Energy Demand in Thai Residential sector

Energy consumption in the residential sector is categorized into electricity consumption (for lighting, conditioning, and others), and thermal energy for cooking. Thermal energy comes from burning of fuel (kerosene), LPG, natural gas (in large urban areas) and firewood (in suburban and rural) for cooking.

In Thailand, total energy demand in the BAU scenario was 2800.1 ktoe in 2010 and will increase to 4723.6 ktoe in 2050. It increases about 41% when compared with base year. In the energy efficiency scenario, the energy demand will increase at lower rates than the BAU scenario due to energy conservation efforts, particularly in energy efficiency improvement. In energy efficiency scenario the projected energy conservation will be able to reduce the energy demand by 22.5% when compared to the BAU scenario. The trend of energy demand in the residential sectors between BAU and energy efficiency scenarios shown in Figure 7.8.

![Figure 7.7. Total energy demands in the residential sector in Thailand.](image)

In Thailand, efficient cooking devices can save up to 20% of energy demand in the residential sector in 2030 [12]; in the modern building scenario with efficiency
improvement of appliances savings will be about 45% in 2050 (BAU: 19,729 ktoe, Efficiency Scenario: 11,758 ktoe) [7]. Figure 7.8 and figure 7.9 present technology mix and fuel mix due to energy efficiency improvement devices in the residential sector.

Figure 7.8. Technology mixes in the residential sector in Thailand.

In the 2050 BAU, technology mix in the residential sector is assumed to be the same as the present trend. By adopting energy efficient devices, energy demand and CO₂ emission will be reduced. Energy savings from efficient stove changed from
conventional cooking devices and efficient lighting change to CFLs and LED lighting is the main factor increasing CO₂ mitigation. Replacement of conventional cooking devices will reduce energy consumption by 12% in 2050. Energy saving in lighting from CFLs and LED lamp will be about 67% in 2050 when compared to the BAU. In energy efficiency scenario, CFLs and LED lamp will be shared in lighting about 53% and 47%, respectively.

The energy efficiency improvement devices will be one of the key actions in CO₂ mitigation in Thailand. In 2050 BAU, electricity consumption will be 3363.35 ktoe, which is 1.7 times higher than 2010. By adoption of energy efficient devices, electricity demand in energy efficiency scenario will be decreased by 2504.2 ktoe in 2050.

The growth of energy consumption is related to population growth, increasing the potential of purchasing and increasing energy access. Energy demand per household will increase in line with GDP per capita growth, and energy access. The higher the income of families, the more is energy consumption. Income levels will also affect the types of energy used. A family which has higher income level will shift towards the modern types of energy such as electricity, LPG, and natural gas.
7.2.2 CO₂ emission in the residential sector in Thailand

GHG emissions had become an important parameter to be considered in development in various sectors, including the energy sector. This projection scenario has been carried out on the calculation of GHG emission trend, especially CO₂ emissions.

Total CO₂ emission result can be presented in Figure 7.10. In Thailand in the BAU scenario, energy demand comes from cooking, cooling, entertainment, and lighting devices. In the residential sector in Thailand, during 2010-2050 in the BAU scenario the CO₂ emission will increase by 1.6 times, about 1913.3 kt-CO₂ in 2010 to 3255.8 kt-CO₂ in 2050. In the energy efficiency scenario, CO₂ emissions will increase by 1.4 times during 2010-2050, about 1913.3 kt-CO₂ in 2010 to 2705.3kt-CO₂ in 2050. The cumulative CO₂ emission reduction will reach 13% when compared with the BAU scenario from 2010-2050.
## Chapter 8

### Comparison between Indonesia and Thailand

The comparative analysis of Indonesia and Thailand power sector and residential sector is presented in this chapter. Table 8.1 compares the socio-economic information between Indonesia and Thailand.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Indonesia</th>
<th>Thailand</th>
<th>Indonesia</th>
<th>Thailand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2050</td>
<td>2010</td>
<td>2050</td>
</tr>
<tr>
<td>Population (millions)</td>
<td>237.64</td>
<td>423</td>
<td>66.4</td>
<td>74.9</td>
</tr>
<tr>
<td>Household (million houses)</td>
<td>59.12</td>
<td>108.5</td>
<td>22.77</td>
<td>38.84</td>
</tr>
<tr>
<td>GDP (billion USD)</td>
<td>688.71</td>
<td>4544.2</td>
<td>318.9</td>
<td>2104.2</td>
</tr>
<tr>
<td>Installed Capacity (MW)</td>
<td>33,983</td>
<td>146,509</td>
<td>176,067</td>
<td>1,166,627</td>
</tr>
<tr>
<td>Electricity consumption (GWh)</td>
<td>18,134.7</td>
<td>36,020.5</td>
<td>2,801.9</td>
<td>4,723.6</td>
</tr>
<tr>
<td>Power generation (ktoe)</td>
<td>12,597.5</td>
<td>100,311.9</td>
<td>12,837.6</td>
<td>62,105.2</td>
</tr>
<tr>
<td>Energy demand in residential sector (ktoe)</td>
<td>18,134.7</td>
<td>36,020.5</td>
<td>2,801.9</td>
<td>4,723.6</td>
</tr>
</tbody>
</table>

In 2010 population in Indonesia was about 237.64 million with 60.9 million households, and it will increase to 423 million with 108.5 million households in 2050. In 2010, the population in Thailand was about 66.4 million with 22.8 million households, and it will increase to 74.9 million with 38.4 households in 2050. Hence, it has to be expected higher electricity demand in Indonesia in 2050 when compared with Thailand. Furthermore, structures of power generation in two countries are also
different where the share of electricity generation in Indonesia was 146,509 GWh in 2010 while in Thailand was 149,301 GWh in the same year. Hence, energy demands in the residential sector between two countries are also different whereas in Indonesia it was 18,134.7 ktoe in 2010 while in Thailand it was 2,801.9 ktoe.

Similar to the population, in 2050 Indonesian GDP will be 2.1 times higher than Thailand. It will effect on capacity expansion in terms of increasing renewable energy share, excessive laws, and regulation management in the power sector of both countries. Hence, developing a sustainable electricity generation and consumption has to be a priority.

8.1 Power sector

This section compares the strength of renewable energy and optimization in terms of CO$_2$ mitigation and its impact on energy system in two countries. Table 8.2 provides the cumulative CO$_2$ emission and CO$_2$ emission per capita in the renewable and optimization scenarios in 2050.

Table 8.2. Cumulative CO$_2$ emissions per capita in 2050

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cumulative CO$_2$ emission (Mt-CO$_2$e)</th>
<th>CO$_2$ emission per capita in 2050 (t-CO$_2$e/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indonesia</td>
<td>Thailand</td>
</tr>
<tr>
<td>BAU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renewable energy</td>
<td>13,685</td>
<td>6,991</td>
</tr>
<tr>
<td>Optimization</td>
<td>13,886</td>
<td>7,629</td>
</tr>
</tbody>
</table>

In Indonesia, renewable energy and optimization scenarios can cumulatively mitigate CO$_2$ by 3,082.7 Mt-CO$_2$e and 2,881.3 Mt-CO$_2$e, respectively. In 2050 CO$_2$ emission
in Thailand can be reduced by 1,023.72 Mt-CO\textsubscript{2}e and 385.78 Mt-CO\textsubscript{2}e in renewable energy and optimization scenarios, respectively. Moreover, the highest percentage cumulative reduction in CO\textsubscript{2} emissions in the renewable energy scenario and optimization scenarios in Indonesia will be 18.4\% and 17.2\% in 2050, respectively. In Thailand cumulative mitigation in CO\textsubscript{2} emission under the renewable energy and optimization scenarios are accounted for 12.76\% and 4.81\%, respectively.

In 2050, in the BAU scenario per capita emission was only 2.46 t-CO\textsubscript{2}e/person in Indonesia and 7.1 t-CO\textsubscript{2}e/person in Thailand. However, in 2050 Thailand per capita emission will be higher than Indonesia due to population aging in Thailand.

8.2 Residential sector

This section discusses emission mitigation potentials in Indonesia and Thailand residential sector. Table 8.3 provides the cumulative CO\textsubscript{2} emission and CO\textsubscript{2} emission from residential sector per capita in 2050 in the energy efficiency scenario in two countries.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cumulative CO\textsubscript{2} emission (Mt-CO\textsubscript{2}e)</th>
<th>CO\textsubscript{2} emission per capita in 2050 (t-CO\textsubscript{2}e/person)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Indonesia, Thailand</td>
<td>Indonesia, Thailand</td>
</tr>
<tr>
<td>BAU</td>
<td>995,016.9, 109,644.3</td>
<td>0.079, 0.044</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>784,523.3, 94,755</td>
<td>0.061, 0.037</td>
</tr>
</tbody>
</table>

In 2050, energy efficiency scenario can cumulatively mitigate 210,493.6 kt-CO\textsubscript{2}e in Indonesia. It is higher than the total cumulative CO\textsubscript{2} emissions in Thailand. CO\textsubscript{2} emission in Thailand can be reduced by 14,889.3 kt-CO\textsubscript{2}e. Moreover, the highest
percentage cumulative reduction in CO$_2$ emission in energy efficiency scenario in Indonesia and Thailand are accounted for 21.15% and 13.58%, respectively.

In 2050, per capita emission from the residential sector will be 0.079 t-CO$_2$e/person in Indonesia and 0.044 t-CO$_2$e/person in Thailand in the BAU scenario. Indonesian per capita emission from residential sector will be higher than Thailand in 2050.
Chapter 9
Conclusion

This study investigated the prospect of CO\textsubscript{2} mitigation under countermeasures policies in the power and residential sectors in Indonesia and Thailand. In addition to the main objective, sustainable development and energy security policies on power and residential sectors of two countries in the optimization, renewable energy and energy efficiency improvement that can be gained from CO\textsubscript{2} mitigation. Optimization and renewable energy were examined in terms of local air pollutants, the cost of production, and impact on energy security in the power sector. Efficient devices were examined in terms of air emissions and impacts on energy security in the residential sector as well.

Potential of CO\textsubscript{2} emissions mitigations were investigated separately between the power and residential sector. In the power sector, renewable energy, power generation efficiency, fixed O&M cost, variable O&M cost were considered as mitigation action. Hence, in this study, renewable energy scenario, and optimization scenario in the power sector with time span 2010-2050 were modeled for both Indonesia and Thailand. In the residential sector, energy efficiency scenario was modeled. Efficient devices utilities in cooking, cooling, lighting and entertainment are examined. Implementation timeframes were taken as the basis since it is one of the major factors that determine the actual CO\textsubscript{2} mitigation that can be achieved.

The result of the study shows that Indonesian power sector will cumulatively emit 16,767.8 Mt-CO\textsubscript{2} during the period of 2010-2050. It has achieved 18.4\% of the cumulative reduction in renewable energy scenario when compared with the BAU, followed by 17.2\% in optimization scenario, respectively. Thus, renewable energy scenario has higher CO\textsubscript{2} mitigation potential in Indonesian power sector. In terms of cost production, optimization scenario has the small amount by 124.3 trillion USD in 2050.
Similarly, in the residential sector, energy saving in the energy efficiency scenario will be 22.5% in 2050. Energy efficiency scenario has the cumulative mitigation by 21.15% when compared with the BAU.

Likewise, in the power sector of Thailand, cumulative mitigation in the period from 2010-2050 is expected to be 8,014.8 Mt-CO$_2$. The highest cumulative CO$_2$ mitigation is the renewable energy scenario (12.76% reduction when compared with BAU), followed by renewable energy scenario (4.81% reduction). In terms of cost production, optimization scenario has the small amount by 18.8 trillion USD in 2050.

In the residential sector of Thailand, energy efficient devices result in high energy saving in the energy efficiency scenario (about 22.5%) in 2050. Energy efficiency scenario has cumulative mitigation of 13.58% when compared with the BAU.

According to the result of both Indonesia and Thailand, renewable energy scenario provides more sustainability in electricity generation to the power sector. However, results are carried out based on developed scenarios. Hence, it cannot be generalized and immediately concluded that implementation of renewable energy is more beneficial over optimization in the power sector of both countries.

The reduction of CO$_2$ emissions from residential appliances plays a crucial role in the transition towards a more sustainable energy system. Energy efficiency improvement is beneficial to the sustainable development in both countries.
References


Economic and Government, ANU Collage of the Asia Pacific, The Australian National University, Bandung.


