ELECTRICITY PLANNING IN THE SELECTED GMS COUNTRIES: CAMBODIA, LAO PDR, THAILAND AND VIETNAM

BY

MR. DEGEORGE DUL

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

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ENTITLED

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was approved as partial fulfillment of the requirements for the degree of Master of Science (Engineering and Technology)

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ABSTRACT

In 2015, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) agreed to adopt the Paris Agreement which aims to limit the mean global temperature increase to well below 2℃ by the end of the 21st century. All Parties were required to submit the Intended Nationally Determined Contribution (INDC) to the UNFCCC. The INDCs hold the pledged greenhouse gas (GHG) mitigation targets of each Party to contribute to the Paris Agreement targets. The total GHG emissions reduction targets of the selected GMS countries namely, Cambodia, Lao PDR, Thailand, and Vietnam collectively range from 177 to 339 Mt-CO_2eq by 2030 when compared to the business-as-usual case. Nonetheless, the emissions gap report 2019 of the United Nations Environmental Programme states that to be able to reach the 2-degree goal of the Paris Agreement, the global annual GHG emissions reduction in 2030 has to be reduced by 15 Gt-CO_2eq below the pledged unconditional NDCs targets. The global emissions gap will have to be fairly shared across all countries which indicates that the selected GMS countries will also have to reset the current NDCs targets to more ambitious targets.

In the power sector of the selected GMS countries, the electricity demand and generation is increasing rapidly along with the economic growth. The firm dependency

on fossil fuels in electricity generation within the four countries releases GHG emissions which leads to negative impacts on the atmosphere and the ecology system. In 2015, the total GHG emissions in the power sector in the selected GMS countries collectively amount to 166.91 Mt-CO_2eq. The emissions are expected to keep increasing as the demand for electricity would increase in the future. A solution to restrict the increasing GHG emissions in the power sector is to shift from the use of fossil fuels to renewable energy sources. According to reports, the renewable energy sources technically available for the power sector are significant. However, the electricity generated from renewable energy in the four selected countries in 2015 collectively amounts to only 26.81% which points out that the potential of phasing out fossil fuels of the power sector is strong. In this case, the cleaner power sector in selected GMS countries would be able to contribute even more to the NDCs targets and the emissions gap of the 2-degree goal of the Paris Agreement.

This study focuses on two main analyses which are the electricity planning analysis and the estimation of the emissions gap for the selected GMS countries. In this planning study, there are three scenarios namely, Business-as-Usual (BAU), Renewable Energy Technologies (RET), and Improved Energy Efficiency (IEE). The Low Emissions Analysis Platform (LEAP) model is used to determine the electricity generation, the electricity production cost, and the GHG emissions mitigation in the three scenarios. The BAU scenario is a scenario where the power generation in the selected GMS countries follows the Power Development Plan (PDP) and no other GHG emissions reduction constraints are considered. On the other hand, the RET scenario considers the high use of renewable energy in the power and the transport sectors in the selected GMS countries. The rates of penetration of renewable energy in RET scenario differ between each selected country. The IEE scenario covers the residential, commercial, power, and transport sectors in the selected GMS countries. Different rates of efficiency improvement in end-use equipment and the efficient equipment penetrations over the inefficient ones are considered in the IEE scenario. Furthermore, the study also considers the inclusion of the Marginal Abatement Cost (MAC) study to sort out the best and worst technologies or adopted measures in the selected GMS countries.

For the emissions gap (excluding LULUCF emissions) estimation in the selected GMS countries, there are 7 scenarios including the Baseline, the unconditional NDCs (NDC-U), the conditional NDCs (NDC-C), the doubled targets of conditional NDCs by 2050 (NDC-C-DOU), the tripled targets of conditional NDCs by 2050 (NDC-C-TRI), the 2-degree emissions pathway (2-D2050) scenario, and the 1.5-degree emissions pathway (1.5-D2050) scenario. Following the emissions gap, four effort-sharing approaches namely, Grandfathering (GF), Immediate Per Capita Convergence (IEPC), Per Capita Convergence (PCC), and Greenhouse Development Rights (GDR) are considered to estimate the carbon budgets (CO_2 emissions only) to further analyze the remaining allowable emissions (including LULUCF emissions) in the four countries to comply with the 2-degree goal and 1.5-degree target during 2011-2050.

The results show that the electricity generated from renewable energy sources in 2050 would amount to 62% in the RET scenario and 41.9% in the IEE scenario. It would result in the GHG emissions mitigation in the power sector of about 63.6% in 2050 in the RET scenario and 5.1% in 2050 in the IEE scenario when compared to the BAU scenario. The CCS technologies considered in the power sector in the RET scenario collectively have the potential to mitigate about 225.75 Mt-CO_2eq in 2050 in the selected GMS countries. The electricity demand of the electric vehicles in the transport sector in the selected four countries would collectively take up about 0.3% of the total electricity demand in 2050 in the IEE scenario. In addition, the emissions reductions in the transport sector in the RET and IEE scenarios in 2050 would be 2.8% and 69.5% respectively. With the reductions of GHG emissions in the power sector and the carbon tax of 9 \$/t-CO_2eq, the total electricity generation cost in the selected GMS countries in 2050 in the RET and IEE scenarios would be cut down by about 11.6% and 3% from the BAU scenario respectively. Besides, the findings of the MAC study suggest that the solar power plants would be the ideal technology to partially phase out the coal and natural gas power plants in the selected GMS countries in 2050.

The findings of emissions gap analysis suggest that there would be still an emissions gap of 416 Mt-CO_2eq in 2030 to reach the 2-degree emissions pathway of the Paris Agreement when considering the full achievement of the conditional NDCs targets of the selected GMS countries. In 2050, the gap would expand to 832 Mt-CO_2eq. The emissions gap between the NDC-C-TRI scenario in which, the current NDCs

targets are assumed to be tripled in 2050, and the 2-degree emissions pathway in 2050 would 89.9 Mt-CO_2eq. The emissions gaps analysis indicates that if the targets of the NDCs of the selected GMS countries were to be set more ambitious in the future, the new targets would have to be more than the triple of the current conditional NDCs targets to have a chance of reaching the 2-degree emissions pathway of the Paris Agreement. Furthermore, the results of the carbon budgets estimation for the selected GMS countries based on the 2-degree goal show that the cumulative allowable emissions during 2011-2050 for the four countries would collectively amount to 13.71 Gt-CO_2eq, 21.17 Gt-CO_2eq, 17.44 Gt-CO_2eq, and 21.89 Gt-CO_2eq in the GF, IEPC, PCC, and GDR approach respectively.

Keywords: Carbon Budgets, Effort Sharing, Electricity Planning, GHG Mitigation, LEAP Model, Renewable Energy

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Mr. Degeorge Dul

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LIST OF SYMBOLS/ABBREVIATIONS

Symbols/Abbreviations	Terms
CCS	Carbon Capture and Storage
COP	Conference of the Parties
DSM	Demand-Side Management
EAC	Electricity Authority of Cambodia
EDL	Électricité du Laos
EE	Energy Efficiency
EGAT	Electricity Generation Authority of Thailand
EVN	Vietnam Electricity
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GMS	Greater Mekong Sub-region
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Planning
LEAP	Long-range Energy Alternative Planning
RE	Renewable Energy
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER 1
INTRODUCTION

1.1 Rationale

Global warming happens as greenhouse gases (GHG) consume the energy of the solar system such as ammonia, carbon, nitrous oxides, and often chlorine, and bromine compounds; which induces ozone depletion (Umair Shahzad, 2015). Extreme use of fossil fuels, such as coal, gas, and petroleum, generates GHG that plays a significant role in global warming. Global warming leaves many negative effects such as rising sea level that leads to floods, rising surface temperature that leads to drought, causing stress to the health of living beings, spreading various diseases, threatening biodiversity…, etc. (Umair Shahzad, 2015). The most effective way to stop this catastrophe is to utilize renewable forms of energy such as wind, solar, biomass, hydro, and geothermal.

The United Nations Framework Convention on Climate Change (UNFCCC), an international environmental treaty, was developed in 1994 to ensure the stability of GHG levels in the atmosphere (UNFCCC, 1992). Every year since the Treaty came into effect, UNFCCC Parties have negotiated how to fulfill the treaty's goals at the conferences, or "Conferences of the Parties" – COPs. The conference is assisted by the assessment report of the Intergovernmental Panel on Climate Change (IPCC), which provides policymakers at all levels with a factual framework for implementing climate policy. All 196 parties in 2015 gathered for the Paris Conference and settled on the Paris Agreement, which seeks to restrict global warming to less than 2°C and further limit the increase to 1.5°C by the end of the 21st century. (Wikipedia, 2021).

Along with the population growth and social-economic development, the energy demand of the world has gone up dramatically leading to even more GHG concentrations in the atmosphere. Many countries have been improving their electricity supply plans by aiming at available renewable sources that are less susceptible to energy price increases, as well as domestic resources while taking into account the global environmental issues. Being addressed as developing countries, the selected GMS countries are facing a problem of rapidly growing electricity demand and are striving to develop electricity generation plans to meet the demand. The four countries have many potential renewable energy sources for future energy development but those sources have not been used at the optimum level yet. The electricity generation in Cambodia, Thailand, and Vietnam is still strongly dependent on fossil fuels as sources of generation such as coal, fuel oil, and natural gas. On the other hand, Lao PDR has been mainly dependent on hydro which is a renewable energy source but it is starting to depend on coal power plants lately.

The limitation of conventional energy sources has become the main worrisome problem for the world. Fossil fuels are expected to be completely run out in the near future which will cause uncertainty in future energy security. In order to guarantee energy security and reduce GHG pollution, the deployment of renewable energy is vital. Integrated electricity planning is important for the selected GMS countries to continuously develop as electricity is essential for social and monetary advancement, and for upgrading the living standard of people in the region.

1.2 Problem Statement

The remarkable economic growth causes a large increment in electricity demand in the selected GMS countries. However, the nations are trying to keep up with the electricity demand by producing electricity with low tariff rates to maintain the nation's development.

Within the selected GMS in 2015, approximately 49.37% of the total households in Cambodia were electrified while the rates in Lao PDR, Thailand, and Vietnam were 90.5%, 100%, and 98.88% respectively (EAC, 2016, EDL, 2015, World Bank, 2015, EVN, 2016). In 2015, Cambodia's total electricity generation accounted for 6.02 TWh of which the electricity generated from fossil fuels and imported electricity accounted for 38.62% and 25.37%, respectively, while electricity generated from renewable energy (excluding hydro) accounts for only 0.64% (EAC, 2016). In the same year, Lao PDR's electricity generation accounted for 16.3 TWh of which the electricity generated from coal and hydro had a share of 13.86% and 86.12% respectively while electricity generated from renewable energy (excluding hydro) accounted for only 0.02% (ERIA, 2018). On the other hand, in Thailand, the total electricity generation in 2015 was 192.246 TWh of which the electricity generated from fossil fuels and imported electricity accounted for 85.3% and 7.5%, respectively, whereas electricity generated from renewable energy (excluding hydro) accounted for 5.2% (EPPO, 2020). Moreover, Vietnam's electricity generation in 2015 is was reported to be 164.182 TWh of which the electricity generated from fossil fuels and hydro had a share of 34.39% and 34.82%, whereas electricity generated from renewable energy (excluding hydro) accounted for only 0.12% (IEA, 2020).

There are renewable energy sources in the selected GMS countries such as hydro, biomass, wind, geothermal, and solar/PV that are not used at high potential. The total potential of hydro (including small hydro) in the selected GMS countries accounts for approximately 86,155 MW. Moreover, the selected countries have a biomass potential of around 897.21 TWh/year. Vietnam and Thailand contribute 373.9 TWh/year and 136.4 TWh/year, respectively, to the biomass potential. The potential of solar, wind, and geothermal within the selected GMS countries are found to be 375.6 TWh/year, 2229.35 TWh/year, and 300-400 MW, respectively (Tran H.N., 2018; Pagnarith, K. and Limmeechokchai, B., 2009; Tun, M.M. et al., 2019; Asian Development Bank, 2015$_a$; Ministry of Energy, 2015; Vietnam National Mekong River Committee, "n.d."; Phomsoupha, X., 2009; Kanit Aroonrat and Somchai Wongwises, 2015).

Statistically, the dependency on fossil fuels as the sources for electricity generation in the selected GMS countries is solid. Year by year, the fuel price increases causing the tariff rates to be high as well. In addition to the high fuel price, GHG emissions from the electricity sector would harm civilization and the atmosphere and boost global temperature rise. Due to concerns about the shortage of conventional sources, increasing GHG emissions, and environmental impacts; it is necessary to conduct integrated resources planning which includes renewable energy integration, environmental costs, and efficient technology for the power sector while keeping the generation cost-optimized.

According to the emissions gap report 2019 issued by the United Nations Environmental Programme, there is a 15 Gt-CO_2eq of GHG emissions gap between the 2℃ emissions pathway of the Paris Agreement and the full implementation of the unconditional NDCs scenario. Another gap of 32 Gt-CO_2eq of GHG emissions is found between the 1.5^{o}C emissions pathway and the unconditional NDCs (UNEP, 2019). The world needs to limit its carbon budgets even lower than the NDCs targets to ensure the possibility of reaching the Paris Agreement goal. To do that, each country needs to contribute its effort to the reduction targets. The effort sharing must consist of fairness so that participation from each country is ensured. No studies have ever been conducted on the small countries like the selected GMS countries; thus this study aims to determine the emissions gap and carbon budgets for the four selected countries in order to comply with the goal of the Paris Agreement.

1.3 Objectives

The objectives of the research are as follow:

1. Forecast future electricity demand of the residential sector, commercial sector, industry sector, and the energy demand of the transport sector in the selected GMS countries,
2. Estimate the future electricity generation in the selected GMS countries,
3. Propose the incorporation of renewable energy sources and energy-efficient technologies in the power sector of selected GMS countries,
4. Evaluate the GHG emissions from the power and transport sector in the selected GMS countries,
5. Estimate the costs of electricity generation in the selected GMS countries,
6. Determine the marginal abatement cost curves (MACC) in different sectors in the selected GMS countries,
7. Estimate the emissions gap for the selected GMS countries to comply with the goal of the Paris Agreement,
8. Evaluate the carbon budgets for the selected GMS countries to comply with the goal of the Paris Agreement.
9. Determine the carbon budget pathway for the selected GMS countries to comply with the goal of the Paris Agreement.

1.4 Scope and Limitation

The scope and limitations of the study are stated below:

1. The study period is from 2015-2050,

2. The forecasts of future electricity demand and electricity generation, as well as GHG emissions, are determined by developing three scenarios: a Business as Usual (BAU) scenario, a Renewable Energy Technologies (RE) scenario, and an Improved Energy Efficiency (IEE) scenario,
3. Low Emission Analysis Platform (LEAP) model is used in the analysis,
4. Power Development Plan is used as a reference for electricity generation while other data are obtained from various international energy organizations and the related authorities in each country,
5. The baseline datasets used in this study follow the Shared Socioeconomic Pathways 2 (SSP2) scenario database that are used for the Assessment Report on Climate Change for the IPCC.

1.5 Significance of the research

With the inclusion of these scenarios, electric utilities and policymakers in the selected GMS countries will positively consider the integration of renewable energy and the introduction of demand-side management programs in their electricity generation planning because of its significant impacts on securing energy security in the future. In addition, not only is the cost of electricity generation that helps to determine the total investment provided in the study but the amount of GHG reduction is also indicated which will help the countries to determine possibilities of achieving the targets in reducing the GHG that is stated in the Intended Nationally Determined Contribution (INDC) of each country. Furthermore, the study of Marginal Abatement Cost will sort out the most preferred renewable energy technology to implement in the power sector in the selected countries. In addition, the study of the emissions gap and carbon budgets will contribute informative data to other researchers to further develop new and relevant researches.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Integrated Resource Planning

Integrated Resource Planning (IRP) is the act of integrating a wider range of energy-efficient technologies and load management on the demand side and scattered sources of the generation with other potential resources. It also takes environmental and social costs as well as the cost of components into consideration to select the best available technical resources for the supply sources expansion plan which make IRP more favorable than the traditional options (Joel N. Swisher et al., 1997).

It has been shown by practice that the Demand Side Management (DSM) solutions cost much less than supply options. Practices in the US have calculated the investment cost of energy-saving per kW to be about 0.1 to 0.5 of the investment costs of constructing a new power plant, thus the growth rate of the load from 20-40% (Liu, D. et al., 1997). Typically the IRP is carried out at a state or utility level. However, it provides additional advantages to extend the basics of IRP to the transnational or regional level. The fundamental technique of IRP can be used at different stages of planning. It may be extended to include the possible economic and environmental advantages arising from varied resources, market features, and economies of scale at a transnational regional level (Graeber, B., & Spalding-Fecher, D. R., 2000). The IRP is necessary, if (Antonette D'Sa, 2005):

- the governmental/regulatory conditions have mandated a standard of resources to be provided,
- the supply of such energy services is to be on a low-cost basis,
- the minimization of environmental impact or expense of pollution mitigation; and the postponement or annulment of the increased cost of production ability utilizing cheaper performance improvement/DSM.

Figure 2.1 and Figure 2.2 illustrate the distinctions between the traditional electric planning model and the integrated electricity planning model. Instead of least-cost supply planning, IRP has become essential in modern electricity.

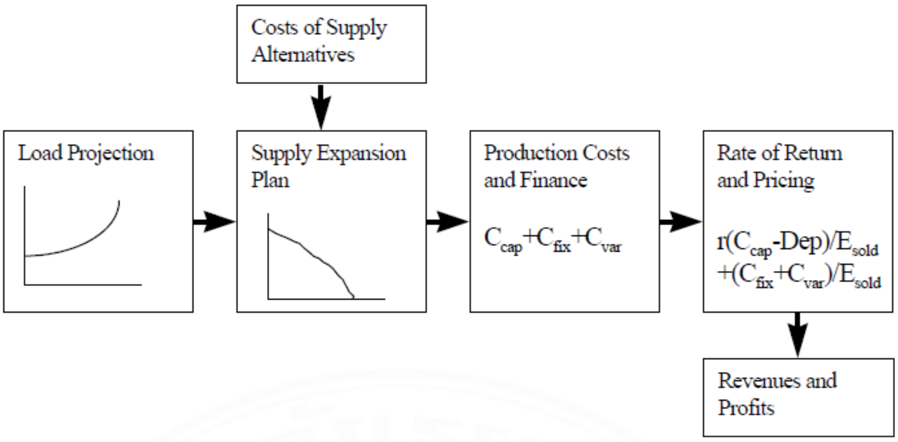

Figure 2.1 The traditional "least cost" electric planning model.

Source: Joel N. Swisher et al., 1997.

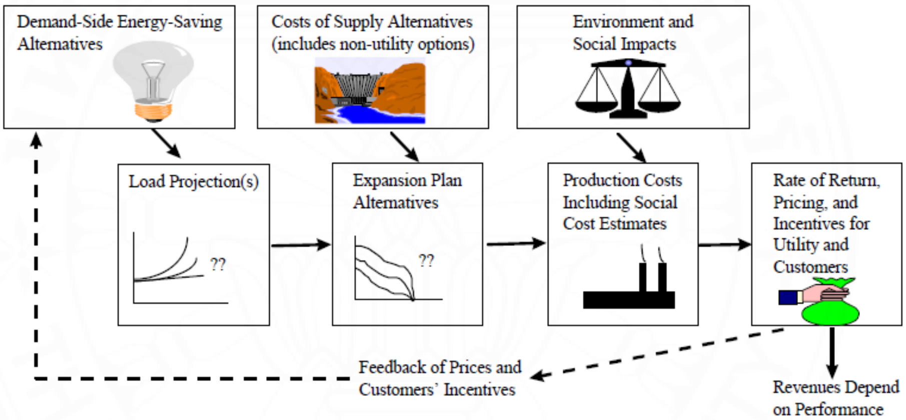

Figure 2.2 An integrated "least cost" electric production cost and load model.

Source: Joel N. Swisher et al., 1997.

2.1.1 Renewable, Energy Efficiency Programs and Demand Side Management

In addition to the economic feasibility of more efficient or renewable energy (RE) technologies, the consumer's behavior or energy companies' behavior in their investments are essential to the IRP process as well. In reaction to behavioral modification criteria, initiatives containing sets of demand side-measures, and policy measures are utilized. This requires increased expenses, energy, and uncertainty in order to promote demand-side behavior which in the sense of an IRP cycle is unavoidable (Joel N. Swisher et al., 1997).

2.1.1.1 Renewables and Energy Substitution Programs

One of the strategies to conserve primary resources and rising costs and emissions is to shift from coal to gas and vice versa on the demand side. Changing from coal power to gas also decreases the total pollution of CO_2 and SO_2, even when methane is a significant source.

The solar energy application is most effective in low-latitude regions. Specific end-use devices can substitute electricity with solar energy. Lighting, space heating, and water heating are among the various significant applications that include economic incentives to supplement solar power with electricity.

Cogeneration corresponds to the procedure for the combination of heat-power production that permits the simultaneous use of fuel energy. Cogeneration may be used with applications in which the generators are steam turbines, gas turbines, and internal combustion engines.

Government agencies can lead to a range of sustainability and energy efficiency (EE) programs and RE projects. Such solutions include government information programs, energy product labeling, construction and infrastructure regulations, technology procurement, research and development (design, improvement, and demonstration) government-sponsored RD&D, and financial and fiscal mechanisms (Joel N. Swisher et al., 1997).

2.1.1.2 Investment in Energy Efficiency

Energy efficiency is a particular type of demand-side management strategy whereby attempts are made to reduce a certain purpose's energy consumption. The aim is often to reduce energy usage together with peak demand growth.

Energy audits in some countries are one of the most commonly implemented services. The inspections can be carried out as a utility or government program, comprising consultations and meetings with power consumers seeking to have their end-use systems reviewed in detail to discuss energy-saving options in response to changes in the tariff system, infrastructure, or use of facilities.

Financial incentives vary from low interest or deferred mortgages to grants or rebates to energy-efficient equipment purchases.

2.1.1.3 Demand-Side Management (DSM) Strategies

Demand-Side Management (DSM) programs entail a concerted attempt to control consumers' scheduling and amount of electricity. Within a specific geographical area, DSM programs are developed and implemented, most often by the utility. In some countries, governments have also focused on DSM initiatives. The assessment of future trends in the utility load profile and power consumption is the first criterion for a DSM system. DSM Policies find measures aimed at altering the form of the load curve or the total area below the load curve. Figure 2.3 shows the classical DSM strategies (Joel N. Swisher et al., 1997).

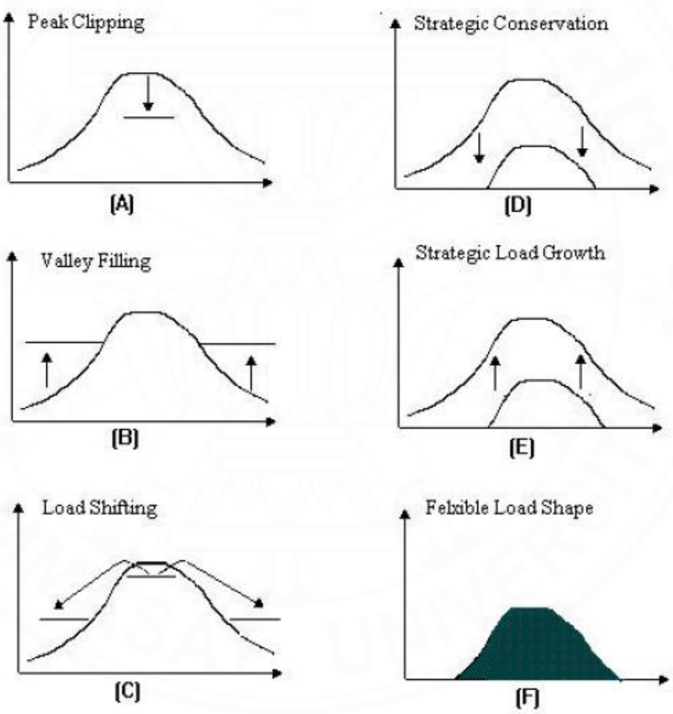

Figure 2.3 DSM load shape objectives.

Source: Joel N. Swisher et al., 1997.

2.2 Lighting Technologies

There exist various lighting technologies used in the world such as the incandescent lamp, the compact fluorescent lamp (CFL), linear fluorescent lamp (LFL), halogen lamp, high-intensity discharge (HID) lamp, and light-emitting-diode (LED) lamp. The lighting system consumed around 13% of the total electricity consumption in Southeast Asia in 2014, of which, the commercial sector, industry sector, and residential sector would take up approximately 90% (IIEC, 2016). The lamp shipments in Southeast Asia countries are expected to reach about 829 million lamps in 2030 which indicates that the future electricity consumption of the lighting system would likely keep increasing as well.

Kamphol Promjiraprawat et al. found that when approximately 50% of the total lighting service in Thailand is replaced by LED lamps, Thailand would be able to mitigate cumulative GHG emissions of approximately 56 Mt-CO_2eq during 2010-2050 in the residential and building sectors (Kamphol Promjiraprawat et al., 2014). The residential savings of the lighting service in Vietnam would reach 13.2 TWh by using efficient lighting technologies (Asian Development Bank, 2015_b). LFLs dominate the market share of the lighting service across ASEAN countries however LED lamps have a fast-growing market share. By 2030 the region's overall energy consumption could be reduced by almost 6% with a related reduction of almost 21 million ton carbon emissions, and costs reduction of over $3.5 billion by a complete transformation into the most effective lighting technologies in the ASEAN Member States (ASEAN-SHINE, 2017). Thus, the efficient lighting technologies would have a tremendous effect on energy consumption and GHG emissions reductions in the selected GMS countries.

2.3 Household Air Conditioner

Air conditioners are used to cool down the temperature in the enclosed rooms or spaces in the house to enhance thermal comfort and indoor air quality. Room air conditioners have an energy efficiency ratio (EER) which is the efficiency rating for the equipment at a particular pair of external temperatures. The coefficient of performance (COP), commonly used in thermodynamics is a ratio of the cooling provided over the electrical energy consumed and sometimes can also be used to refer to the efficiency of the air conditioners. Air conditioners (ACs) represent close to 50% of household electricity consumption in ASEAN (ASEAN-SHINE, 2017).

The air conditioners with COP-6 and COP-8 have the potential to reduce the cumulative GHG emissions in the residential and building sectors in Thailand by approximately 566 Mt-CO_2eq during 2010-2050 over the traditional air conditioners (Kamphol Promjiraprawat et al., 2014). When homes use fluorescent tube lighting or more reliable air conditioners and the like, GMS countries expect energy savings of 10%, leading policymakers to put systems for these purposes in place (Asian Development Bank, 2015_b). A complete transition of the market will result in reduced energy demand by 5,373 GWh per year, pursuing the use of more efficient ACs (ASEAN-SHINE, 2017). The penetration of the high EER air conditioners would therefore lead to preferable mitigation of GHG and a reduction in energy demand.

2.4 Household Refrigerator

Refrigerators are used in households across the world to store food at a low temperature in order to prevent it from spoiling. Globally, about 1.4 billion home refrigerators and freezers were in operation in 2012. They accounted for about 14 percent of the residential sector's overall energy use and triggerred 450 million tons of CO_2eq global annual greenhouse gas (Claus Barthel and Thomas Götz, 2012).

Globally, domestic refrigerators and freezers could reduce their annual electricity usage from 649 TWh by 2020 to 475 TWh if old appliances were replaced by modern appliances (Claus Barthel and Thomas Götz, 2012). On the basis of optimum technology selection, the most effective mitigating solution with low MAC values will be advanced refrigeration systems such as the refrigerator with the 6 and 8 COPs. They would be able to reduce the cumulative GHG emissions in Thailand's residential and building sectors by about 54 Mt-CO_2eq during 2010-2050 (Kamphol Promjiraprawat et al., 2014). The efficient refrigerators in Vietnam would be able to reduce the energy consumption of the residential by about 2.3 TWh in 2030 over the existing refrigerators (Asian Development Bank, 2015_b). Refrigerators contribute a big portion to the residential sector energy consumption, though not as much as air conditioners.

2.5 Biofuels as Energy Source for Transportation

Biofuels can be used as alternative fuels to the petroleum utilized in the transport sector. Different types of biofuels such as B5 (5% biodiesel by volume blended with 95% petroleum diesel by volume), B20 (20% biodiesel blended with 80% petroleum diesel), B100 (100% biodiesel), E5 (5% ethanol blended with 95% gasoline), E10 (10% ethanol blended with 90% gasoline), E15 (15% ethanol blended with 85% gasoline), E85 (85% ethanol blended with 15% gasoline), E100 (100% ethanol), compressed natural gas (CNG), and fuel cell hydrogen are currently being used in the transport sector across the world. In 2017, the global biofuel production is 144 billion liters and increased to 154 billion liters in 2018. Biofuel output is expected to increase from 190 to 225 billion liters by 2024 (IEA, 2019). As the production of biofuel grows, the renewable energy share of the transport demand is expected to increase from 3.7% in 2018 to 4.6% in 2024 (IEA, 2019).

The fuel economy of vehicles using biofuels is likely to be lower than that of vehicles using petroleum. L. Tuan and P. M. Tuan investigated the impacts of E5 and E10 fuels on the performance and exhaust emissions of the motorcycles and cars in Vietnam. The results suggest that there are improvements in fuel consumption of the vehicles and the emissions components such as CO and HC (L. Tuan and P. M., 2009). Eight heavy-duty vehicles such as transit buses, school buses, class-8 Freightliner trucks, and motor coaches were tested (R.L. McCormick et al., 2006). The vehicles were tested on diesel-fuel and B20 diesel-fuel and the outcomes suggest that on average, there are 16%, 17%, and 12% reductions in PM, CO, and HC when B20 is used instead of diesel. The NO_x emissions impact of the B20 did not change, statistically (R.L. McCormick et al., 2006). Varieties of fuels for passenger cars in Vietnam such as RON92 gasoline, E10 gasoline, E15 gasoline, and E20 gasoline, were tested. The findings of the experiment show that for the carbureted car, there are reductions in fuel consumption, CO, and HC emissions, while the NO_x emissions see an increment when compared to RON92 gasoline. However, for fuel-injected cars, the blends do not affect fuel consumption, and increments in HC and CO emissions are seen for all alternative fuels tested (Pham Huu Truyen et al., 2012).

2.6 Electric Vehicle (EV)

Electric vehicles (EV) are the ones that run on electricity. As a car, the EV is silent, easy to drive, and has no fuel costs like for conventional vehicles. They are very useful as a means of urban transportation and do not emit any emissions while idling. An EV is capable of regular start-stop operation, delivers the entire torque from start-up, and requires no trips to the gas station; nor does it add to the smog that pollutes the city's climate (Fuad Un-Noor et al., 2017). Electric vehicles have 2 to 3 times better fuel economy than internal combustion engine vehicles, which contributes to lower renewable energy consumption when compared with biofuels (IEA, 2019). The global electric car stock in 2015 hit a record of 1.26 million (all electric vehicles including plug-in hybrid electric vehicles) (IEA, 2016). Targets of 100 million electric cars and 400 million 2-wheelers and 3-wheelers are set to be reached in 2030 according to the Paris Declaration on Electro-Mobility and Climate Change and Call to Action (IEA, 2016).

A study on electric vehicles (including hybrid and plug-in hybrid vehicles) in Thailand was done in 2014 to observe the CO_2 emissions in road transport. Different rates of penetration of electric vehicles were considered and the results of the study suggest that electric vehicles could be able to reduce 689 ktoe of energy demand for transport by 2030. Also, the CO_2 emissions reduction of 4.84 Mt-CO_2eq could be achieved in 2030 (Nicha Sritong et al., 2014). Sengsuly Phoualavanh and Bundit Limmeechokchai analyzed the energy-saving and CO_2 mitigation of electric vehicle technology in the Lao transport sector in 2016 and suggested that by adding 25% of HEVs and 15% of PHEVs and BEVs to the Lao transport sector in 2050, the energy demand and CO_2 emissions could be cut down by around 5.3% and 6%, respectively, in 2050 (Sengsuly Phoualavanh and Bundit Limmeechokchai, 2016). When the share of electric cars (including PHEVs, HEVs, and BEVs) and electric motorbikes reach 34% and 30%, respectively, of the total number of cars and motorbikes in Vietnam's road transport in 2040, the overall CO_2 emissions in Vietnam will increase 5.2% annually due to strong reliance on fossil-fuel to generate electricity (Shigeru Suehiro and Alloysius Joko Purwanto, 2019). If the energy generation industry is not decarbonized, the impact of BEV penetration is restricted to reducing CO_2 emissions.

2.7 Environmental Impact of Electricity Generation

The production of electricity has had several environmental effects. The multiple results can be described as (Joel N. Swisher et al., 1997):

Land use: building power generation and distribution systems require large quantities of property which raises concerns to people in the neighborhood.

Waste Disposal: the issue of liquid and solid waste management is caused by ash emitted by traditional coal plants and by waste from air pollution control systems and in part from processing nuclear or highly toxic waste.

Cooling Water: as a result of higher or lower temperatures of water from the nuclear energy plants as well as some gas and oil-fired plants, which can affect marine life, this practice can become a concern.

Air Emissions: particulate matter (PMs), sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2) or water vapor causes global warming.

2.8 Carbon Tax

Carbon taxation or carbon pricing is an integral component of the decarbonization process to achieve the objective of the Paris Agreement by 2100. The carbon tax sets the price on the carbon emissions of services to put pressure on the carbon emitters to reduce emissions. The carbon tax is set at different prices according to different countries. In 2015, the carbon tax in Sweden was set at 130$ per ton of CO_2 which is the highest in the world whereas Poland's carbon tax was set at lower than 1$ per ton of CO_2 (Alexandre Kossoy et al., 2015).

The result of the AIM/Enduse model in the study by Puttipong Chunark and Bundit Limmeechokchai assessing Thailand's 1.5-degree goal suggests that the suitable price to set the carbon tax is 500 USD – 1000 USD per ton of CO_2 to cut down the CO_2 emissions (Puttipong Chunark and Bundti Limmeechokchai, 2019). The carbon tax of 10$/t-$CO_2$ and different other sectoral carbon prices were set for Southeast Asia countries uniformly to find out its impact on the economy of the countries (Ditya A. Nurdianto and Budy P. Resosudarmo, 2016). The carbon tax in China varied according to different cities, for example, the tax rates were set at 8 $/t-$CO_2$, 7 $/t-$CO_2$, and 4 $/t-$CO_2$ in Beijing, Shenzhen, Chongqing cities respectively (Alexandre Kossoy et al., 2015).

2.9 Carbon Capture and Storage (CCS)

The CO_2 removal from industrial or utility plants and subsequent storage in secure reservoirs is called carbon capture and storage (CCS) (Howard Herzog and Dan Golomb, 2004). Three steps are involved in the CCS process: carbon capture, carbon transport, and carbon storage. Flue gas separation, oxy-fuel combustion in power plants, and pre-combustion separation are the three normal classifications of the CO_2 capturing processes. Two known storage media for the captured CO_2 are geologic sinks and deep ocean (Howard Herzog and Dan Golomb, 2004).

Normally, the CO_2 abatement that can be achieved through the CCS technology ranges from 85% to 90% (IEA, 2010). Similarly, the report of Lawrence Irlam on Global Costs of Carbon Capture and Storage in 2017 states that coal-fired power supply systems equipped with CCS produce about 90% less CO_2 than the coal-fired plants that are not equipped with CCS; including even modern, highly productive coal-fired plants (Lawrence Irlam, 2017). The emissions intensity of the Integrated Gasification Combined Cycle (IGCC) power plants with and without the CCS technology is reported to be 99 kg/MWh and 724 kg/MW respectively whereas that of the Natural Gas Combined Cycle (NGCC) power generation plant with and without the CCS is reported to be 40 kg/MWh and 356 kg/MWh accordingly (Lawrence Irlam, 2017). Bingyin Hu and Haibo Zhai investigated the performance and cost for coal-fired power plants with and without CCS in China (Bingyin Hu and Haibo Zhai, 2017). The net plant efficiency with CCS was found to be 11.3% lower than that of the plant without CCS and the Levelized Cost of Electricity in the CCS-equipped plant was 73% higher than that of the unabated plant. However, the CO_2 emissions rate from the coal-fired plant with and without the CCS are about 0.106 kg/kWh and 0.778 kg/kWh respectively (Bingyin Hu and Haibo Zhai, 2017).

2.10 Demand Forecast Models

2.10.1 The Technological Structure of Energy Demand Projections

Energy and peak load projections are the key factors in IRP because of their ability in assessing the demand for various new resources. Disaggregated projections indentify which efficiency and DSM programs should be selected and when they should be implemented, as well as indicating the end uses and sectors that should implement the programs. Many utilities and planning organizations utilize the two primary solutions now, primarily on an econometric or end-use (engineering) basis (Joel N. Swisher et al., 1997).

2.10.2 Econometric Models

There is a strong theoretical mathematical basis for econometric models, which need less data than end-use models. They are used for a general-purpose without considering who the customers are. Hence, they have a more detailed design than the end-use method focused on technologies.

The most typical form of the econometric equation is focused on the Cobb-Douglas production function in energy studies (Joel N. Swisher et al., 1997):

$$E = a \times Y^{\alpha} \times P^{-\beta} \tag{2.1}$$

where E is the energy demand,

Y is the income,

P is the energy price,

a is the coefficient,

α is the income elasticity of energy demand,

β is the price elasticity of energy demand.

Income and price elasticity demonstrate how energy demand varies due to price and income shifts in econometric models. Income elasticities are determined as (Joel N. Swisher et al., 1997):

$$\alpha = \frac{\Delta E / E}{\Delta Y / Y} = \frac{\%Change \text{ in E}}{\%Change \text{ in Y}} \tag{2.2}$$

where E is the energy demand,

Y is the income (GDP),

α is the income elasticity of energy demand.

The price elasticity β of energy demand is interpreted closely in connection to the price of energy spent by customers (Joel N. Swisher et al., 1997):

$$\beta = \frac{\Delta E / E}{\Delta P / P} = \frac{\%Change \text{ in E}}{\%Change \text{ in P}} \tag{2.3}$$

where E is the energy demand,

P is the price of energy,

β is the price elasticity of energy demand.

The econometric model forecasts the parameters a, α, and β of Equation (2.1) statistically by using past data by mean of regression analysis or other analysis.

2.10.3 End-Use Models

The analysis of End-Use projection models may be simple but are much more detailed than the econometric models. It suits the energy-efficiency projections because of its explicit consideration of changes in technology and service levels. A summation of the products of the level of activity and the energy intensity gives the total energy demand (Joel N. Swisher et al., 1997).

$$Energy\ use = \sum_{i=1}^{i=n} Q_i \times I_i \qquad (2.4)$$

where Q_i is the quantity of energy service i,

I_i is the intensity of energy use for energy service i,

The quantity of energy services Q_i relies on several elements, taking the population into account, the share using the end-use service, and the usage range of each service (Joel N. Swisher et al., 1997).

$$Q_i = N_i \times P_i \times M_i \qquad (2.5)$$

where Q_i is the quantity of energy service i,

N_i is the number of customers eligible for end-use i,

P_i is the penetration (total units/total customers) of end-use service i (can be > 100%),

M_i is the magnitude or extent of use of end-use service i.

2.11 The Costs of Electricity Generation

2.11.1 The Costs of Electricity Generation: The Utility Revenue Requirements

The income requirements of a utility are projected profits that can meet shareholders ' minimum acceptable returns. In the IRP context, the revenue requirement is determined by (Joel N. Swisher et al., 1997):

$$Revenue\ Requirement = C_S + C_D + C_P \qquad (2.6)$$

where C_S is the cost of electricity supply,

C_D is the cost of DSM programs,

C_P is the cost of pollutant emissions.

2.11.2 The Costs of Electricity Generation: The Externality Values

Ideally, part of supply costs would be regarded due to the burdens placed on the community by the environmental effects of the energy market. Including these additional environmental costs would cause clear economic comparisons between traditional technology and greener alternatives, which would still be more expensive. Marginal environmental costs, however, prefer to include marginal energy cost (MEC) rather than capacity costs, and adding environmental cost would prefer, rather than to support peak-demand load management approaches, DSM measures of substantial energy savings. The MEC should be expanded to cover carbon impacts and other externalities due to the corresponding marginal cost of energy (MCOE) (Joel N. Swisher et al., 1997).

$$MEC_{ex} = MEC + \sum_i [\mathrm{C}_{em\,(i)} \times F_{em\,(i)}] \tag{2.7}$$

and

$$MCOE_{ex} = MCOE + \sum_i [\mathrm{C}_{em\,(i)} \times F_{em\,(i)}] \tag{2.8}$$

where MEC_{ex} is the marginal energy cost including environmental externalities,

MEC is the marginal energy cost excluding environmental externalities,

$MCOE_{ex}$ is the cost of energy including environmental externalities,

$MCOE$ is the cost of energy excluding environmental externalities,

$\mathrm{C}_{em\,(i)}$ is the external cost of emissions for impact i ($/kg),

$F_{em\,(i)}$ is the emission factor for impact i (kg/MWh).

2.11.3 The Levelized Cost of Electricity (LCOE)

The Levelized Energy Cost (LCOE) is an additional way of electricity generation comparison measuring. It is the average total cost of production (capital cost + fixed O&M cost + variable O&M cost + fuel cost) per total electricity generation over a lifetime of a power plant. The LCOE is usually expressed as $/kWh and it can be calculated using Equation (2.9) (Chun Sing Lai et al., 2017).

$$LCOE = \frac{C_{cap} + \sum_{n=0}^{N} \frac{C_{O\&M_n} + C_{fuel_n}}{(1+d)^n}}{\sum_{n=0}^{N} \frac{E_n}{(1+d)^n}} \tag{2.9}$$

where $LCOE$ is the Levelized Cost of Electricity,

C_{cap} is the fixed capital cost of the power plant,

$C_{O\&M}$ is the total operation and maintenance cost,

C_{fuel} is the total fuel cost,

E is the total energy production,

n is the lifetime year of the power plant,

d is the discount rate.

2.12 United Nations Framework Convention on Climate Change (UNFCCC)

2.12.1 Introduction to UNFCCC

The United Nations Framework Convention on Climate Change (UNFCCC) is an international environmental treaty adopted in 1992 and entered into force on 21 March 1994 (WHO, 2020). The ultimate objective of this convention is to achieve, following the relevant provisions of the convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner (UNFCCC, 1992).

After the signing of the UNFCCC treaty, the Parties to the UNFCCC have met annually at conferences, called "Conferences of the Parties (COPs)", to discuss how to achieve the treaty's aims. In 2015, parties to the convention came together for the UN Climate Change Conference in Paris and adopted by consensus the Paris Agreement, aimed at limiting global warming to less than two degrees Celsius, and pursue efforts to limit the rise to 1.5 degrees Celsius by the end of the year 2100 (Wikipedia, 2021).

2.12.2 Intended Nationally Determined Contributions (INDCs)

Intended nationally determined contributions (INDCs) are (intended) reductions in greenhouse gas emissions under the UNFCCC. All countries that signed the UNFCCC were asked to publish their INDCs at the 2013 United Nations Climate Change Conference held in Warsaw, Poland, in November 2013 (UNFCCC, 2014; Climate Policy Observer, 2017). The intended contributions were determined without prejudice to the legal nature of the contributions.

Under the Paris Agreement, adopted in December 2015, the INDC will become the first Nationally Determined Contribution (NDC) when a country ratifies the agreement unless it decides to submit a new NDC at the same time. Once the Paris Agreement is ratified, the NDC will become the first greenhouse gas targets under the UNFCCC that applied equally to both developed and developing countries (World Resources Institute, 2014). The timeline of the NDCs submitted to the UNFCCC in 2015 only covers until 2030.

2.12.3 Intended Nationally Determined Contributions (INDCs) of the Selected GMS countries

Cambodia, Lao PDR, Thailand, and Vietnam communicated their NDCs to the UNFCCC in 2015. The NDCs of the four countries aim to reduce the total GHG emissions in the range of 177 to 339 Mt-CO_2eq by 2030 when compared to the Business-as-Usual (BAU) scenario (UNFCCC, 2015_a; UNFCCC, 2015_b; UNFCCC, 2015c; UNFCCC, 2015d; Puttipong Chunark et al., 2017). Cambodia's INDC embodies the target of reducing the national GHG emissions by 3.1 Mt-CO_2eq from the energy industries, manufacturing industries, transport, and other sectors by 2030. In addition, without any restrictions, Cambodia also intends to reduce the GHG emissions from the Land Use, Land-Use Change, and Forestry (LULUCF) sector by 7.897 Mt-CO_2eq by 2030 as well (UNFCCC, 2015_a). On the other hand, no targets of GHG emissions reduction were declared by Lao PDR under its INDC. Nevertheless, its INDC presents the country's intended GHG emissions mitigation measures to show the efforts in reducing the global GHG emissions (UNFCCC, 2015_b). Under the INDC of Thailand, 20-25% of the national GHG emissions would be reduced by 2030, leaving the national GHG emissions at approximately 444-416.25 Mt-CO_2eq by 2030 (UNFCCC, 2015_c).

The GHG emissions reduction will cover the power sector, manufacturing industry, transport sector, commercial sector, residential sector, waste sector, and industrial processes and product use (IPUU) sector (Puttipong Chunark et al., 2017). According to the INDC of Vietnam, Vietnam intends to reduce its national GHG emissions by 8% by 2030 under unconditional contribution and 25% by 2030 under conditional contribution. The eight percent and twenty-five percent of GHG emissions reduction would account for approximately 63 Mt-CO_2eq and 197 Mt-CO_2eq respectively. The national GHG emissions reduction targets will be applied to the energy sector, agriculture sector, waste sector, and LULUCF sector (UNFCCC, 2015$_d$). Table 2.1 presents GHG reduction targets of the selected GMS countries under their INDCs.

Table 2.1 GHG emissions reduction targets in the selected GMS countries under their INDCs (Unit: Mt-CO_2eq).

	Cambodia	Lao PDR	Thailand	Vietnam
Energy sector	1.8	-	113	29.46 - 65.93
Manufacturing industry	0.727	-	-	-
Agriculture sector	-	-	-	6.36 - 45.78
Transport sector	0.39	-	-	-
Waste sector	-	-	2	4.16 - 20.23
Other sector	0.155	-	-	-
IPPU	-	-	0.6	-
LULUCF	-	-	-	22.67 - 66
Total		177.062 - 338.672		

2.13 Intergovernmental Panel on Climate Change (IPCC)

2.13.1 Introduction to the IPCC

The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the science related to climate change. The IPCC was set up in 1988 by the World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation. The IPCC assessments provide a scientific basis for governments at all levels to develop climate-related policies, and they underlie negotiations at the UN

Climate Conference – the United Nations Framework Convention on Climate Change (UNFCCC) (IPCC, 2013).

The IPCC assessments are written by hundreds of leading scientists who volunteer their time and expertise as Coordinating Lead Authors and Lead Authors of the reports. They enlist hundreds of other experts as Contributing Authors to provide complementary expertise in specific areas. The IPCC reports undergo multiple rounds of drafting and review to ensure they are comprehensive and objective and produced openly and transparently. Thousands of other experts contribute to the reports by acting as reviewers, ensuring the reports reflect the full range of views in the scientific community. Teams of Review Editors provide a thorough monitoring mechanism for making sure that review comments are addressed (IPCC, 2013).

2.13.2 Assessment Report of the IPCC

Up until 2020, the IPCC has prepared five comprehensive Assessment Reports (AR) about knowledge on climate change, its causes, potential impacts, and response options:

- First Assessment Report (FAR): 1990
- Second Assessment Report (SAR): 1995
- Third Assessment Report (TAR): 2001
- Fourth Assessment Report (AR4): 2007
- Fifth Assessment Report (AR5): 2014

The AR5 of the IPCC states that it is extremely likely (95-100% probability) that human influence was the dominant cause of global warming between 1951 and 2010. Increasing magnitudes of global warming increase the likelihood of severe, pervasive, and irreversible impacts. Without new policies to mitigate climate change, projections suggest an increase in global mean temperature in 2100 of 3.7 to 4.8℃, relative to pre-industrial levels (median values; the range is 2.5 to 7.8℃ including climate uncertainty). The current trajectory of global annual and cumulative emissions of GHGs is not consistent with widely discussed goals of limiting global warming at 1.5 to 2 degrees Celsius above the pre-industrial level.

2.14 Carbon Budgets

2.14.1 Emissions Gap and Global Effort Sharing

The global greenhouse gas emissions have been increasing since the start of the industrial revolution in 1850 (van den Berg, N.J. et al., 2020). The first Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) described the cause and effects of the greenhouse gas (GHG) concentrations in the earth's atmosphere in 1990 (Houghton, J T et al., 1990).

Nationally Determined Contributions (NDCs) of the countries have been declared in order to comply with the goal of the Paris Agreement (UNFCCC, 2015_e). However, even taking into account the NDCs declaration, the report of the United Nations Environment Programme (UNEP) entitled Emissions Gap Report 2019 stated that the emissions gap to imply for the 2-degree goal or 1.5-degree target is still large. In 2030, annual world emissions need to be 15 Gt-CO_2eq lower than the unconditional NDCs target to reach the 2-degree goal, and 32 Gt-CO_2eq lower for the 1.5-degree target as can be seen from Figure 2.4 (United Nations Environment Programme, 2019).

The world needs to limit its carbon budgets even lower than the NDCs targets to ensure the possibility of reaching the Paris Agreement goal. To do that, each country needs to contribute its effort to the reduction targets. The effort sharing must consist of fairness so that participation from each country is ensured.

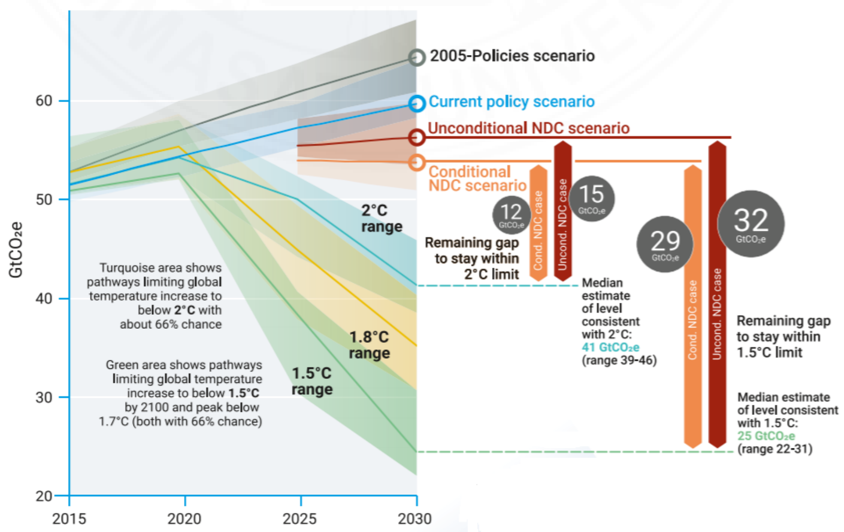

Figure 2.4 Global emissions gap by 2030.

Source: United Nations Environment Programme, 2019.

2.14.2 Effort Sharing Approaches for Carbon Budgets Estimation

In industrialized countries like Europe, the European Union (EU) issued legislations called Effort Sharing Decision (ESD) and Effort Sharing Regulation (ESR) in 2009 and 2018 respectively. The binding national GHG targets of the EU's members would reach a 10% reduction by 2020 in the ESD whereas, in the ESR, the binding targets would reach a 30% cut by 2030 when compared to 2005. Under both legislations, every member state in the EU has a different annual GHG emissions target for the periods 2013-2020 and 2021-2030 respectively. To ensure fairness on the reduction targets of each member of the EU, the EU allocated the targets based on the Member States' gross domestic product (GDP) per capita compared to the EU average GDP per capita. However, the Member States that have the GDP per capita above the EU average GDP per capita are adjusted to reflect cost-effectiveness in a fair manner (European Union, 2016).

There is no commonly agreed way to define or measure a fair and ambitious mitigation contribution for each country (Xunzhang Pan et al., 2017). In different parts of the world, various effort-sharing approaches have been proposed based on the equity principles which are general concepts of distributive fairness. Höhne et al. compared an extensive number of studies on the regional GHG reduction targets based on effort sharing in 2014 and stated that the four most common effort sharing approaches are based on the categories such as responsibility, capability, equality, and cost-effectiveness (Niklas Höhne et al., 2014).

2.14.2.1 Grandfathering (GF) Approach

Nicole J. van Berg et al. did a study on the implications of various effort-sharing approaches for national carbon budgets and emissions pathways using a grandfathering approach (van den Berg, N.J. et al., 2020). Robiou du Pont et al. discussed the equitable mitigation to achieve the Paris Agreement goals using the constant emissions ratio approach (Robiou du Pont et al., 2016). Based on the study of Nicole J. van den Berg, et al., the grandfathering approach falls under the category of "acquired rights" that is justified by established custom and usage. Nicole J. van den Berg et al. also confirmed that the GF approach is one of the most effective cost optimization approaches for most countries. The GF approach is grouped within the staged approach which is believed to be a fair choice for developing countries (Xunzhang Pan et al., 2017). The methodology for the carbon budgets for a country or a region in this approach is based on the base-year emissions share of the country or region. The calculation for the carbon budget of this approach is shown in Equation (2.10).

$$b_i GF = \frac{e_{i,t=2010}}{E_{t=2010}} \cdot B \qquad (2.10)$$

where b is the national or regional budget allowance,
i is the region,
t is the year (2010 is the base-year in this case),
B is the global carbon budget.

Besides the carbon budgets, the emissions pathway of the GF approach can also be determined using Equation (2.11).

$$a_i GF = \frac{e_{i,t=2010}}{E_{t=2010}} \cdot A_t \qquad (2.11)$$

where a is the national or regional emission allowance,
A is the global emission allowance.

2.14.2.2 Immediate per capita convergence (IEPC) Approach

Robiou du Pont et al. discussed the equitable mitigation to achieve the Paris Agreement goals using the equal per capita approach (Robiou du Pont et al., 2016). Nicole J. van Berg et al. did a study on the implications of various effort-sharing approaches for national carbon budgets and emissions pathways using the immediate per capita convergence (IEPC) approach (van den Berg, N.J. et al., 2020). The IEPC approach is based on the equality of shared humanity and the value to all humans of global collective goods (i.e. equal individual rights to atmospheric space). The IEPC approach stands on the equality concept which prioritizes that all humans have equal rights to atmospheric space (van den Berg, N.J. et al., 2020). The methodology for the carbon budgets for a country or a region in this approach is based on the average population shares during the base year and the end year. The calculation for the carbon budget and the emission pathway of this approach are shown in Equation (2.12) and Equation (2.13) respectively.

$$b_i IECPC = \frac{\sum_{t=2010}^{2050} pop_{i,t}}{\sum_{t=2010}^{2050} POP_t} \cdot B \qquad (2.12)$$

where *b* is the national or regional budget allowance,

i is the region,

t is the year (2010 is the base-year, 2050 is the end-year in this case),

B is the global carbon budget,

pop is the national or regional population,

POP is the global population.

$$a_{i,t} IECPC = \frac{pop_{i,t}}{POP_t} \cdot A_t \qquad (2.13)$$

where *a* is the national or regional emission allowance,

A is the global emission allowance.

2.14.2.3 Per capita convergence (PPC) Approach

Nicole J. van Berg et al. did a study on the implications of various effort-sharing approaches for national carbon budgets and emissions pathways using the per capita convergence (PCC) approach (van den Berg, N.J. et al., 2020). The PPC approach is the combination of the GF approach and the IEPC approach. Nicole J. van Berg et al. also confirmed that the PCC approach is the other most effective cost optimization approach for most countries. The methodology for the carbon budgets for a country or a region in this approach is based on both the current emissions shares and population shares of the country or region. The calculation for the carbon budget of this approach is shown in Equation (2.14).

$$b_i PCC = (1-w) \cdot b_i GF + (w \cdot b_i\ IEPC) \qquad (2.14)$$

where *b* is the national or regional budget allowance,

i is the region,

w is the weighting factor.

The emission pathway of the PCC approach is calculated using Equation (2.15) below.

$$a_{i,t}PCC = A_t \cdot \begin{pmatrix} MIN(\frac{t-2010}{tconv-2010},1)\cdot\frac{pop_{i,t}}{POP_t} \\ +MAX(1-\frac{t-2010}{tconv-2010},0)\cdot\frac{e_{i,t=2010}}{E_{t=2010}} \end{pmatrix} \tag{2.15}$$

where *a* is the national or regional emission allowance,

tconv is the convergence year in the PCC approach,

A is the global emission allowance.

2.14.2.4 Equal cumulative per capita emissions (ECPC) Approach

Raupach et al. estimated the carbon budget for the world using the equal per-capita distribution of cumulative emissions (Davis et al., 2014). Robiou du Pont et al. discussed the equitable mitigation to achieve the Paris Agreement goals using the equal cumulative per capita approach (Robiou du Pont et al., 2016). Nicole J. van Berg et al. did a study on the implications of various effort-sharing approaches for national carbon budgets and emissions pathways using equal cumulative per capita emissions (ECPC) approach (van den Berg, N.J. et al., 2020). The ECPC approach is an approach that is based on equality and responsibility. This approach ensures that the cumulative emissions per capita in all countries are equal during a certain period. The methodology in this approach is based on the historical cumulative emissions and the share of the population. The calculation for the carbon budget of this approach is shown in Equation (2.16) and Equation (2.17).

$$Debt_i = \sum_{t=s}^{2010} \frac{pop_{i,t}}{POP_t} \cdot E_t \cdot d_t - e_{i,t} \cdot d_t \tag{2.16}$$

$$b_i ECPC = \frac{\sum_{t=2010}^{2050} pop_{i,t}}{\sum_{t=2010}^{2050} POP_t} \cdot B + Debt_i \tag{2.17}$$

where *b* is the national or regional budget allowance,

t is the year (2010 is the base-year, 2050 is the end-year in this case),

s is the historical starting year,

i is the region,

d is the discount factor,

B is the global carbon budget,

pop is the national or regional population,

POP is the global population.

2.14.2.5 Ability to pay (AP) Approach

Robiou du Pont et al. discussed the equitable mitigation to achieve the Paris Agreement goals using the capability approach (Robiou du Pont et al., 2016). Nicole J. van Berg et al. did a study on the implications of various effort-sharing approaches for national carbon budgets and emissions pathways using the ability to pay (AP) approach (van den Berg, N.J. et al., 2020). According to Nicole J. van Berg et al., the AP approach leads to overestimation for the developing countries but underestimation for the developed countries. The AP approach is based on the ability to bear the burden. The methodology for the carbon budgets for a country or a region in this approach is based on the average GDP per capita over the period between the base year and the end year. The calculation for the carbon budget of this approach is shown from Equation (2.18) to Equation (2.20).

$$rb_i AP = \sqrt[3]{\frac{\sum_{t=2010}^{2050} gdp_{i,t} \cdot \sum_{t=2010}^{2050} \frac{GDP_t}{POP_t}}{\sum_{t=2010}^{2050} pop_{i,t}}} \cdot \sum_{t=2010}^{2050} \frac{BAU_t - B}{BAU_t} \cdot \sum_{t=2010}^{2050} bau_{i,t} \tag{2.18}$$

$$corr\_rb = \frac{\sum_{i}^{N} rb_i AP}{\sum_{t=2010}^{2050} BAU_t - B} \tag{2.19}$$

$$b_i AP = \sum_{t=2010}^{2050} bau_{i,t} - \frac{rb_i AP}{corr\_rb} \tag{2.20}$$

where *r* is the reduction before correction factor,

corr_r is the global correction factor,

gdp is the national or regional GDP,

GDP is the global GDP,

pop is the national or regional population,

POP is the global population,

bau is the national or regional baseline emissions,

BAU is the global baseline emissions,

N is the number of regions,

b is the national or regional carbon budget,

B is the global carbon budget,

i is the country or region, t is the year (2010 is the base-year, 2050 is the end-year).

The emission pathway of the AP approach can be calculated using Equation (2.21) below.

$$a_{i,t}AP = bau_{i,t} - \frac{\sqrt[3]{\left(\frac{gdp_{i,t} \cdot POP_t}{GDP_t \cdot pop_{i,t}}\right)} \cdot \frac{BAU_t - A_t}{BAU_t} \cdot bau_{i,t}}{\frac{\sum_i^N (\sqrt[3]{\left(\frac{gdp_{i,t} \cdot POP_t}{GDP_t \cdot pop_{i,t}}\right)} \cdot \frac{BAU_t - A_t}{BAU_t} \cdot bau_{i,t})}{BAU_t - A_t}} \qquad (2.21)$$

where a is the national or regional emission allowance,

A is the global emission allowance.

2.14.2.6 Greenhouse development rights (GDR) Approach

Chakravarty et al. studied the allocation of CO_2 emissions among one billion high emitters by using the concept of “common but differentiated responsibilities” (Shoibal Chakravarty et al., 2009). Robiou du Pont et al. discussed the equitable mitigation to achieve the Paris Agreement goals using the greenhouse development rights approach (Robiou du Pont et al., 2016). Nicole J. van Berg et al. did a study on the implications of various effort-sharing approaches for national carbon budgets and emissions pathways using greenhouse development rights (GDR) (van den Berg, N.J. et al., 2020).

Based on Nicole J. van Berg et al., the GDR approach allocates large budgets to the developing countries which makes it suitable for the developing countries since reducing emissions affects the economic development of the countries. However, this approach is not preferable if applied to the industrialized countries which have already emitted a big portion of the world's emissions. The GDR approach safeguards people’s right to reach a dignified level of sustainable human development. This approach considers both the responsibility and capability of a country or a region to determine the carbon budget. The methodology in this approach is based on the Responsibility-Capacity Index (RCI) that includes GDP per capita and measures of the income distribution. The calculation for the carbon budget of this approach is shown in Equation (2.22).

$$b_i GDR = \sum_{t=2010}^{2050} bau_{i,t} - \left(\sum_{t=2010}^{2050} BAU_t - B\right) \cdot \left(\sum_{t=2010}^{2050} \frac{rci_i}{2050 - 2010}\right) \tag{2.22}$$

where *b* is the national or regional carbon budget,
bau is the national or regional baseline emissions,
BAU is the global baseline emissions,
B is the global carbon budget,
rci is the national or regional responsibility capability index,
i is the country or region,
t is the year (2010 is the base-year, 2050 is the end-year).

In addition, the emissions pathway of the GDR approach can also be viewed using Equation (2.23) and Equation (2.24) below.

For $t < 2031$:

$$a_{i,t} GDR = bau_{i,t} - (BAU_t - A_t) \cdot rci_{i,t} \tag{2.23}$$

For $t > 2030$:

$$\begin{aligned} a_{i,t} GDR = {} & ((2100 - t)/70) \cdot bau_{i,t} - (BAU_t - A_t) \cdot rci_{i,2030} \\ & + ((t - 2030)/70) \cdot a_{i,t} PCC \end{aligned} \tag{2.24}$$

where *a* is the national or regional emission allowance,
A is the global emission allowance.

2.15 Marginal Abatement Cost

To assess emissions mitigation policies, policymakers have been using the Marginal Abatement Cost (MAC) concept to assign preference to viable technologies in order to implement the correct and cost-efficient emissions mitigation options (Kamphol Promjiraprawat et al., 2014). The MAC curve enables policymakers to have a clear vision of the potential of emissions reduction and its abatement costs. The MAC curve classifies the emissions mitigation technologies from the cheapest to the most costly. The marginal abatement cost is calculated using Equation (2.25) below (Phitsinee Muangjai et al., 2020):

$$MAC = \frac{C_{PS,y} - C_{BS,y}}{E_{BS,y} - E_{PS,y}} \quad (2.25)$$

where MAC is the Marginal Abatement Cost of electricity generation (\$/t-CO_2eq),

$C_{PS,y}$ is the electricity generation cost in policy scenario in year y (\$/kWh),

$C_{BS,y}$ is the electricity generation cost in baseline scenario in year y,

$E_{PS,y}$ is the GHG emission in policy scenario in year y (t-CO_2eq/kWh),

$E_{BS,y}$ is the GHG emission in the baseline scenario in year y (t-CO_2eq/kWh).

2.16 Energy Commodity

Due to the fact that global fossil fuels such as coal, oil, diesel, and natural gas are depleting as time goes by, the prices of these fuels are increasing as well. The prices of diesel for transportation and crude oil have increased by approximately 1.8 times during 2000-2015 while the price of natural gas has decreased around 0.4 times during the same period (U.S. Energy Information Administration, 2020).

In 2015, the prices of coal, natural gas, diesel, oil, biomass, and uranium werr reported to be 49 $ per ton of coal equivalent, 2.61 $/Mbtu, 52.6 $/barrel, 50.8 $/barrel, 3.55 $/Mbtu, and 35.5 $/lb respectively (EREA & DEA, 2019; U.S. Energy Information Administration, 2020; N. Sönnichsen, 2020; Cameco, 2020). These prices are expected to increase at different rates by 2030 as listed in Table 2.2 (EREA & DEA, 2019; U.S. Energy Information Administration, 2018).

The increasing prices and the uncertainties in the energy prices would affect the future electricity prices of the nations whose power system relies strongly on fossil fuels. This will lead to the existence of economic development obstacles for the developing countries as well as the industrialized countries.

Table 2.2 Energy commodity.

Fuel	Price in 2015	Price in 2050
Coal	49 $/tce	64 $/tce
Natural gas	2.61 $/Mbtu	10 $/Mbtu
Diesel	52.6 $/barrel	119.7 $/barrel
Oil	50.8 $/barrel	70 $/barrel
Biomass	3.55 $/Mbtu	*3.55 $/Mbtu
Nuclear	35.5 $/lb	*35.5 $/lb

Note: * Price in 2050 is assumed to stay the same as in 2015.
tce = ton of coal equivalent.

CHAPTER 3
METHODOLOGY

3.1 Overview Methodology of the Thesis

This thesis is made up of different stages as can be seen from Figure 3.1. First of all, the collected data are analyzed and then divided into three different scenarios: Business-as-Usual (BAU), Improved Energy Efficiency (IEE), and Renewable Energy Technologies (RET). The data are then inputted into the LEAP model for the modeling process to get the results. In addition to the results from the LEAP model, the analyses of emissions gap, marginal abatement cost, and carbon budgets are also included in the study.

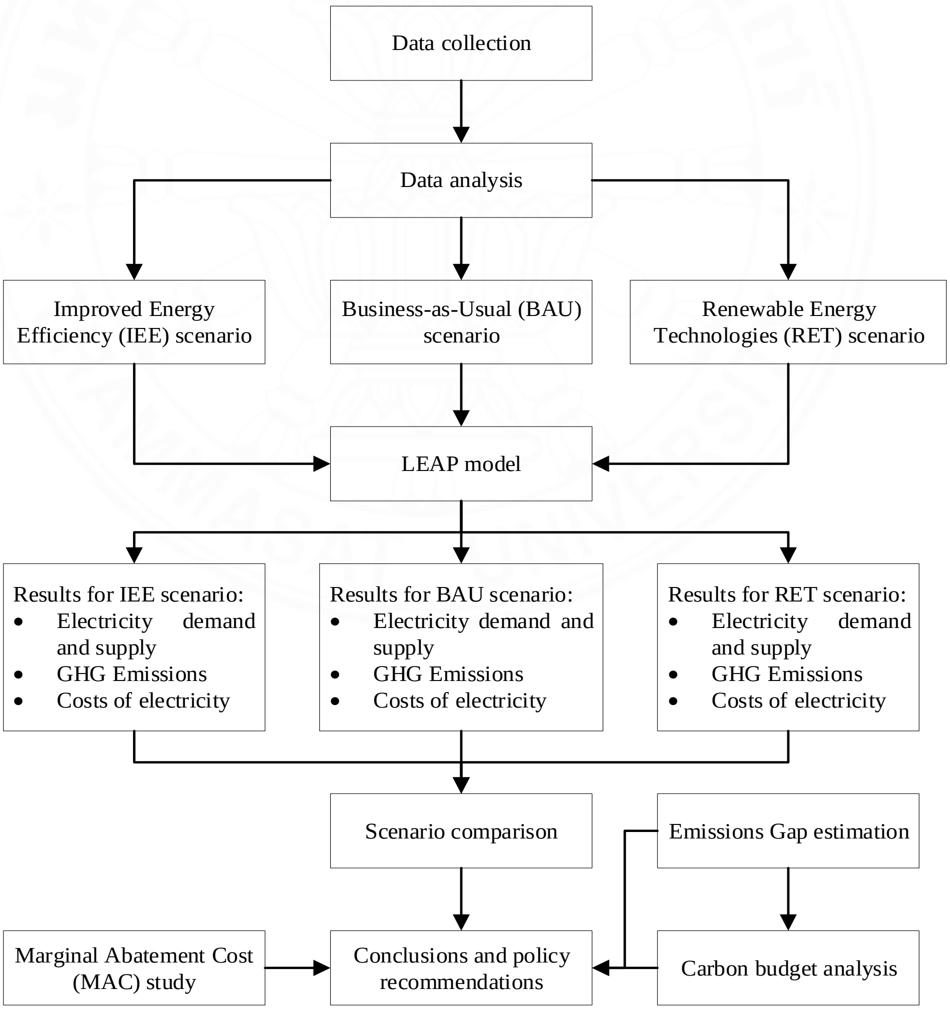

Figure 3.1 Methodology flowchart of the thesis.

3.2 LEAP Model

LEAP is an energy policy review and climate change mitigation evaluation software program produced by the Stockholm Environment Institute (SEI) (Heaps, C.G., 2021). LEAP includes a comprehensive structure in energy system accounting, which requires all demand and supply-side infrastructure to be taken into account and brings total system impacts into account. LEAP will track pollutants from each phase of the fuel chain by adding them to the environmental network. It includes lowering GHG emissions from processing, storage, delivery, and production that could come from more productive use of energy or other forms of fuel (Lazarus, M. et al., 1994).

LEAP includes a technology and environmental database (TED), which contains a variety of functional features, cost, and environmental consequences, including existing, best available practice and next-generations technologies. LEAP is a scenario-based accounting and modeling software to evaluate the effects of power generation LFG on the Korean energy system. (Shin, H.-C. et al., 2005). Tri Vicca Kusumadewi, et al. did a scenario-based study on GHG mitigation in the power sector in Thailand using LEAP Model (Tri Vicca Kusumadewi, et al, 2017). Nigeria's LEAP model structural strategies will have a remarkable effect on energy consumption reduction and GHG released (Emodi, N. V. et al., 2017). Consequently, the use of LEAP is very significant in forecasting energy demand and in producing CO_2 reductions as per the necessity of the research to be conducted (J.A. Nieves et al., 2019). Nayyar Hussain Mirjat et al. did a study on the long-term electricity planning for Pakistan from 2015-2050 using the LEAP model for policies review in 2018 (Nayyar Hussain Mirjat et al., 2018). The versatile data framework of the long-range energy alternative planning model (LEAP) is used for classifying demand for electricity, power production, and GHG pollution from the power sector with specific scenarios (Lyheang Chhay and Bundit Limmeechokchai, 2019). The accounting framework of LEAP compares supply-side energy technology with network impacts such as electricity generation by configuration, resource scarcity, electricity costs, and climate change possibilities (Madeleine McPherson and Bryan Karney, 2014).

The existing research applications of the LEAP Model stand as proof that the LEAP Model is widely used all around the globe and is reliable and suitable to project alternative scenarios to examine the energy demand and generation, policies, and GHG emissions.

3.2.1 Data Requirement of LEAP Model

It is almost not possible to point out the LEAP's data requirements because it is a tool used to build different area models. Its data requirements mostly depend on the model of the data set (aggregate or disaggregated) that the user wants to develop. However, the following points are some of the basic data that will be stated to help users develop an initial national-level LEAP data set (Clima-Med, n.d.).

- Demographic data (Population, household sizes, urbanization rates…)
- Economic data (GDP, income level, value-added…)
- General energy data (National energy balances, national energy policies…)
- Demand data (Activity level, energy intensity, historical demand…)
- Transformation data (Historical installed capacities, historical energy generation, operating cost, capital cost…)

3.2.2 Modelling Methodologies of LEAP Model

LEAP supports various modeling methods: from the top-down, end-use accounting approaches to macroeconomic simulations, on the demand side. Figure 3.2 shows the structure of the LEAP model (Heaps, C.G., 2021).

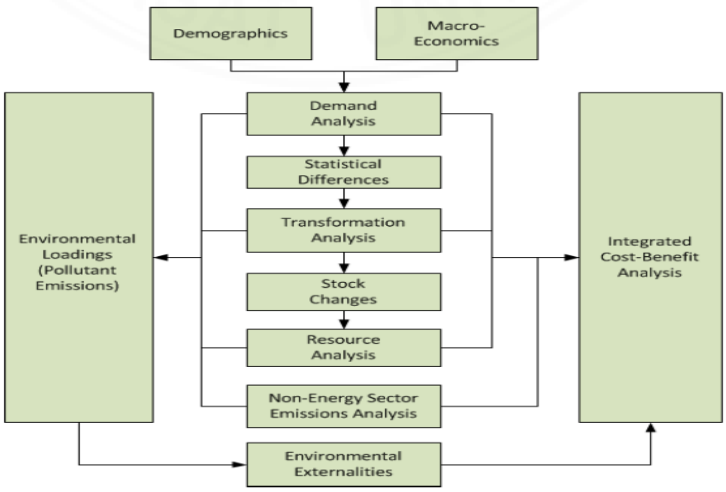

Figure 3.2 LEAP model's structure.

In terms of supply-side, LEAP provides a variety of accounting techniques, modeling, and optimization, efficient enough to model the generation of electrical industries.

3.2.3 Schematic Diagram of LEAP Model in the Study

The schematic diagram of the LEAP model in this study is constructed under various steps. Figure 3.3 illustrates the schematic diagram of the LEAP model in this study.

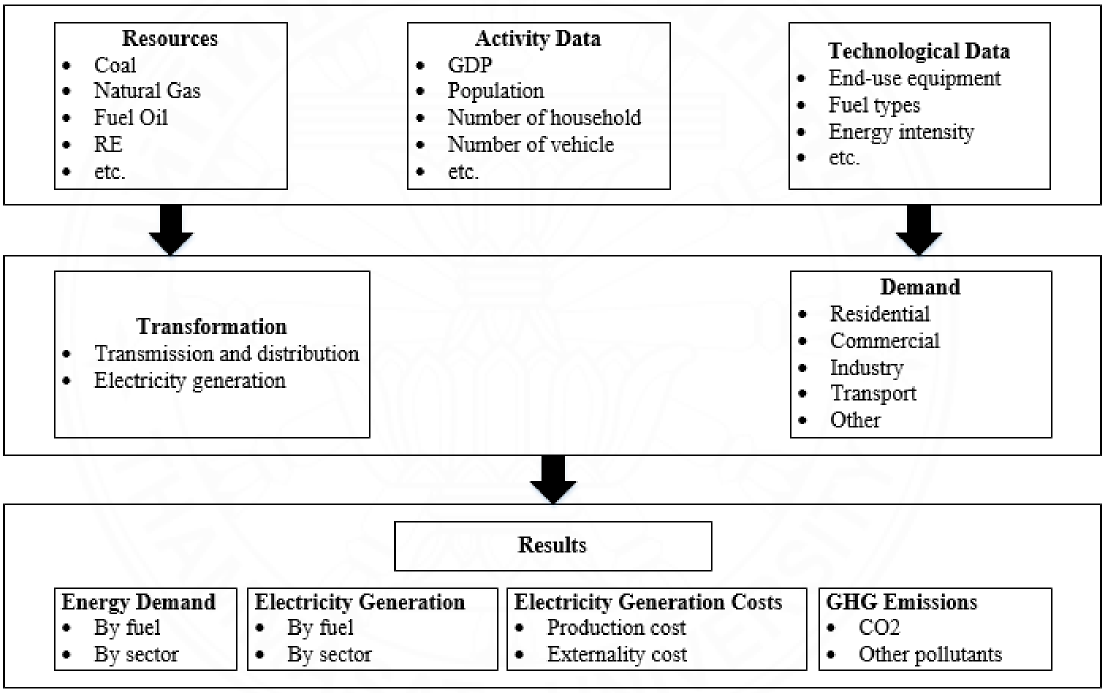

Figure 3.3 Schematic diagram of Cambodia's LEAP model in the study.

3.2.4 Model of selected GMS Countries' Power Generation

The power generation in Cambodia, Lao PDR, Thailand, and Vietnam is constructed under the transformation module of the LEAP model. Historical production, installed capacity, plant efficiency, dispatching rule, merit order, lifetime and end-use energy demand are the key parameters in the LEAP modeling. The power plant technology in the LEAP model in Cambodia consists of coal, natural gas, diesel, hydro, biomass, and solar power plants. Unlike Cambodia, the power plants technology in Lao PDR and Thailand consists of a variety of technologies such as bituminous coal and lignite, natural gas, diesel, fuel oil, municipal solid waste, wind, hydro, solar, biomass, and biogas power plants as can be seen from Figure 3.4, Figure 3.5, Figure 3.6, and Figure 3.7.

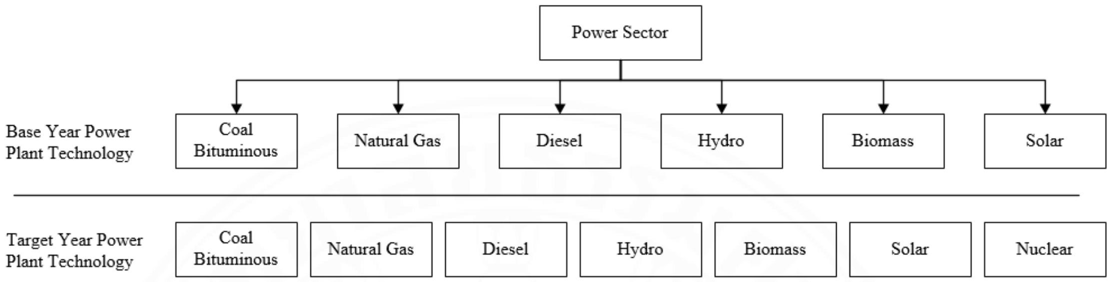

Figure 3.4 Structure of Cambodia's electricity generation in the LEAP model.

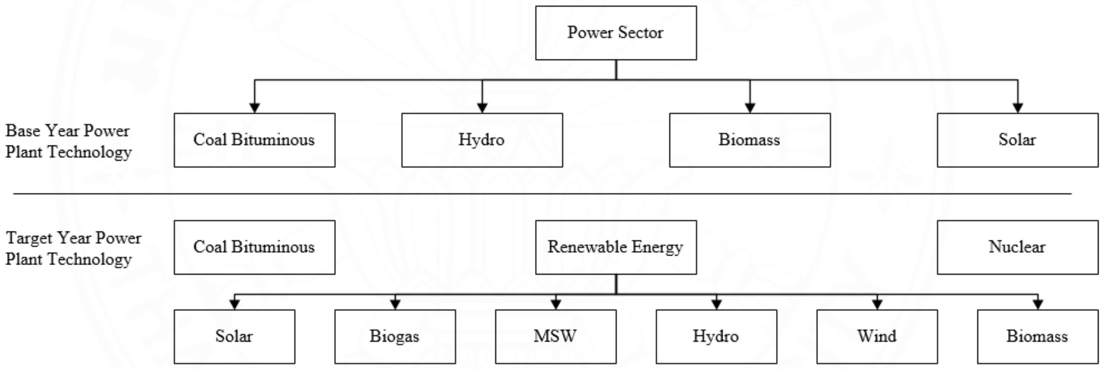

Figure 3.5 Structure of Lao PDR's electricity generation in the LEAP model.

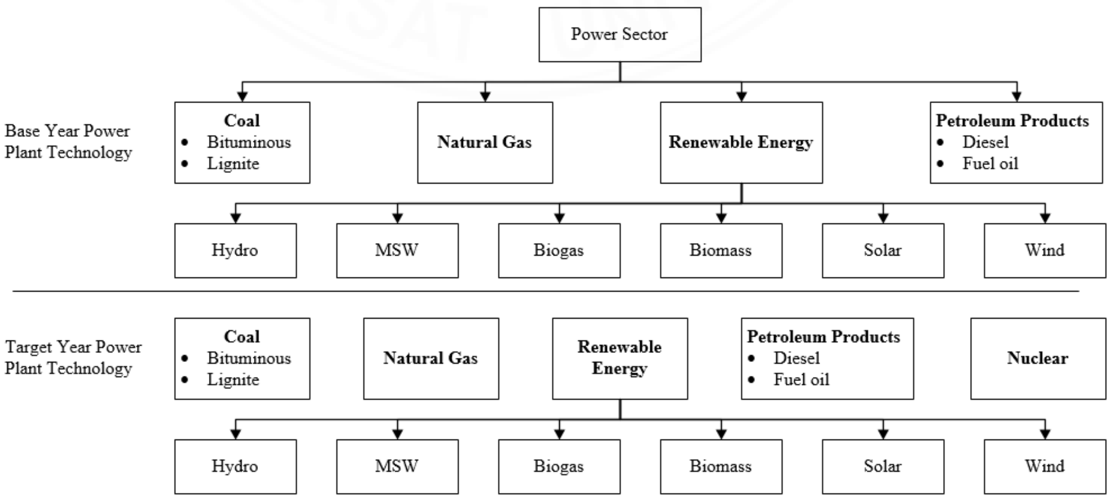

Figure 3.6 Structure of Thailand's electricity generation in the LEAP model.

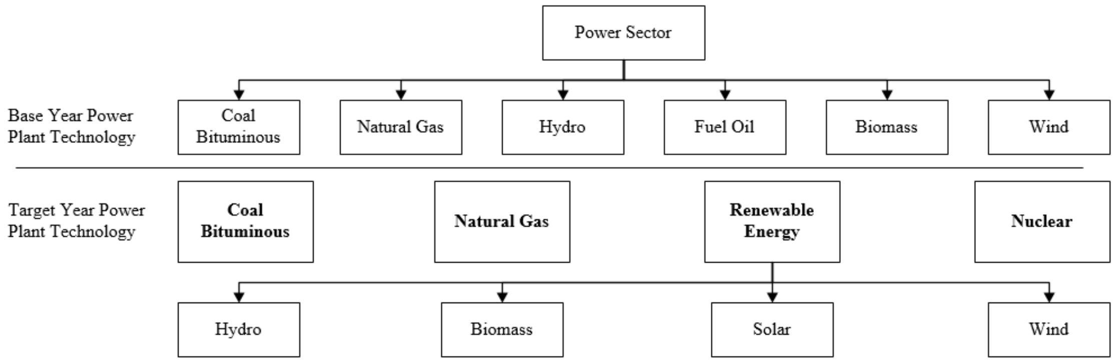

Figure 3.7 Structure of Vietnam's electricity generation in the LEAP model.

3.2.5 The Algorithm of the LEAP Model

Within the LEAP concept, there is the energy usage calculation, carbon emissions, and transformation (electricity production, oil refining, coal mining). In the LEAP model, the values are entered using the necessary information, which can be open to the customer. The following portions are listed.

3.2.5.1 Energy Consumption

The total consumption of energy is estimated as follows (Feng YY, et al., 2012):

$$EC_n = \sum_i \sum_j AL_{n,j,i} \times EI_{n,j,i} \tag{3.1}$$

where EC reflects a sector's aggregate energy use, AL is the activity level. EI is the energy intensity, n is the fuel type, i is the sector, and j is the device.

The transformation's net energy consumption is determined according to:

$$ET_s = \sum_m \sum_t ETP_{t,m} \times \left(\frac{1}{f_{t,m,s}} - 1 \right) \tag{3.2}$$

where ET is the transformation's net energy use, ETP is the energy transformation commodity, f is the efficiency of energy transformation, s is the class of primary energy, m is the machinery, and t is the class of secondary energy.

3.2.5.2 Transformation

The transformation section converts the primary energy to the secondary energy and also consists of the conversion of electricity transmission and distribution centers.

The transformation section includes power plants, petroleum refineries, coal mining, etc. (Lazarus ML et al., 1997):

For each process p:

$$INPUT_P = \frac{OUTPUT_P}{EFFICIENCY_P} \quad (3.3)$$

For a Transmission and Distribution module:

$$EFFICIENCY_P = 1 - LOSSES_P \quad (3.4)$$

where the fuel or feedstock is $INPUT$, $OUTPUT$ is the electricity generated, or the refinery outcome, $EFFICIENCY$ is the power plants or refinery plant efficiency.

3.2.5.3 Carbon Emission

The carbon emission is measured in the following way from final energy consumption (Feng YY, et al., 2012):

$$CEC = \sum_i \sum_j \sum_n AL_{n,j,i} \times EI_{n,j,i} \times EF_{n,j,i} \quad (3.5)$$

Where the carbon emission is CEC, AL is the activity level, EI is the energy intensity, and is the carbon emission factor from fuel type n for machinery j from sector i. The emission of carbon is measured according to the following:

$$CET = \sum_s \sum_m \sum_t ETP_{t,m} \times \frac{1}{f_{t,m,s}} \times EF_{\mathrm{t,m,s}} \quad (3.6)$$

where the carbon emission is CET, ETP is the energy transformation commodity, f is the efficiency of energy transformation, and is the emission factor from one unit of primary fuel type s consumed for generating secondary fuel type t by machinery m.

CHAPTER 4
ENERGY AND GHG EMISSIONS IN SELECTED GMS COUNTRIES

4.1 Geography of the Selected GMS Countries

The selected Greater Mekong Sub-region countries are located in Southeast Asia and are neighbors to each other. The four countries are home to nearly 200 million people. Vietnam has the highest population which accounts for more than 50% of the total population of the four countries, followed by Thailand which accounts for around 37%.

Figure 4.1 Map of selected GMS countries.

4.2 Economic Situation in the Selected GMS Countries

The four selected countries were known to be developing countries in 2015. In the same year, the combined GDP of the four countries was 626.94 Billion USD.

Thailand is the leading country among the four countries in terms of GDP and accounted for 64% of the total GDP of the four countries in 2015. During 2005-2015, the average GDP growth of Cambodia, Lao PDR, Thailand, and Vietnam saw significant growth. Cambodia had an average GDP growth of 8.3% whereas Lao PDR, Thailand, and Vietnam had 8.6%, 3.8%, and 6.87% respectively.

4.3 Energy Situation in the Selected GMS Countries

4.3.1 Electricity Demand and Generation

The electricity demand in the selected GMS countries will be increased from 41 TWh in 1990 to 1,532.27 TWh in 2050 while the electricity generation in 1990 was 54.6 TWh and will be increased to 1,655.65 TWh in 2050. Figure 4.2 shows the historical and future electricity demand and generation within the four countries.

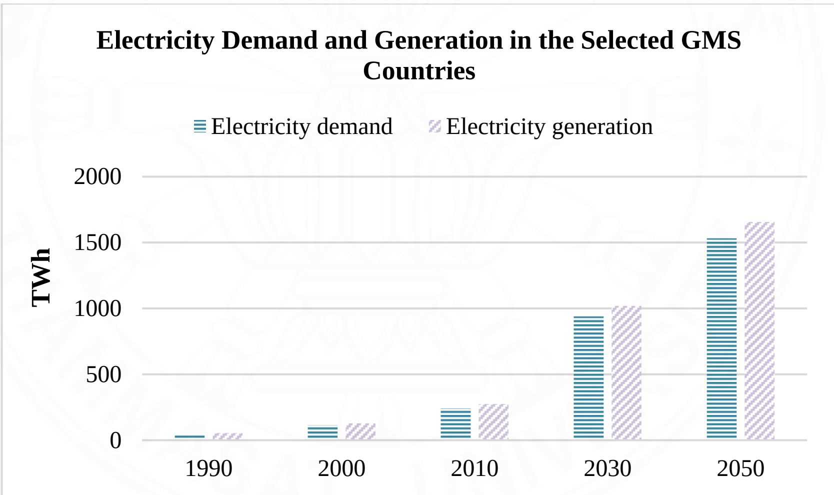

Figure 4.2 Historical and future electricity demand in the selected GMS countries.

Source: Asian Development Bank, 2008; EDC, 2010; ERIA, 2018; ERIA, 2019; Chhay Lyheang, and Bundit Limmeechokchai, 2018; IES & MKE, 2016$_a$; EGAT, 2001; EPPO, 2020; Kong Pagnarith, Bundit Limmeechokchai, 2015; Tri Vicca Kusumadewi et al., 2017; IEA, 2020; IES & MKE, 2016$_b$.

4.3.2 Renewable Energy

Potential alternative resources such as hydro, biomass, geothermal, wind, and solar are yet to be explored in the selected GMS countries. Table 4.1 shows the potential of renewable energy sources in the countries.

Table 4.1 Potential of renewable energy sources in the selected GMS countries.

	Cambodia	Lao PDR	Thailand	Vietnam
Hydro*	10,000	26,000	15,155	35,000
Biomass	15.89	7.02	136.4	373.9
Geothermal*	-	-	-	300-400 (2015)
Wind	154	1112	899	64.35
Solar	11.9	11.7	33.4	18

Unit: TWh/year, * Unit: MW

Source: Tran H.N., 2018; Pagnarith, K. and Limmeechokchai, B., 2009; Tun, M.M. et al., 2019; Asian Development Bank, 2015$_a$; Ministry of Energy, 2015; Vietnam National Mekong River Committee, "n.d."; Phomsoupha, X., 2009; Kanit Aroonrat and Somchai Wongwises, 2015.

4.4 GHG Emissions Situation in the Selected GMS Countries

The emissions of GHG from the power sector in the selected GMS countries in 1990 were 35.23 Mt-CO_2eq in 1990 and will increase to 1,209.3 Mt-CO_2eq in 2050. Figure 4.3 shows the total historical and future GHG emissions from the power sector within the countries during 1990-2050.

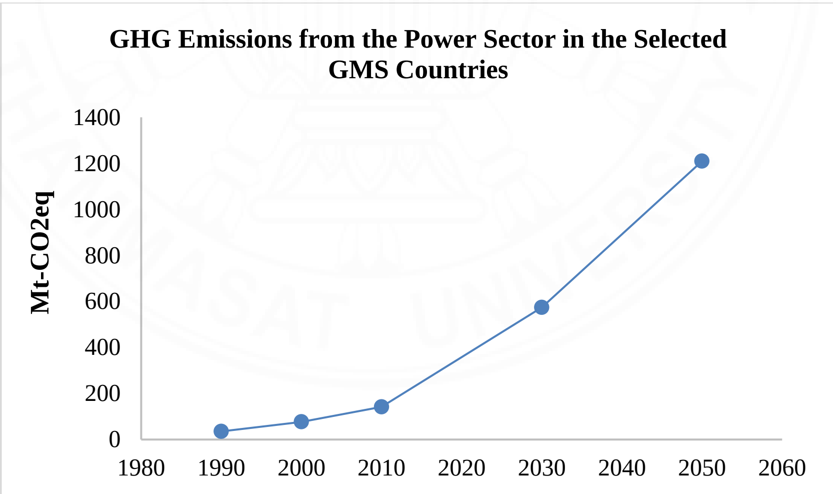

Figure 4.3 Historical and future GHG emissions from the power sector in the selected GMS countries.

Source: CAIT Climate Data Explorer, 2015; GSSD, 2015; Green Climate Fund, 2019; Roman Roehrl and Dennis Tirpak, 2014; IES & MKE, 2016; Rajbhandari, S. et al., 2019; An Ha Truong et al., 2018; Asian Development Bank, 2017.

4.5 Renewable Energy Policy in the Selected GMS Countries

4.5.1 Cambodia

The Cambodian Government is dedicated to renewable energy development. The administration has developed Cambodia's energy policy to ensure a fair and sustainable energy supply throughout Cambodia. The National Policy on Rural Electrification seeks to provide rural areas with an equal and balanced supply of efficient, secure, healthy, and reasonably priced electricity focused predominantly on renewable energy sources,. A detailed domestic strategy that encourages the usage of renewable energy to reduce greenhouse gas pollution is the National Climate Change Strategic Plan 2014-2023 (ERIA, 2019).

The Cambodian government has made a significant effort to decrease the carbon concentration of its energy sector. Through its INDC, Cambodia suggested a 16% cut in the business-as-usual 2030 energy sector to mitigate greenhouse gas mitigation, depending on the availability of international aid. In 2013, the Prime Minister unveiled a strategic plan to foster a greener and more equitable development, which includes growing renewable deployment and promoting loan for a sustainable project, the Cambodian Climate Change Strategic Plan 2014-2023, the National Policy for Green Growth 2013-2023 and the National Strategic Plan for Green Growth 2013-2030 (ERIA, 2019). Although measures and policies in the energy sector are implemented by the Cambodian government, some of them linked to the usage of RE, the government still has not set a national target for the use of RE.

4.5.2 Lao PDR

In 2011, the Lao PDR government set a goal to promote RE growth so that energy stability, socioeconomic prosperity, and environmental and social sustainability progress can be assured as a significant component of domestic economic prosperity through the master plan called The Renewable Energy Development Strategy in Lao PDR. In 2025, the government expects to have expanded green energies to 30% of overall electricity use. The government has set a goal of achieving ten percent of the overall transport energy use of biofuels in order to reduce fossil fuel imports (GoL, 2011). Table 4.2 shows the potential and capacity of RE development to meet a 30% target until 2025 in Lao PDR.

Table 4.2 Potential and capacity of renewable energy development until 2025.

Item	Renewable Energy Types	2015		2025	
		MW	ktoe	MW	ktoe
A	Electricity	140	89	728	416
B	Bio-fuel	-	20	-	662
C	Thermal energy	-	62	-	400
Energy demand (ktoe)		-	2,504	-	4,930
Renewable energy contribution		-	172	-	1479
Proportion		-	7%	-	30%

4.5.3 Thailand

Renewable energy development is expected to be incorporated within a separate energy strategy as part of an overarching climate program so that all the plans can be compatible. Thailand's Alternative Energy Development Plan 2015 (AEDP2015) aims at the substitution of final energy used in the form of electricity, heat, and biofuel by renewable energies up to 30% by 2036 (Ministry of Energy, 2015). Table 4.3 presents the target of the AEDP2015 of Thailand.

Table 4.3 Target of AEDP2015.

Share of Renewable Energy in Final Energy Consumption			
Energy	Share of RE (%)		Final Energy Consumption at 2036 (ktoe)
	Status as of 2014	Target by 2036	
Electricity: Electricity	9	15 - 20	27,789
Heat: Heat	17	30 - 35	68,414
Bio-fuels: Fuels	7	20 - 25	34,798
RE: Final Energy Consumption	12	30	131,000

In 2018, Thailand revised its Alternative Energy Development Plan 2015 to Alternative Energy Development Plan 2018 which covers from 2018 to 2037. The AEDP2018 aims at keeping the 30% target of substitution of the final energy used by 2037 with different targets of electricity production, biofuel, and heat (Ministry of Energy, 2018). Table 4.4 lists the targets of the AEDP2018 of Thailand.

Table 4.4 Target of AEDP2018.

Share of Renewable Energy in Final Energy Consumption			
Energy	Share of RE (%)		Final Energy Consumption at 2037 (ktoe)
	Status as of 2014	Target by 2037	
Electricity: Electricity	9	34.23	21,320
Heat: Heat	17	41.61	64,657
Bio-fuels: Fuels	7	9.99	40,890
RE: Final Energy Consumption	12	30	126,867

4.5.4 Vietnam

Vietnam has the intention to promote the growth of RE technology and industries, and to set up industrial RE systems (MoIT, 2015). Table 4.5 shows the summary of the targets of Vietnam's Renewable Energy Development Strategy up to 2030 with an outlook to 2050.

Table 4.5 Summary of the targets of Vietnam's Renewable Energy Development Strategy up to 2030 with an outlook to 2050.

Perspective	Unit	Status at 2015	Target at 2030	Target at 2050
1. Coal import reduction	Million tons	-	40	150
2. Oil import reduction	Million tons	-	3.7	10.5
3. Energy production from RE sources	Million toe	25	62	138
4. Energy consumption from RE sources	%	31.8	32.3	44
5. Electricity production from RE sources	Billion kWh	58	186	452
6. Solar water-heating supply	Million toe	-	3.1	6
7. Increase the volume of Biogas technologies	Million m^3	4	60	100
8. Production of Bio-fuels for transport	Million toe	0.0015	3.7	10.5
9. Establish RE industrial systems and increase the proportion of domestically manufactured machine	%	-	60	-

4.6 Energy Efficiency Policy in the Selected GMS Countries

4.6.1 Cambodia

Cambodia has a national energy efficiency policy called The National Policy, Strategy, and Action Plan on Energy Efficiency in Cambodia which consists of two key goals (MIME, 2013):

- To reduce potential national demand for energy by 20% by 2035, as opposed to the business-as-usual scenario.
- To reduce national carbon dioxide pollution by 3 million by 2035.

The "Alternative Policy Scenario" of the Ministry of Manufacturing, Mines, and Energy (MIME), has modified the effects of the supposed improved EE in the several sectors defined as the focus areas of national energy efficiency policy, strategy, and action plan, intending to achieve the overall energy efficiency goal.

The energy-saving possibilities in the different subsectors were presumed as shown in Table 4.6.

Table 4.6 Saving potential of the policy.

Priority Area	Saving Potential	The main driver of saving potential
Industrial	20% (garment industry) - 70% (ice factories)	Based on behavioral shifts and inefficient system removal.
End-use products in the residential sector	Up to 50%	Introduction of household appliance energy efficiency labeling systems.
Building	20-30% (for new commercial buildings)	Apply the required materials and construction standards to uniform wiring with particular emphasis.
Rural electricity generation and distribution	Up to 80%	Shrinking of Rural Energy Enterprises (REE's) massive generation and distribution losses.
Biomass resources for residential and industrial purposes	30-50%	Improved cook stoves, more efficient charcoal briquettes kilns, fuelwood, and biomass substitution.

Source: MIME, 2013.

4.6.2 Lao PDR

Lao PDR has no clear institutional policy on energy efficiency, but the Ministry of Energy and Mines (MEM) is studying the proposed institutional plan for energy efficiency and conservation. In view of the absence of officially accepted energy conservation measures or approaches, for the duration up to 2025, Lao PDR has a general energy-saving goal of only 10 percent (Asian Development Bank, 2015b).

4.6.3 Thailand

Thailand has a national energy efficiency master plan called the 20-year Energy Efficiency Development Plan (EEDP) which has two goals (MoE, 2011):

- To set the short-term (five years) and long-term (20 years) energy efficiency targets in the national and high energy-consumption sectors such as household sector, industry sector, transport sector, and commercial sector;
- To define energy-saving methods and recommendations to fulfill particular goals and set down steps and work schedules for the entities involved to implement their respective action plans for the promotion of energy conservation.

Table 4.7 presents targets developed under the 20-year Energy Efficiency Development Plan (EEDP).

Table 4.7 Share of energy-saving potential by economic sector in 2030.

Economic Sector	Technical Potential			Specified Target (ktoe)	Share (%)
	Heat (ktoe)	Electricity (GWh)	Total (ktoe)		
Transportation	16,250	-	16,250	13,400	44.7
Industry	10,950	33,500	13,790	11,300	37.7
Commercial Building & Residential	4,197	50,640	6,410	5,300	17.6
Total	29,300	84,140	36,450	30,000	100

In 2018, Thailand revised its Energy Efficiency Development Plan to Energy Efficiency Plan (EEP) 2018 which will cover 2018 to 2037. Table 4.8 illustrates the targets of the EEP2018 of Thailand (Ministry of Energy, 2018a).

Table 4.8 Targets of the EEP2018 of Thailand in 2037.

Economic Sector	Technical Potential			Share (%)
	Heat (ktoe)	Electricity (GWh)	Total (ktoe)	
Industry	14,360	6,777	21,137	43.1
Commercial	886	5,532	6,418	13.1
Residential	377	2,923	3,300	6.7
Agriculture	380	147	527	1.1
Transport	17,682	-	17,682	36
Total	33,685	15,379	49,064	100

4.6.4 Vietnam

Vietnam has issued a national energy efficiency master plan called the Vietnam National Energy Efficiency Program for the period of 2019-2030. The summary of the objectives of the Vietnam National Energy Efficiency Program are as follows (MoIT, 2018):

- 2019-2025: Achieve an efficiency rate of 5-7% per total national commercial energy consumption.
- By 2025: Reduce power loss to be less than 6.5%.
- By 2025: To connect and implement energy-efficient technologies in 70% of manufacturing and 50% of manufacturing clusters.
- By 2025: Lower the average energy consumption for the industrial sectors/ subsectors compared to that from 2015 to 2018, namely: (i) For the steel sector: from 3% to 10% according to commodity and manufacturing processes; (ii) For the chemical industry: minimum 7%; (iii) For the plastic manufacturing industry: from 18-22.46%; (iv) For the cement industry: minimum 7.50%; (v) For the textile and garment industry: minimum 5%; (vi) For the alcohol, beer and beverage industry: from 3-6.88% according to commodity and manufacturing processes; (vii) For the paper industry: from 8-15.80% depending on product type and production scale.
- 2019-2030: Achieve savings of 8-10% of the total national energy consumption.
- Towards 2030: Reduce electricity loss to less than 6.0%.

- Towards 2030: Lower the average energy consumption for industrial sectors/ subsectors compared to that from 2015 to 2018, namely: (i) For the steel industry: from 5-16.50% according to commodity and manufacturing processes; (ii) For the chemical industry: minimum 10%; (iii) For the plastic manufacturing industry: from 21.55-24.81%; (iv) For the cement industry: minimum 10.89%; (v) For the textile and garment industry: minimum 6.80%; (vi) For the alcohol, beer and beverage industry: from 4.60-8.44% according to commodity and manufacturing processes; (vii) For the paper industry: from 9.90-18.48% according to commodity and manufacturing processes.
- Towards 2030: Decrease 5% of fuel and oil consumption in transportation against the forecast of fuel consumption demand by 2030; Formulate regulations on fuel consumption for newly produced, assembled, and imported 2-wheel motorbikes and automobiles of 9 seats or less.
- Towards 2030: Carry out energy labeling for 50% of all kinds of construction materials and products requiring thermal insulation to be used in construction works.

CHAPTER 5
SCENARIO SETTINGS

5.1 Scenario Developments

5.1.1 Business-as-Usual (BAU) Scenario

The Power Development Plan (PDP) 2015 of Cambodia, PDP of Lao PDR, PDP2015 of Thailand, and Revised PDP VII of Vietnam will be used as the main aspects of the research. The study period of the research is from 2015 to 2050. The future electricity demand, as well as the electricity generation and other aspects of each country, will be determined based on the conditions listed below:

- The population of each country: the populations of each country from 2015 onward were taken from the forecast of the United Nations (United Nations, 2019). Cambodia's population had an average growth rate of 1% annually during the study period while Lao PDR and Vietnam had an average growth rate of 1.01% and 0.45% annually during the study period. Thailand's annual population growth rate will increase by 0.16% on average from 2016-2030 and start to decrease by 0.32% on average annually from 2031-2050.
- GDP of each country: the GDP of each country from 2015 onward is taken from its individual sources. The GDP of Cambodia has an average growth rate of 5.8% annually during the study period 2016-2030 while that of Lao PDR, Thailand, and Vietnam will be 5.11%, 3.76%, and 5.04% respectively (Asian Development Bank, 2019$_a$; USDA, 2020; Sengsuly Phoualavanh, and Bundit Limmeechokchai, 2016; Ministry of Energy, 2015; John Hawksworth and Danny Chan, 2015; Asian Development Bank, 2019$_b$; Asian Development Bank, 2011).
- The number of households: the number of households of each country is extrapolated linearly from the historical data.
- Electrification rates of each country: the electrification rates in Cambodia, Lao PDR, Thailand, and Vietnam in 2015 were 49.37%, 90.51%, 99.6%, and 98.88%, respectively (EAC, 2016; EDL, 2015; World Bank, 2015; EVN, 2016). The electrification rates in Lao PDR, Thailand, and Vietnam will be 100% by

2020. By 2030 and 2050, the electrification rate in Cambodia will be 70% and 100% respectively.

- Transmission and Distribution (T&D) losses: In 2015, the T&D losses in Cambodia, Lao PDR, Thailand, and Vietnam were 13%, 10.5%, 6.8%, and 7.94%, respectively (ERIA, 2019; EDL, 2015; Emiri Yokota and Ichiro Kutani, 2018; EVN, 2016).
- GDP elasticity: the GDP elasticity in each country is estimated using a linear regression model using the historical electricity demand from 2005-2015. The GDP elasticity of Cambodia will be 2.1 from 2015-2025, 1.5 from 2026-2030, 1 from 2031-2040, and 0.8 from 2041-2050. The GDP elasticity of Lao PDR was calculated to be 2 from 2016-2020, 1 from 2021-2025, 0.9 from 2026-2035, and 1 from 2036-2050. The GDP elasticity of Thailand is estimated to be 1.6 from 2016-2020, 1 from 2021-2030, 0.9 from 2031-2035, and 1 from 2036 onward. The GDP elasticity of Vietnam from 2015-2020 was 1.1 and will be decreased to 1 from 2021 until 2050.
- Characteristics of all power plants: the characteristics of the power plants in the selected GMS countries are presented in Table 5.1 (Kachoee, Salimi, and Amidpour, 2018).

Table 5.1 Power plant characteristics.

Technology	Capital cost ($/kW)	Fixed O&M cost	Variable O&M cost ($/MWh)	Process efficiency	Capacity credit	Life time	Merit order
Coal	866.5	13.6	3.71	38	100	30	1
Oil	753	5.7	3	37	100	30	2
Diesel	350	3.5	30	35.4	100	20	2
Natural gas	614	2.6	3.67	44	100	30	1
Biomass	2,180	8.67	0	35	100	30	1
Geothermal	2,000	40	0	15	80	30	1
Hydro	1,750	30	6	100	100	50	1
Solar PV	990	50	0	100	36	30	1
Wind	1,100	50	0	100	36	20	1
Nuclear	1,800	80	0	33	100	40	1
MSW	1,488	9	15	25	100	30	1
Biogas	2,100	20	3	30	100	30	1

5.1.2 Renewable Energy Technologies (RET) Scenario

The Renewable Energy Technologies scenario emphasizes mostly the supply side and has the goal of integrating renewable energy as energy sources for daily life and electricity generation. The RET scenario covers two sectors: the power sector and the transport sector. The measures that are considered in the power sector and the transport sector in the RET scenario in Cambodia, Lao PDR, Thailand, and Vietnam are listed in Table 5.2, Table 5.3, Table 5.4, and Table 5.5, respectively.

Table 5.2 Measures included in the power and the transport sectors in Cambodia in the RET scenario.

Power sector
1. Shares of Installed Capacity of Renewable Energy Power Plants (excluding hydro) will be 20% in 2035 and 30% in 2050. 2. Nuclear power capacity will be 1,000 MW in 2035 and 2,000 MW in 2050. 3. Carbon Capture and Storage for Coal Power Plants will be phased in 25% by 2040 and 50% by 2050. 4. Carbon Capture and Storage for Natural Gas Power Plants will be phased in 25% by 2040 and 50% by 2050.
Transport sector
1. The travel demand of E20 light-duty vehicles, B20 buses, E10 motorcycles, and B20 trucks will replace the travel demand of gasoline light-duty vehicles, diesel buses, gasoline motorcycles, and diesel trucks by 10% in 2030 and 20% in 2050.

Table 5.3 Measures included in the power and the transport sectors in Lao PDR in the RET scenario.

Power sector
1. Shares of Installed Capacity of Renewable Energy Power Plants (excluding hydro) will be 5% in 2035 and 10% in 2050. 2. Nuclear power capacity will be 1,000 MW in 2040 and 3,000 MW in 2050. 3. Carbon Capture and Storage for Coal Power Plants will be phased in 25% by 2040 and 50% by 2050.
Transport sector
1. The travel demand of E20 light-duty vehicles, B20 buses, E10 motorcycles, and B20 trucks will replace the travel demand of gasoline light-duty vehicles, diesel buses, gasoline motorcycles, and diesel trucks by 15% in 2030 and 25% in 2050.

Table 5.4 Measures included in the power sector in the RET scenario in Thailand.

Power sector
1. Shares of Installed Capacity of Renewable Energy Power Plants (excluding hydro) will be 20% in 2035 and 50% in 2050. 2. Nuclear power capacity will be 1,000 MW in 2035 and 4,000 MW in 2050. 3. Carbon Capture and Storage for Coal Power Plants will be phased in 25% by 2040 and 50% by 2045. 4. Carbon Capture and Storage for Natural Gas Power Plants will be phased in 25% by 2040 and 50% by 2045.
Transport sector
1. The travel demand of E20 light-duty vehicles, B20 buses, and E10 motorcycles will replace the travel demand of gasoline light-duty vehicles, diesel buses, and gasoline motorcycles by 15% in 2030 and 40% in 2050 respectively. 2. The travel demand of B20 trucks and B20 trailers will replace the travel demand of diesel trucks and diesel trailers by 12.5% in 2030 and 20% in 2050.

Table 5.5 Measures included in the power sector in the RET scenario in Vietnam.

Power sector
1. Shares of Installed Capacity of Renewable Energy Power Plants (excluding hydro) will be 10% in 2035 and 30% in 2050. 2. Nuclear power capacity will be 4,600 MW from 2035 until 2050. 3. Carbon Capture and Storage for Coal Power Plants will be phased in 25% by 2040 and 50% by 2045. 4. Carbon Capture and Storage for Natural Gas Power Plants will be phased in 25% by 2040 and 50% by 2045.
Transport sector
1. The travel demand of E20 light-duty vehicles, B20 buses, and E10 motorcycles will replace the travel demand of gasoline light-duty vehicles, diesel buses, and gasoline motorcycles by 15% in 2030 and 25% in 2050 respectively. 2. The travel demand of B20 trucks and B20 trailers will replace the travel demand of diesel trucks and diesel trailers by 9.2% in 2030 and 12.5% in 2050.

5.1.3 Improved Energy Efficiency (IEE) Scenario

The Improved Energy Efficiency (IEE) scenario focuses on the demand side. The key target of this scenario is to improve the energy efficiency in end-use equipment in various sectors across the economy including the residential sector, the commercial sector, the transport sector, and the power sector to improve the living standard of the citizens and to reduce the future electricity demand intensity and GHG emissions in each selected GMS country. For the residential sector in each country, the efficiency improvement and penetration of efficient technology will be applied to the lighting, air conditioning, and refrigerating systems. For Cambodia and Lao PDR, this study assumes that the traditional air conditioners have an EER of 9, and the EER-10, EER-11.2, and EER-12.8 represent the efficiency improvement of 10%, 20%, and 30% respectively. For Thailand, the traditional air conditioners are assumed to have 11.6 EER, and the EER-12.9, EER-14.5, and EER 16.5 represent efficiency improvement of 10%, 20%, and 30% respectively. The traditional air conditioners of Vietnam are assumed to have EER-11 ratings and the EER-12.2, EER-13.7, and EER15.7 correspond to the efficiency improvement of 10%, 20%, and 30% respectively. The details of the efficiency improvement of the lamps, as well as the penetration of efficient lamps along with the improvement of the household air conditioner and refrigerator in Cambodia, Lao PDR, Thailand, and Vietnam, are presented in Table 5.6, Table 5.7, Table 5.8, and Table 5.9, respectively.

Table 5.6 Measures included in the residential sector in Cambodia in the IEE scenario.

Residential sector
A. Replacement of Incandescent Lamps with Compact Fluorescent Lamps by: 1. 50% by 2020 2. 75% by 2035 + CFL efficiency improved by 30% 3. 100% by 2050 + CFL efficiency improved by 50% B. Replacement of Linear Fluorescent Lamps with LED Tubes by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 30% 3. 100% by 2050 + LED Lamps efficiency improved by 50% C. Replacement of Compact Fluorescent Lamps with LED Lamps by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 30% 3. 100% by 2050 + LED Lamps efficiency improved by 50%
A. Replacement of EER-9 air conditioners with: 1. EER-10 air conditioners + Penetration rate of 50% by 2020 2. EER-11.2 air conditioners + Penetration rate of 75% by 2035 3. EER-12.8 air conditioners + Penetration rate of 100% by 2050
A. Replacement of traditional refrigerators with: 1. COP-5 refrigerators + Penetration rate of 25% by 2020 2. COP-5 refrigerators + Penetration rate of 50% by 2035 3. COP-5 refrigerators + Penetration rate of 75% by 2050

Table 5.7 Measures included in the residential sector in Lao PDR in the IEE scenario.

Residential sector
A. Replacement of Incandescent Lamps with Compact Fluorescent Lamps by: 1. 50% by 2020 2. 75% by 2035 + CFLs efficiency improved by 30% 3. 100% by 2050 + CFLs efficiency improved by 50% B. Replacement of Linear Fluorescent Lamps with LED Tubes by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 30% 3. 100% by 2050 + LED Lamps efficiency improved by 50% C. Replacement of Compact Fluorescent Lamps with LED Lamps by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 30% 3. 100% by 2050 + LED Lamps efficiency improved by 50%
A. Replacement of EER-9 air conditioners with: 1. EER-10 air conditioners + Penetration rate of 50% by 2020 2. EER-11.2 air conditioners + Penetration rate of 75% by 2035 3. EER-12.8 air conditioners + Penetration rate of 100% by 2050
A. Replacement of traditional refrigerators with: 1. COP-5 refrigerator + Penetration rate of 25% by 2020 2. COP-5 refrigerator + Penetration rate of 50% by 2035 3. COP-5 refrigerator + Penetration rate of 75% by 2050

Table 5.8 Measures included in the residential sector in Thailand in the IEE scenario.

Residential sector
A. Replacement of Incandescent lamps with Compact Fluorescent Lamps by: 1. 50% by 2020 2. 75% by 2035 + CFLs efficiency improved by 40% 3. 100% by 2050 + CFLs efficiency improved by 60% B. Replacement of Linear Fluorescent Lamps with LED Tubes by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 40% 3. 100% by 2050 + LED Lamps efficiency improved by 60% C. Replacement of Compact Fluorescent Lamps with LED Lamps by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 40% 3. 100% by 2050 + LED Lamps efficiency improved by 60%
A. Replacement of EER-11.6 air conditioners with: 1. EER-12.9 air conditioners + Penetration rate of 50% by 2020 2. EER-14.5 air conditioners + Penetration rate of 75% by 2035 3. EER-16.5 air conditioners + Penetration rate of 100% by 2050
A. Replacement of traditional refrigerators with: 1. COP-5 refrigerator + Penetration rate of 50% by 2020 2. COP-5 refrigerator + Penetration rate of 75% by 2035 3. COP-5 refrigerator + Penetration rate of 100% by 2050

Table 5.9 Measures included in the residential sector in Vietnam in the IEE scenario.

Residential sector
A. Replacement of Incandescent Lamps with Compact Fluorescent Lamps by: 1. 50% by 2020 2. 75% by 2035 + CFL efficiency improved by 35% 3. 100% by 2050 + CFL efficiency improved by 55% B. Replacement of Linear Fluorescent Lamps with LED Tubes by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 35% 3. 100% by 2050 + LED Lamps efficiency improved by 55% C. Replacement of Compact Fluorescent Lamps with LED Lamps by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 35% 3. 100% by 2050 + LED Lamps efficiency improved by 55%
A. Replacement of EER-11 air conditioners with: 1. EER-12.2 air conditioners + Penetration rate of 50% by 2020 2. EER-13.7 air conditioners + Penetration rate of 75% by 2035 3. EER-15.7 air conditioners + Penetration rate of 100% by 2050
A. Replacement of traditional refrigerators with: 1. COP-5 refrigerator + Penetration rate of 30% by 2020 2. COP-5 refrigerator + Penetration rate of 60% by 2035 3. COP-5 refrigerator + Penetration rate of 90% by 2050

The lighting systems in the commercial sector in Cambodia, Lao PDR, Thailand, and Vietnam will have efficiency improvement as shown in Table 5.10, Table 5.11, Table 5.12, and Table 5.13, respectively.

Table 5.10 Measures included in the commercial sector in Cambodia in the IEE scenario.

Commercial sector
A. Replacement of Compact Fluorescent Lamps with LED Lamps by: 1. 50% by 2020 2. 75% by 2035 + LED lamps efficiency improved by 30% 3. 100% by 2050 + LED Lamps efficiency improved by 50% B. Replacement of Linear Fluorescent Lamps with LED Tubes by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 30% 3. 100% by 2050 + LED Lamps efficiency improved by 50%

Table 5.11 Measures included in the commercial sector in Lao PDR in the IEE scenario.

Commercial sector
A. Replacement of Incandescent Lamps and Compact Fluorescent Lamps with LED Lamps by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 30% 3. 100% by 2050 + LED Lamps efficiency improved by 50% B. Replacement of Linear Fluorescent Lamps with LED Tubes by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 30% 3. 100% by 2050 + LED Lamps efficiency improved by 50%

Table 5.12 Measures included in the commercial sector in Thailand in the IEE scenario.

Commercial sector
A. Replacement of Compact Fluorescent Lamps with LED Lamps by: 1. 50% by 2020 2. 75% by 2035 + LED lamps efficiency improved by 40% 3. 100% by 2050 + LED Lamps efficiency improved by 60% B. Replacement of Linear Fluorescent Lamps with LED Tubes by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 40% 3. 100% by 2050 + LED Lamps efficiency improved by 60%

Table 5.13 Measures included in the commercial sector in Vietnam in the IEE scenario.

Commercial sector
A. Replacement of Compact Fluorescent Lamps with LED Lamps by: 1. 50% by 2020 2. 75% by 2035 + LED lamps efficiency improved by 35% 3. 100% by 2050 + LED Lamps efficiency improved by 55% B. Replacement of Linear Fluorescent Lamps with LED Tubes by: 1. 50% by 2020 2. 75% by 2035 + LED Lamps efficiency improved by 35% 3. 100% by 2050 + LED Lamps efficiency improved by 55%

In the transport sector, the fuel economy of vehicles will be improved along with the penetration of energy-efficient vehicles. In addition, the shift to energy-efficient transport modes will be encouraged throughout the IEE scenario as well. Table 5.14, Table 5.15, Table 5.16, and Table 5.17 indicate the details of the changes that will be applied to the transport sector under the IEE scenario in Cambodia, Lao PDR, Thailand, and Vietnam respectively. The transmission and distribution (T&D) losses within the power sector of each country will be improved. The T&D losses in each country are shown in Table 5.18.

Table 5.14 Measures included in the transport sector in Cambodia in the IEE scenario.

Improvement Aspects	Transport sector
Fuel Economy	A. Improve Fuel-Economy of vehicles by: 1. Passenger car: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively 2. Motorcycle: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively 3. Bus: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively 4. Truck: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively B. Penetration of efficient vehicles: 1. Electric car: 5%, 10%, and 15% by 2020, 2035, and 2050, respectively 2. Electric motorcycle: 5%, 10%, and 15% by 2020, 2035, and 2050, respectively 3. Electric Bus: 5%, 10%, and 15% by 2020, 2035, and 2050, respectively 4. CNG Truck: 3%, 7%, and 10% by 2020, 2035, and 2050, respectively
Mode Shift	A. Travel demand for passenger transport: 1. Travel demand for road passenger transport of the total passenger transport will be: 100% in 2015, 98.6% in 2035, and 95% in 2050 2. Travel demand for rail passenger transport of the total passenger transport will be: 0% in 2015, 1.4% in 2035, and 5% in 2050 B. Travel demand for freight transport: 1. Travel demand for road freight transport of the total freight transport will be: 91.14% in 2015, 90.25% in 2035, and 85% in 2050 2. Travel demand for rail freight transport of the total freight transport will be: 8.86% in 2015, 9.75% in 2035, and 15% in 2050

Table 5.15 Measures included in the transport sector in Lao PDR in the IEE scenario.

Improvement Aspects	Transport sector
Fuel Economy	A. Improve Fuel-Economy of vehicles by: 1. Passenger car: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively 2. Motorcycle: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively 3. Bus: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively 4. Truck: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively B. Penetration of efficient vehicles: 1. Electric car: 3%, 5%, and 10% by 2020, 2035, and 2050, respectively 2. Electric motorcycle: 3%, 5%, and 10% by 2020, 2035, and 2050, respectively 3. Electric Bus: 3%, 5%, and 10% by 2020, 2035, and 2050, respectively 4. CNG Truck: 3%, 7%, and 10% by 2020, 2035, and 2050, respectively
Mode Shift	A. Travel demand for passenger transport: 1. Travel demand for road passenger transport of the total passenger transport will be: 99% in 2015, 90.25% in 2035, and 85% in 2050 2. Travel demand for rail passenger transport of the total passenger transport will be: 1% in 2015, 9.75% in 2035, and 15% in 2050 B. Travel demand for freight transport: 1. Travel demand for road freight transport of the total freight transport will be: 100% in 2015, 87.5% in 2035, and 80% in 2050 2. Travel demand for rail freight transport of the total freight transport will be: 0% in 2015, 12.5% in 2035, and 20% in 2050

Table 5.16 Measures included in the transport sector in Thailand in the IEE scenario.

Improvement Aspects	Transport sector
Fuel Economy	A. Improve Fuel-Economy of vehicles by: 1. Passenger car: 20%, 35%, and 50% by 2020, 2035, and 2050 respectively 2. Motorcycle: 20%, 35%, and 50% by 2020, 2035, and 2050 respectively 3. Bus: 20%, 35%, and 50% by 2020, 2035, and 2050 respectively 4. Truck: 20%, 35%, and 50% by 2020, 2035, and 2050 respectively B. Penetration of efficient vehicles: 1. Electric car: 10%, 15%, and 20% by 2020, 2035, and 2050 respectively 2. Electric motorcycle: 10%, 15%, and 20% by 2020, 2035, and 2050 respectively 3. Electric Bus: 10%, 15%, and 20% by 2020, 2035, and 2050 respectively 4. CNG Truck: 10%, 15%, and 20% by 2020, 2035, and 2050 respectively
Mode Shift	A. Travel demand for passenger transport: 1. Travel demand for road passenger transport of the total passenger transport will be: 98.74% in 2015, 93% in 2035, and 89% in 2050 2. Travel demand for rail passenger transport of the total passenger transport will be: 1.3% in 2015, 7% in 2035, and 11% in 2050 - Rail passenger transport's travel demand by electric rail will be 23.4% from 2015 to 2050 - Rail passenger transport's travel demand by fossil fuel-based rail will be 76.6% from 2015 to 2050 B. Travel demand for freight transport: 1. Travel demand for road freight transport of the total freight transport will be: 90.5% in 2015, 74.2% in 2035, and 63% in 2050 2. Travel demand for rail freight transport of the total freight transport will be: 1.2% in 2015, 12.5% in 2035, and 20% in 2050 3. Travel demand for waterway freight transport of the total freight transport will be: 7.3% in 2015, 11% in 2035, and 14% in 2050 4. Travel demand for aviation freight transport of the total freight transport will be: 1% in 2015, 2.2% in 2035, 3% in 2050

Table 5.17 Measures included in the transport sector in Vietnam in the IEE scenario.

Improvement Aspects	Transport sector
Fuel Economy	A. Improve Fuel-Economy of vehicles by: 1. Passenger car: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively 2. Motorcycle: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively 3. Bus: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively 4. Truck: 20%, 35%, and 50% by 2020, 2035, and 2050, respectively B. Penetration of efficient vehicles: 1. Electric car: 7%, 15%, and 20% by 2020, 2035, and 2050, respectively 2. Electric motorcycle: 7%, 15%, and 20% by 2020, 2035, and 2050, respectively 3. Electric Bus: 7%, 15%, and 20% by 2020, 2035, and 2050, respectively 4. CNG Truck: 7%, 15%, and 20% by 2020, 2035, and 2050, respectively
Mode Shift	A. Travel demand for passenger transport: 1. Travel demand for road passenger transport of the total passenger transport will be: 96.21% in 2015, 95% in 2035, and 90% in 2050 2. Travel demand for rail passenger transport of the total passenger transport will be: 3.79% in 2015, 5% in 2035, and 10% in 2050 - Rail passenger transport's travel demand by electric rail will be 0% in 2015, 25% in 2035, 40% in 2050 - Rail passenger transport's travel demand by fossil fuel-based rail will be: 100% in 2015, 75% in 2035, and 60% in 2050 B. Travel demand for freight transport: 1. Travel demand for road freight transport of the total freight transport will be: 22.4% in 2015, 58.2% in 2035, and 59.7% in 2050 2. Travel demand for rail freight transport of the total freight transport will be: 1.7% in 2015, 6.2% in 2035, and 10% in 2050 3. Travel demand for waterway freight transport of the total freight transport will be: 75.6% in 2015, 35.2% in 2035, and 30% in 2050 4. Travel demand for aviation freight transport of the total freight transport will be: 0.3% in 2015, 0.3% in 2035, 0.3% in 2050

Table 5.18 Improvement aspects of the power sector in each country in the IEE scenario.

Improvement Aspects	Power sector
Cambodia	
Transmission and Distribution Losses	T&D losses will be 10% by 2020, 8% by 2035, and 7% by 2050.
Lao PDR	
Improvement Aspects	Power sector
Transmission and Distribution Losses	T&D losses will be 10% by 2020, 9% by 2035, and 8% by 2050
Thailand	
Improvement Aspects	Power sector
Transmission and Distribution Losses	T&D losses will be 6% by 2020, 5% by 2035, and 5% by 2050
Vietnam	
Improvement Aspects	Power sector
Transmission and Distribution Losses	T&D losses will be 7% by 2020, 6% by 2035, and 5% by 2050

Recently Thailand revised its Power Development Plan in 2018, this study considers including a special observation on the impacts of the PDP2018 of Thailand on electricity generation and GHG emissions. The BAU scenario of the special observation would follow the PDP2018 of Thailand. However, the measures in the RET and IEE scenario would remain unchanged as in the case of the PDP2015.

5.2 Marginal Abatement Cost (MAC)

5.2.1 Residential Sector

The marginal abatement cost study for the residential sector aims at the lighting, air conditioning, and refrigerating systems. In the lighting system, the MAC study considers replacing incandescent lamps, compact fluorescent lamps (CFLs), and linear fluorescent lamps (LFLs) with light-emitting-diode (LED) lamps. Conventional air conditioners with a low Energy Efficiency Ratio (EER) will be replaced by higher EER air conditioners. Traditional refrigerators will be replaced by the refrigerators having a Coefficient of Performance (COP) of 5 with selected penetration rates and years. Table

5.19, Table 5.20, Table 5.21, and Table 5.22 show the MACs in the residential sector in Cambodia, Lao PDR, Thailand, and Vietnam respectively.

Table 5.19 Descriptions of technology changes in the residential sector in Cambodia for the study of marginal abatement cost.

Descriptions
A. Replacement of Incandescent Lamps with Compact Fluorescent Lamps by 50% in 2020, 75% in 2035, and 100% in 2050 B. Replacement of Linear Fluorescent Lamps with LED Tubes by 50% in 2020, 75% in 2035, and 100% in 2050 C. Replacement of Compact Fluorescent Lamps with LED Lamps by 50% in 2020, 75% in 2035, and 100% in 2050
A. Replacement of EER-9 air conditioners with: 1. EER-10 air conditioners + Penetration rate of 50% by 2020 2. EER-11.2 air conditioners + Penetration rate of 75% by 2035 3. EER-12.8 air conditioners + Penetration rate of 100% by 2050
A. Replacement of traditional refrigerators with: 1. COP-5 refrigerators + Penetration rate of 25% by 2020 2. COP-5 refrigerators + Penetration rate of 50% by 2030 3. COP-5 refrigerators + Penetration rate of 75% by 2050

Table 5.20 Descriptions of technology changes in the residential sector in Lao PDR for the study of marginal abatement cost.

Descriptions
A. Replacement of Incandescent Lamps with Compact Fluorescent Lamps by 50% in 2020, 75% in 2035, and 100% by 2050 B. Replacement of Linear Fluorescent Lamps with LED Tubes by 50% in 2020, 75% in 2035, and 100% by 2050 C. Replacement of Compact Fluorescent Lamps with LED Lamps by 50% in 2020, 75% in 2035, and 100% by 2050
A. Replacement of EER-9 air conditioners with: 1. EER-10 air conditioners + Penetration rate of 50% by 2020 2. EER-11.2 air conditioners + Penetration rate of 75% by 2035 3. EER-12.8 air conditioners + Penetration rate of 100% by 2050
A. Replacement of traditional refrigerators with: 1. COP-5 refrigerator + Penetration rate of 25% by 2020 2. COP-5 refrigerator + Penetration rate of 50% by 2035 3. COP-5 refrigerator + Penetration rate of 75% by 2050

Table 5.21 Descriptions of technology changes in the residential sector in Thailand for the study of marginal abatement cost.

Descriptions
A. Replacement of Incandescent lamps with Compact Fluorescent Lamps by 50% in 2020, 75% in 2035, and 100% by 2050 B. Replacement of Linear Fluorescent Lamps with LED Tubes by 50% in 2020, 75% in 2035, and 100% by 2050 C. Replacement of Compact Fluorescent Lamps with LED Lamps by 50% in 2020, 75% in 2035, and 100% by 2050
A. Replacement of EER-11.6 air conditioners with: 1. EER-12.9 air conditioners + Penetration rate of 50% by 2020 2. EER-14.5 air conditioners + Penetration rate of 75% by 2035 3. EER-16.5 air conditioners + Penetration rate of 100% by 2050
A. Replacement of traditional refrigerators with: 1. COP-5 refrigerator + Penetration rate of 50% by 2020 2. COP-5 refrigerator + Penetration rate of 75% by 2035 3. COP-5 refrigerator + Penetration rate of 100% by 2050

Table 5.22 Descriptions of technology changes in the residential sector in Vietnam for the study of marginal abatement cost.

Descriptions
A. Replacement of Incandescent Lamps with Compact Fluorescent Lamps by 50% in 2020, 75% in 2035, and 100% in 2050 B. Replacement of Linear Fluorescent Lamps with LED Tubes by 50% in 2020, 75% in 2035, and 100% in 2050 1. Replacement of Compact Fluorescent Lamps with LED Lamps by 50% in 2020, 75% in 2035, and 100% in 2050
A. Replacement of EER-11 air conditioners with: 1. EER-12.2 air conditioners + Penetration rate of 50% by 2020 2. EER-13.7 air conditioners + Penetration rate of 75% by 2035 3. EER-15.7 air conditioners + Penetration rate of 100% by 2050
A. Replacement of traditional refrigerators with: 1. COP-5 refrigerator + Penetration rate of 30% by 2020 2. COP-5 refrigerator + Penetration rate of 60% by 2035 3. COP-5 refrigerator + Penetration rate of 90% by 2050

The specifications of lighting technologies, air conditioners, and refrigerators are listed in table 5.23, table 5.24, and table 5.25, respectively.

Table 5.23 Basic specification of lighting technologies.

Lighting devices	Rated Power (W)	Lifetime (hours)	Unit Price ($)
Cambodia			
Incandescent lamp	132	1,000	0.525
Compact Fluorescent Lamp (CFL)	15	8,000	3.8
Linear Fluorescent Lamp (LFL)	28	18,000	1.4
Light-Emitting-Diode (LED) lamp	5	30,000	9.5
Lao PDR			
Incandescent lamp	60	1,000	0.6
Compact Fluorescent Lamp (CFL)	14	8,000	7.25
Linear Fluorescent Lamp (LFL)	32	18,000	1.25
Light-Emitting-Diode (LED) lamp	10	30,000	7.7
Thailand			
Incandescent lamp	60	1,000	0.6
Compact Fluorescent Lamp (CFL)	14	8,000	3.5
Linear Fluorescent Lamp (LFL)	28	18,000	3.25
Light-Emitting-Diode (LED) lamp	7.2	30,000	7.5
Vietnam			
Incandescent lamp	60	1,000	0.7
Compact Fluorescent Lamp (CFL)	24	8,000	2.5
Linear Fluorescent Lamp (LFL)	26	18,000	3.25
Light-Emitting-Diode (LED) lamp	7.2	30,000	6.25

Note: The data in the table above are the average value of each technology in each country.
IIEC, 2016.

Table 5.24 Basic specifications of domestic air conditioners.

Air conditioners	**Cooling Capacity (BTU/h)	+Rated Power (kW)	Lifetime (years)	*Unit Price ($)
EER-9 rating	9,000	0.617	15	171.8
EER-10 rating	9,000	0.555	15	232
EER-11 rating	9,000	0.505	15	292
EER-11.2 rating	9,000	0.496	15	304
EER-11.6 rating	10,000	0.333	15	368
EER-12.2 rating	9,000	0.455	15	364
EER-12.8 rating	9,000	0.434	15	400
EER-12.9 rating	10,000	0.270	15	446
EER-13.8 rating	9,000	0.291	15	460
EER-14.5 rating	10,000	0.240	15	542
EER-15.7 rating	9,000	0.256	15	574
EER-16.5 rating	10,000	0.210	15	662

Note: * CLASP and Niwat Phansilpakom, 2019.
** ASEAN-SHINE, 2015.
+ Chiharu Murakoshi et al., 2015 and assumptions.

Table 5.25 Basic specifications of traditional domestic refrigerators.

Refrigerating devices	*Annual Energy Cons. (kWh/year)	Lifetime (years)	Unit Price ($)
Traditional refrigerator (Cambodia)	417	10	**463
Traditional refrigerator (Lao PDR)	417	10	**463
Traditional refrigerator (Thailand)	388	10	403
Traditional refrigerator (Vietnam)	417	10	***400
COP-5 refrigerator (Cambodia)	125.1	10	602
COP-5 refrigerator (Lao PDR)	125.1	10	602
COP-5 refrigerator (Thailand)	117	10	525
COP-5 refrigerator (Vietnam)	125.1	10	520

Note: * Claus Barthel and Thomas Götz, 2012.
** Unit prices of refrigerators in Cambodia and Lao PDR are assumed to be 15% higher than that of Thailand due to the import taxation.
*** DI-Marketing, 2016.

5.2.2 Commercial Sector

The marginal abatement cost study for the commercial sector includes only the lighting system. Different lighting technologies such as LED lamps, CFLs, and LFLs are considered in the study within this sector. Table 5.26 presents the details of the MAC study on the commercial sector.

Table 5.26 Descriptions of technology changes in the commercial sector in the selected GMS countries for the study of marginal abatement cost.

Cambodia	
Systems	Descriptions
Lighting	1. LED tubes replace LFLs by 50% in 2020, 75% in 2035, and 100% in 2050 2. LED lamps replace CFLs by 50% in 2020, 75% in 2035, and 100% in 2050
Lao PDR	
Systems	Descriptions
Lighting	1. LED tubes replace LFLs by 50% in 2020, 75% in 2035, and 100% in 2050 2. LED lamps replace CFLs by 50% in 2020, 75% in 2035, and 100% in 2050
Thailand	
Systems	Descriptions
Lighting	1. LED tubes replace LFLs by 50% in 2020, 75% in 2035, and 100% in 2050 2. LED lamps replace CFLs by 50% in 2020, 75% in 2035, and 100% in 2050
Vietnam	
Systems	Descriptions
Lighting	1. LED tubes replace LFLs by 50% in 2020, 75% in 2035, and 100% in 2050 2. LED lamps replace CFLs by 50% in 2020, 75% in 2035, and 100% in 2050

5.2.3 Transport Sector

In the transport sector, the MAC study for the selected GMS countries considers various technologies. The details of the technology's penetrations in Cambodia, Lao PDR, Thailand, and Vietnam are presented in Table 5.27, Table 5.28, Table 5.29, and Table 5.30 respectively.

Table 5.27 Descriptions of technology changes in the transport sector in Cambodia for the study of marginal abatement cost.

Systems	Descriptions
Passenger transport	1. The share of electric motorcycles in the travel demand (passenger-kilometer) would replace the share of 91-octane gasoline motorcycles by 5% in 2020, 10% in 2035, and 15% in 2050 2. The share of E10 motorcycles in the travel demand (passenger-kilometer) would replace the share of 91-octane gasoline motorcycles by 10% in 2030, 15% in 2040, and 20% in 2050 3. The share of electric light-duty vehicles in the travel demand (passenger-kilometer) would replace the share of 95-octane gasoline light-duty vehicles by 5% in 2020, 10% in 2035, and 15% in 2050 4. The share of E20 light-duty vehicles in the travel demand (passenger-kilometer) would replace the share of 95-octane gasoline light-duty vehicles by 10% in 2030, 15% in 2040, and 20% in 2050 5. The share of electric buses in the travel demand (passenger-kilometer) would replace the share of diesel buses by 5% in 2020, 10% in 2035, and 15% in 2050 6. The share of B20 buses in the travel demand (passenger-kilometer) would replace the share of diesel buses by 10% in 2030, 15% in 2040, and 20% in 2050
Freight transport	1. The share of CNG trucks in the freight travel demand (ton-kilometer) would replace the share of diesel trucks by 3% in 2020, 7% in 2035, and 10% in 2050 2. The share of B20 trucks in the freight travel demand (ton-kilometer) would replace the share of diesel trucks by 10% in 2030, 15% in 2040, and 20% in 2050

The transport sector is divided into passenger transport and freight transport. For MAC study in the passenger transport, technologies such as electric motorcycles, electric light-duty vehicles, electric buses, E20 vehicles, E10 motorcycles, and B20 buses are considered to replace gasoline motorcycle, gasoline light-duty vehicles, and diesel buses at different rates of penetration and different years. For the freight transport, the CNG trucks and B20 trucks are expected to replace the diesel trucks from different perspectives.

Table 5.28 Descriptions of technology changes in the transport sector in Lao PDR for the study of marginal abatement cost.

Systems	Descriptions
Passenger transport	1. The share of electric motorcycles in the travel demand (passenger-kilometer) would replace the share of 91-octane gasoline motorcycles by 3% in 2020, 7% in 2035, and 10% in 2050 2. The share of E10 motorcycles in the travel demand (passenger-kilometer) would replace the share of 91-octane gasoline motorcycles by 5% in 2020, 17.5% in 2035, and 25% in 2050 3. The share of electric light-duty vehicles in the travel demand (passenger-kilometer) would replace the share of 95-octane gasoline light-duty vehicles by 3% in 2020, 5% in 2035, and 10% in 2050 4. The share of E20 light-duty vehicles in the travel demand (passenger-kilometer) would replace the share of 95-octane gasoline light-duty vehicles by 5% in 2020, 17.5% in 2035, and 25% in 2050 5. The share of electric buses in the travel demand (passenger-kilometer) would replace the share of diesel buses by 3% in 2020, 5% in 2035, and 10% in 2050 6. The share of B20 buses in the travel demand (passenger-kilometer) would replace the share of diesel buses by 5% in 2020, 17.5% in 2035, and 25% in 2050
Freight transport	1. The share of CNG trucks in the freight travel demand (ton-kilometer) would replace the share of diesel trucks by 3% in 2020, 5% in 2035, and 10% in 2050 2. The share of B20 trucks in the freight travel demand (ton-kilometer) would replace the share of diesel trucks by 5% in 2020, 17.5% in 2035, and 25% in 2050

Table 5.29 Descriptions of technology changes in the transport sector in Thailand for the study of marginal abatement cost.

Thailand	
Systems	Descriptions
Passenger transport	1. The share of electric motorcycles in the travel demand (passenger-kilometer) would replace the share of 91-octane gasoline motorcycles by 10% in 2020, 15% in 2035, and 20% in 2050 2. The share of E10 motorcycles in the travel demand (passenger-kilometer) would replace the share of 91-octane gasoline motorcycles by 5% in 2020, 22.5% in 2035, and 40% in 2050 3. The share of electric light-duty vehicles in the travel demand (passenger-kilometer) would replace the share of 95-octane gasoline light-duty vehicles by 10% in 2020, 15% in 2035, and 20% in 2050 4. The share of E20 light-duty vehicles in the travel demand (passenger-kilometer) would replace the share of 95-octane gasoline light-duty vehicles by 5% in 2020, 22.5% in 2035, and 40% in 2050 5. The share of electric buses in the travel demand (passenger-kilometer) would replace the share of diesel buses by 10% in 2020, 10% in 2035, and 20% in 2050 6. The share of B20 buses in the travel demand (passenger-kilometer) would replace the share of diesel buses by 5% in 2020, 22.5% in 2035, and 40% in 2050
Freight transport	1. The share of CNG trucks in the freight travel demand (ton-kilometer) would replace the share of diesel trucks by 10% in 2020, 15% in 2035, and 20% in 2050 2. The share of B20 trucks in the freight travel demand (ton-kilometer) would replace the share of diesel trucks by 7.5% in 2020, 15% in 2035, and 20% in 2050

Table 5.30 Descriptions of technology changes in the transport sector in Vietnam for the study of marginal abatement cost.

Vietnam	
Systems	Descriptions
Passenger transport	1. The share of electric motorcycles in the travel demand (passenger-kilometer) would replace the share of 91-octane gasoline motorcycles by 7% in 2020, 15% in 2035, and 20% in 2050 2. The share of E10 motorcycles in the travel demand (passenger-kilometer) would replace the share of 91-octane gasoline motorcycles by 5% in 2020, 17.5% in 2035, and 25% in 2050 3. The share of electric light-duty vehicles in the travel demand (passenger-kilometer) would replace the share of 95-octane gasoline light-duty vehicles by 7% in 2020, 15% in 2035, and 20% in 2050 4. The share of E20 light-duty vehicles in the travel demand (passenger-kilometer) would replace the share of 95-octane gasoline light-duty vehicles by 5% in 2020, 17.5% in 2035, and 25% in 2050 5. The share of electric buses in the travel demand (passenger-kilometer) would replace the share of diesel buses by 7% in 2020, 15% in 2035, and 20% in 2050 6. The share of B20 buses in the travel demand (passenger-kilometer) would replace the share of diesel buses by 5% in 2020, 17.5% in 2035, and 25% in 2050
Freight transport	1. The share of CNG trucks in the freight travel demand (ton-kilometer) would replace the share of diesel trucks by 7% in 2020, 15% in 2035, and 20% in 2050 2. The share of B20 trucks in the freight travel demand (ton-kilometer) would replace the share of diesel trucks by 7.5% in 2020, 10% in 2035, and 12.5% in 2050

5.2.4 Power Sector

The MAC in the power sector in the year 2050 in the selected GMS countries is discussed in this section. In the MAC study for Cambodia in 2050, a total capacity of coal and natural gas power plants of 7,007 MW is considered to be replaced by biomass, solar, hydro, and nuclear. For Lao PDR, only 500 MW of coal power plants is considered to be replaced by biomass, solar, hydro, wind, nuclear, and MSW. In Thailand, a total capacity of 17,400 MW of coal and natural gas power plants is considered to be replaced by solar, MSW, wind, hydro, biomass, and nuclear. For Vietnam, a total capacity of 33,700 MW of coal and natural gas power plants is considered to be replaced by hydro, biomass, solar, nuclear, and wind technology.

5.3 Emissions Gap Estimation

The emissions gap does not include the GHG emissions from the LULUCF. There are seven scenarios in the emissions gap estimation in this study which are baseline scenario, NDC-U scenario, NDC-C scenario, NDC-C-DOU scenario, NDC-C-TRI scenario, 2-D2050 scenario, and 1.5-D2050 scenario. The necessary data for the baseline scenario until 2030 were collected from the official NDCs documents, the AIM/CGE 2.1 model in Shared Socioeconomic Pathways (SSP) scenarios, and other reports (UNFCCC, 2017; UNFCCC, 2020; Paltsev, S. et al., 2018; UNFCCC, 2020$_a$; UNFCCC, 2020$_b$; Climate Action Tracker, 2020; UNFCCC, 2020$_c$; and Gütschow et al., 2020). The data from 2031 onward were determined using the Immediate Per Capita Convergence method adopted in this study. The data of the 2-D2050 and 1.5-D2050 scenarios of selected GMS countries were determined based on the global emissions pathways from the AIM/CGE 2.1 model in SSP scenarios using the Immediate Per Capita Convergence method (Gütschow et al., 2020). The data for the NDC-U and NDC-C scenarios were taken from the official NDCs documents (UNFCCC, 2017; UNFCCC, 2020; Paltsev, S. et al., 2018; UNFCCC, 2020$_a$; UNFCCC, 2020$_b$; Climate Action Tracker, 2020; UNFCCC, 2020$_c$). The data of the NDC-U and NDC-C scenarios in 2050 were assumed to have the same percentage as in the original targets. The data of the NDC-C-DOU scenario assumed that the planned targets in the official conditional NDCs will be doubled by 2050. The data of the NDC-C-TRI scenario assumed that the planned targets in the official conditional NDCs will be tripled by

2050. Table 5.31 shows the methodology of the estimation of the emissions gap for the selected GMS countries.

Table 5.31 The methodology of emissions gap estimation as well as the selected GMS countries.

Cases	Methodology
Baseline	Follows the BAU emissions (exclude LULUCF) of the NDCs documents until 2030. Data are assumed after 2030 onward.
NDC-U	Follows the targets of the official NDCs in 2030. The percentage targets are assumed to stay the same in 2050.
NDC-C	Follows the targets of the official NDCs in 2030. The percentage targets are assumed to stay the same in 2050.
NDC-C-DOU	Follows the targets of the official NDCs in 2030. The percentage targets are assumed to be doubled in 2050.
NDC-C-TRI	Follows the targets of the official NDCs in 2030. The percentage targets are assumed to be tripled in 2050.
2-D2050	This scenario indicates the emissions pathway of the 2℃ goal of the Paris Agreement.
1.5-D2050	This scenario indicates the emissions pathway of the 1.5℃ target.

5.4 Carbon Budgets Analysis

This study adopts four effort-sharing approaches namely, grandfathering (GF), immediate per capita convergence (IEPC), per capita convergence (PCC) and greenhouse development rights (GDR) to determine the carbon budgets for the selected GMS countries. Table 5.32 shows the descriptions of the four approaches.

The GF approach is grouped within the “staged” approach which is believed to be a fair choice for developing countries (Xunzhang Pan et al., 2017). Plus, the GF and PCC approaches are two cost-optimal reductions approaches for most countries (van den Berg et al., 2020). The IEPC stands on the equality concept which prioritizes human rights in atmospheric space. This concept is decently fair in terms of humanity and the value of all humans (van den Berg et al., 2020). The GDR approach allocates large budgets to the developing countries which makes it suitable for the developing countries since reducing emissions affects the economic development of the countries. However, this approach is not preferable if applied to industrialized countries that have already emitted a big portion of the world's emissions. Thus this study adopts the GF approach, IEPC approach, PCC approach, and GDR approach from the study of van den Berg et al. to determine the carbon budgets (CO_2 emissions only) for the selected GMS countries based on the 2°C goal of the Paris Agreement and the 1.5°C target.

Table 5.32 Descriptions of effort-sharing approaches.

Approach	Description
Grandfathering (GF)	Based on "acquired rights" that is justified by established custom and usage. Carbon budgets are allocated based on base-year emissions shares.
Immediate per capita convergence (IEPC)	Equal individual rights to atmospheric space. Carbon budgets are allocated based on the population shares during a certain period.
Per capita convergence (PCC)	Based on the equity principle of sovereignty and equality. Carbon budgets are allocated based on emissions shares and population shares.
Greenhouse development rights (GDR)	Based on the equity principle of responsibility/capability/need. Carbon budgets are allocated based on the Responsibility-Capacity Index (RCI) that includes GDP per capita and measures of the income distribution.

The necessary datasets such as the baseline global carbon budget are taken from the AIM/CGE 2.1 model in the CD-LINKS Scenario Database (McCollum DL et al., 2018). The historical and future baseline emissions data (excluding LULUCF) are based on and follow the Shared Socioeconomic Pathways 2 (SSP2) scenario of the study of Gütschow et al. (Gütschow et al., 2020). The requisite LULUCF emissions data are estimated based on historical data, future forest land area, and future population of each country. The RCI values are based on the work of Kemp-Benedict et al. (Kemp-Benedict et al., 2019). The RCI values of Cambodia and Lao PDR stand on the setting of zero percent responsibility for the historical emissions. For Thailand and Vietnam, the RCI values are taken based on 10 percent responsibility for the historical emissions. The RCI values of the four countries are assumed to stay constant from 2030 until 2050. Table 5.33 shows the RCI values of the four countries from 2010 to 2050 for the 2°C and 1.5°C pathways.

Table 5.33 The RCI values of the selected GMS countries from 2010 to 2050 following the 2-degree pathway of the Paris Agreement and the 1.5-degree targets.

2°C Pathway					
Country	2010	2020	2030	2040	2050
Cambodia	0.0002194	0.000298	0.000330	0.000331	0.000331
Laos	0.0001242	0.000177	0.000200	0.0002	0.0002
Thailand	0.0054042	0.005553	0.005898	0.005898	0.005898
Vietnam	0.0020142	0.002700	0.003034	0.003035	0.003035
1.5°C Pathway					
Country	2010	2020	2030	2040	2050
Cambodia	0.0002194	0.000298	0.000331	0.000332	0.000332
Laos	0.0001242	0.000178	0.000200	0.0002	0.0002
Thailand	0.0054042	0.005554	0.005902	0.005903	0.005903
Vietnam	0.0020142	0.002702	0.003042	0.003042	0.003042

5.5 Carbon Budgets Pathways

In addition to the carbon budgets estimation, the pathways of the carbon budgets for the selected GMS countries can also be viewed. The carbon budgets pathways based on the 2°C goal of the Paris Agreement and the 1.5°C target are chosen to show in this study for illustration purposes. The pathways would be able to guide the viewer to have a better understanding of the remaining allowable carbon emissions in the selected GMS countries.

CHAPTER 6
RESULTS OF CAMBODIA

6.1 Electricity Demand

6.1.1 Business-as-Usual (BAU) Scenario

The results of the modeling suggest that the electricity demand in Cambodia would increase rapidly from 5.2 TWh in 2015 to 70.54 TWh in 2050 in the BAU scenario. The shares of the electricity demand by type of sector are shown in Figure 6.1. By 2050, the "other" sector will account for 31.28% of the total electricity demand whereas the commercial sector, industry sector, and residential sector would account for 25.9%, 18.92%, and 23.9%, respectively.

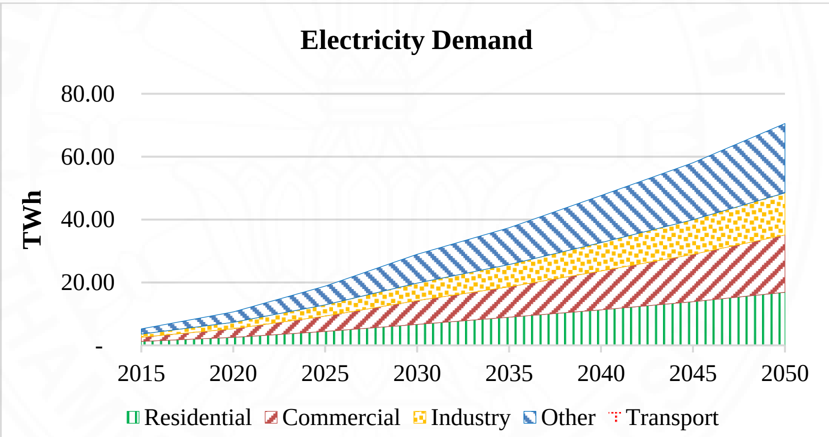

Figure 6.1 Electricity demand in Cambodia in the BAU scenario.

6.1.2 Renewable Energy Technologies (RET) Scenario

In the RET scenario, the electricity demand in Cambodia during the study period is the same as that in the BAU scenario.

6.1.3 Improved Energy Efficiency (IEE) Scenario

The consequences of efficiency improvement in end-use equipment within various sectors will make the electricity demand in Cambodia in the IEE scenario increase by 5.17 TWh from the BAU scenario in 2050. The "other" sector will cover 29.14% of the total electricity demand while the residential, commercial, industry, and transport sectors would cover 16.6%, 23.58%, 17.63%, and 13.05% respectively. Figure 6.2 presents the electricity demand by sector in Cambodia in the IEE scenario.

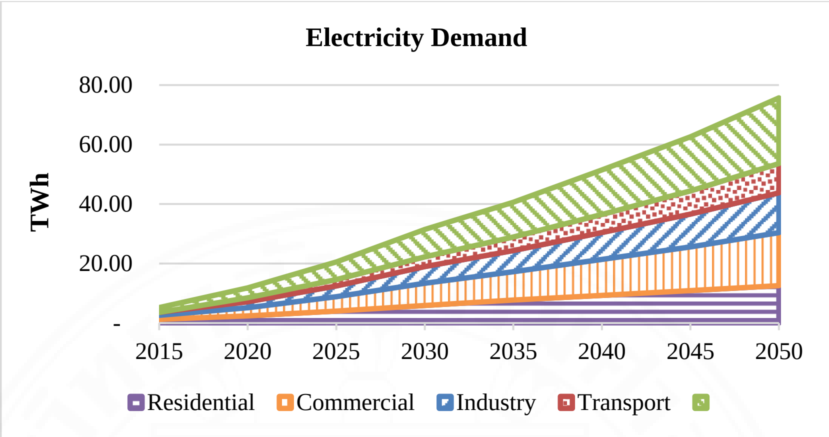

Figure 6.2 Electricity demand in Cambodia in the IEE scenario.

6.2 Electricity Generation

6.2.1 Business-as-Usual (BAU) Scenario

The electricity generation in Cambodia will be increased from 6.02 TWh in 2015 to 75.85 TWh in 2050. In 2050, there will be no imported electricity. The shares of the electricity generation from hydro, biomass, solar, diesel, bituminous coal, and natural gas in 2050 are 46.55%, 1.8%, 2.94%, 31.86%, and 16.84%, respectively. Figure 6.3 shows the electricity generation by type of fuel in Cambodia from 2015 to 2050 in the BAU scenario.

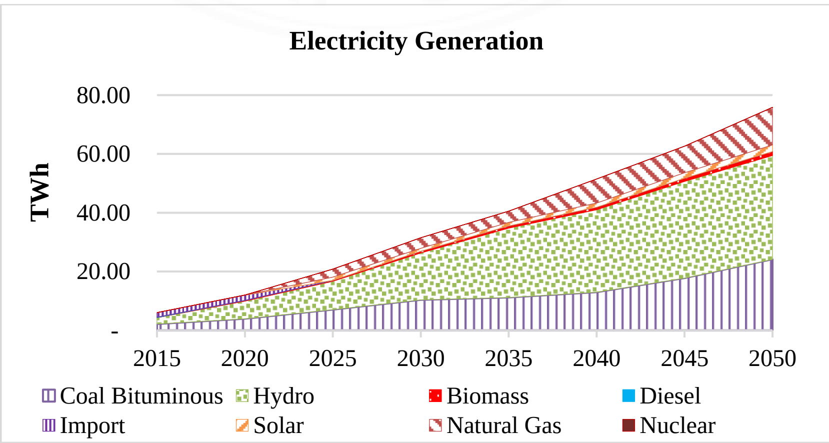

Figure 6.3 Electricity generation in Cambodia in the BAU scenario.

6.2.2 Renewable Energy Technologies (RET) Scenario

With the integration of more renewable energy sources into the power sector in the RET scenario, the share of the electricity generation from bituminous coal, hydro, biomass, diesel, imported electricity, solar, natural gas, and nuclear in 2050 will be 5.67%, 45.27%, 13.46%, 0%, 0%, 16.98%, 9.42%, and 9.21%, respectively, while the shares in 2015 are 35.9%, 35.37%, 0.63%, 2.72%, 25.37%, 0%, 0%, and 0% respectively. Figure 6.4 shows the electricity generation by type of fuel in Cambodia from 2015 to 2050 in the RET scenario.

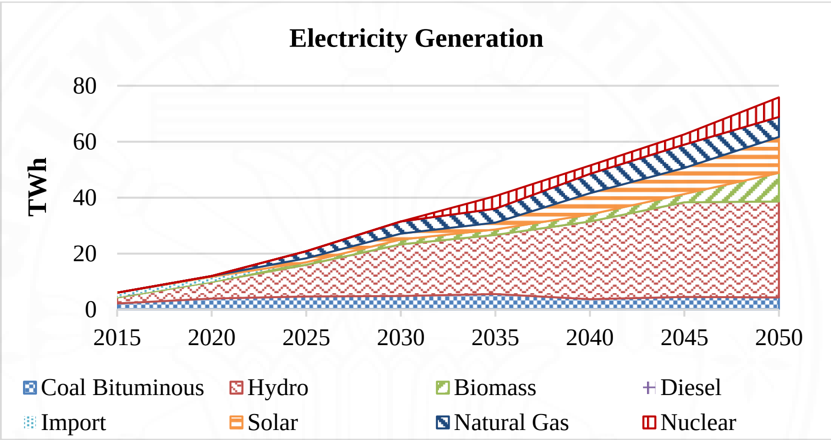

Figure 6.4 Electricity generation in Cambodia in the RET scenario.

6.2.3 Improved Energy Efficiency (IEE) Scenario

By 2050, in the IEE scenario, the electricity generation in Cambodia will increase from 6.02 TWh in 2015 to 81.41 TWh in 2050 due to the additional electricity demand in the transport sector. The shares of the electricity generation from hydro, biomass, solar, diesel, bituminous coal, and natural gas in 2050 would be 46.55%, 1.8%, 2.94%, 0%, 31.86%, 16.84%, respectively. Figure 6.5 illustrates the electricity generation by type of fuel in Cambodia from 2015 to 2050 in the IEE scenario.

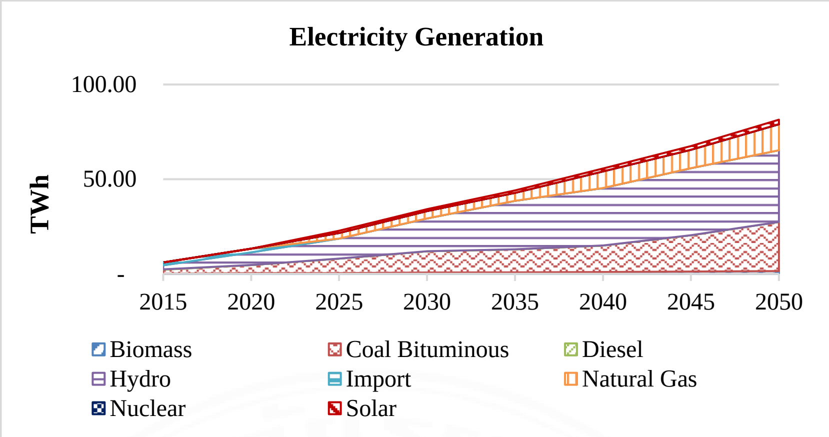

Figure 6.5 Electricity generation in Cambodia in the IEE scenario.

6.3 Emissions in the Power Sector

In the BAU scenario, the CO_2 emissions in the power sector in Cambodia will shoot up rapidly from 2,01 Mt-CO_2eq in 2015 to 27.06 Mt-CO_2eq in 2050 due to the use of fossil fuels as sources of electricity generation. Compared to the BAU scenario, the CO_2 emissions in the RET scenario can be reduced to only 3.99 Mt-CO_2eq in 2050. The huge emissions reduction is the result of using more renewable energy sources as well as low-emission technology such as CCS technology. Unlike the RET scenario, the CO_2 emissions in the IEE scenario will be increased by 1.98 Mt-CO_2eq when compared to the BAU scenario due to the high electricity demand caused by the transport sector. Figure 6.6 presents the CO_2 emissions in the power sector in Cambodia in all scenarios from 2015 to 2050.

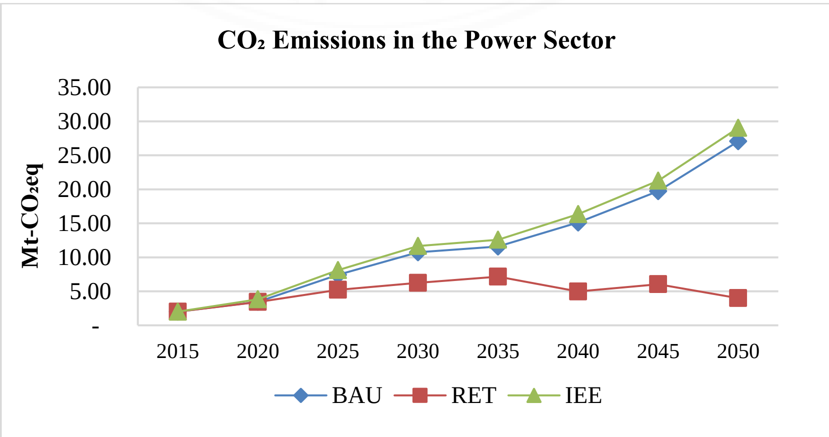

Figure 6.6 Carbon dioxide emissions in the power sector in Cambodia.

Besides carbon dioxide emissions, the emissions of several other pollutants such as nitrogen oxide (NO_x), carbon monoxide (CO), and sulfur dioxide (SO_2); are also considered within the emissions in the power sector in Cambodia as well. Those emissions are shown in Figure 6.7.

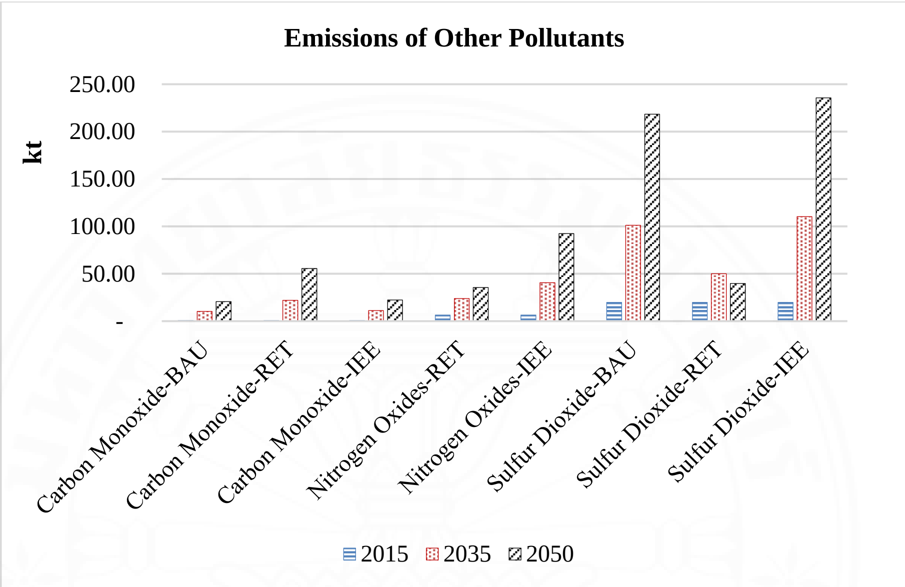

Figure 6.7 Emissions of other pollutants in the power sector in Cambodia.

6.4 Energy Demand in the Transport Sector

In the BAU scenario, the transport sector in Cambodia in 2015 consumes 1.8 Mtoe of energy and it is expected to increase to 10.86 Mtoe by 2050 while that in the RET scenario and IEE scenario is estimated to be 10.72 Mtoe and 4.61 Mtoe respectively, by 2050. In 2015, road transport had a share 99.81% of the total energy demand in the transport sector and it is expected to be decreased to 99.69% by 2050 in the BAU scenario. The share of the total energy demand in the transport sector of road transport in the RET scenario and IEE scenario is forecasted to be 99.7% and 92.14% respectively by 2050. The energy demand for road passenger transport in the BAU scenario will be increased from 1.62 Mtoe in 2015 to about 9.18 Mtoe in 2050, while in the RET scenario and IEE scenario, the demand is expected to increase to be 9.41 Mtoe and 3.49 Mtoe, respectively, by 2050. In the road passenger transport, the energy demand for light-duty vehicles (LDVs) was 1.15 Mtoe in 2015 while that for the bus, and motorcycle, and three-wheelers were 0.006 Mtoe and 0.47 Mtoe, respectively, in the same year. In the BAU scenario, energy demands are expected to be increased to 6.51 Mtoe, 0.03 Mtoe, and 2.64 Mtoe for LDVs, motorcycles, and three-wheelers, respectively by 2050. For the RET scenario, the energy demand would be 6.41 Mtoe, 0.36 Mtoe, and 2.97 Mtoe for LDVs, motorcycles, and three-wheelers, respectively, by 2050. In the IEE scenario, the energy demands are expected to be 1.92 Mtoe, 0.26 Mtoe, and 0.46 Mtoe for LDVs, motorcycles, and three-wheelers, respectively, by 2050. Figure 6.8 illustrates the energy demand in the transport sector in Cambodia during 2015-2050.

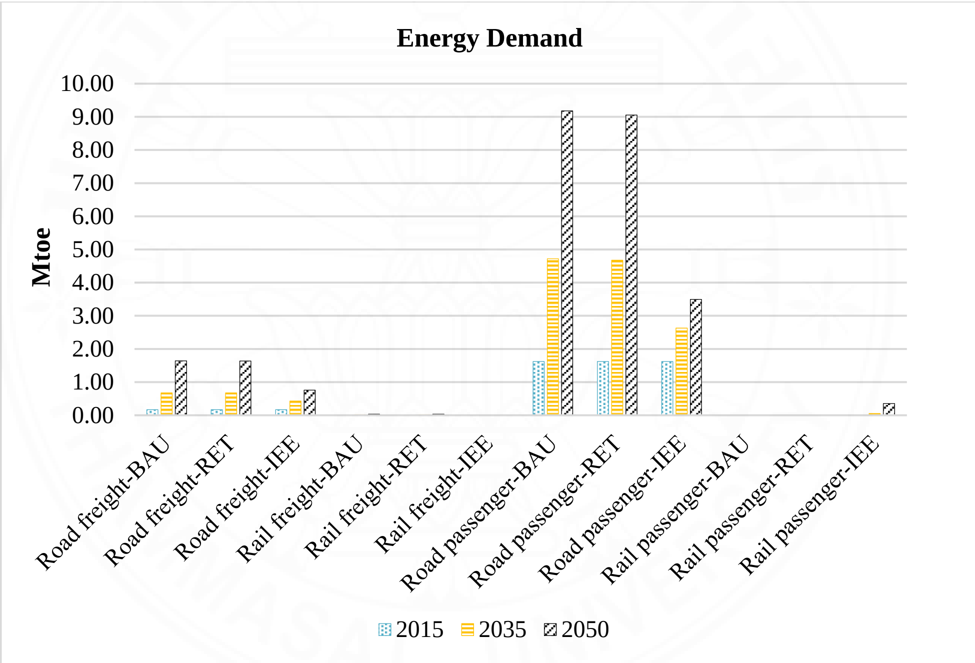

Figure 6.8 Energy demand in the transport sector in Cambodia.

6.5 Emissions in the Transport Sector

The transport sector in Cambodia in 2015 released 5.28 Mt-CO_2eq of greenhouse gases and the number is expected to increase to 31.75 Mt-CO_2eq, 31.45 Mt-CO_2eq, and 11.1 Mt-CO_2eq by 2050 in the BAU scenario, RET scenario, and IEE scenario, respectively. By 2050, the emissions from freight transport will account for 16.24% of the total GHG emissions in the transport sector in the BAU scenario while that from the RET scenario and IEE scenario will account for 16.37% and 20.9%, respectively. Figure 6.9 shows the emissions in the transport sector in Cambodia from 2015-2050.

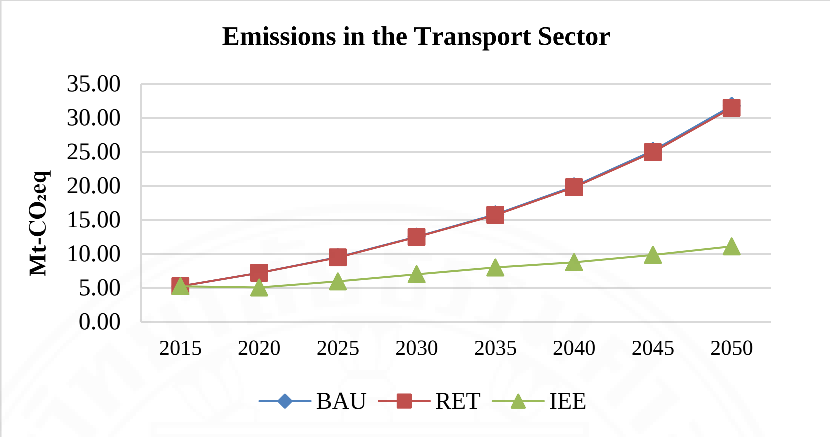

Figure 6.9 GHG emissions in the transport sector in Cambodia.

6.6 Cost of Electricity Generation

The costs of electricity generation in Cambodia are made up of the electricity production cost and the externality cost. The carbon price considered in this study is 9$/t$CO_2$ (Kossoy et al., 2015). In 2015, the cost of electricity production, the cost of externality, and the total cost of electricity generation were 0.116 billion USD, 0.018 billion USD, and 0.134 billion USD, respectively. By 2050, the cost of electricity production in the BAU scenario, RET scenario, and IEE scenario will be 3.699 billion USD, 3.787 billion USD, and 3.835 billion USD, respectively, as shown in Figure 6.10.

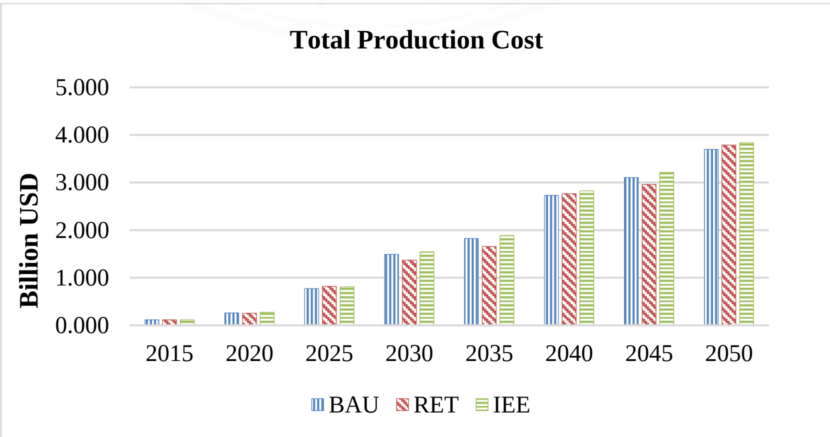

Figure 6.10 Total cost of electricity production in Cambodia.

On the other hand, the externality cost of electricity generation by 2050 in the BAU scenario, RET scenario, and IEE scenario will be 0.243 billion USD, 0.035 billion USD, and 0.261 billion USD respectively. The total cost of electricity generation by 2050 in the BAU scenario will be 3.942 billion USD whereas in the RET scenario and IEE scenario will be 3.822 billion USD and 4.096 billion USD respectively. Figure 6.11 and Figure 6.12 show the cost of externality and the total cost of electricity generation in the four scenarios.

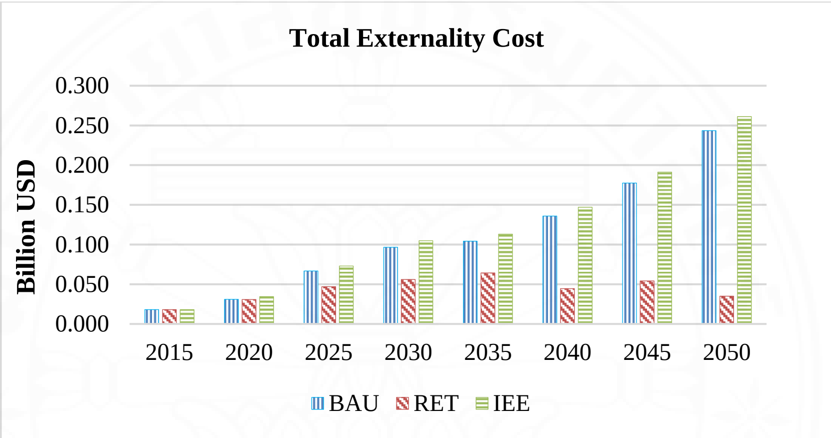

Figure 6.11 Total cost of externality in the power sector in Cambodia.

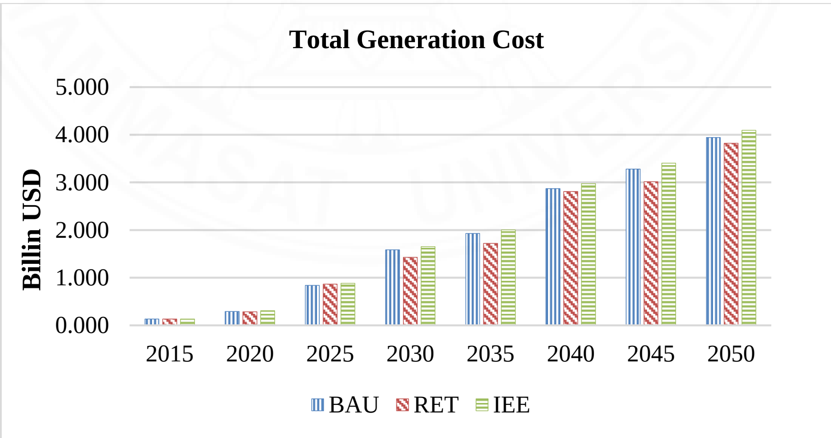

Figure 6.12 Total cost of electricity generation in Cambodia.

6.7 Marginal Abatement Cost

6.7.1 Residential Sector

The MAC study in the residential sector considers the adoption of the three technology systems namely, lighting, air conditioning, and refrigerating systems. The systems are also considered in the Improved Energy Efficiency (IEE) scenario in this study.

In the lighting system in Cambodia, the penetrations of LED tubes replacing the LFLs in 2035 and 2050 at 75% and 100% respectively will result in the cumulative GHG emissions reduction during 2015-2050 of approximately 4.781 Mt-CO_2eq with the MAC of -488.4 $/t-$CO_2$eq. Moreover, the results suggest that by replacing 75% and 100% incandescent lamps in 2035 and 2050 respectively by CFLs, the cumulative GHG emissions during 2015-2050 could be mitigated by about 0.296 Mt-CO_2eq with the MAC of -551.6$/t-$CO_2$eq. Replacing 75% of CFLs with LED lamps in 2035 would result in the MAC of -514.6 $/t-$CO_2$eq with the cumulative GHG emissions cut of about 1.131 Mt-CO_2eq during 2015-2050.

In the air conditioning system, the domestic air conditioners with an efficiency rating of EER-9 will be replaced by air conditioners having higher efficiency ratings. The results show that when replacing the EER-9 air conditioners with EER-10 air conditioners at a penetration rate of 50% by 2020, the cumulative GHG emissions that could be reduced during 2015-2050 will be 4.18 Mt-CO_2eq with the MAC of -226.6 $/t-$CO_2$eq. The replacement of EER-9 air conditioners with EER-11.2 air conditioners with a penetration rate of 75% by 2030 would result in a cumulative emissions reduction of 8.19 Mt-CO_2eq with the MAC of -480.4 $/t-$CO_2$eq during the same period. When replacing the EER-9 air conditioners with 100% of the EER-12.8 air conditioners by 2050, the cumulative emissions that could be cut down during 2015-2050 would be 12.37 Mt-CO_2eq with the MAC of -471.2 $/t-$CO_2$eq in 2050.

In the refrigerating system, the traditional refrigerators will be replaced by refrigerators with the COP-5 rating at different penetration rates and years. The cumulative GHG emissions during 2015-2050 of 1.63 Mt-CO_2eq could be mitigated by replacing the traditional refrigerators with the COP-5 refrigerators at a penetration rate of 25% in 2020. The cumulative MAC of replacing old technology, in this case, will be -419.3 $/t-$CO_2$eq. Similarly, the replacement of traditional refrigerators with COP-5 refrigerators at the penetration rates of 50% in 2035 and 75% in 2050 would result in cumulative GHG emissions reductions and cumulative MAC of about 3.27 Mt-CO_2eq and -383$/t-$CO_2$eq and 4.13 Mt-$CO_2$eq and -363$/t-CO_2eq respectively. Figure 6.13 illustrates the cumulative MAC curve during 2015-2050 in the residential sector in Cambodia. Table 6.1 presents the details of the cumulative MAC during 2015-2050 in the residential sector in Cambodia.

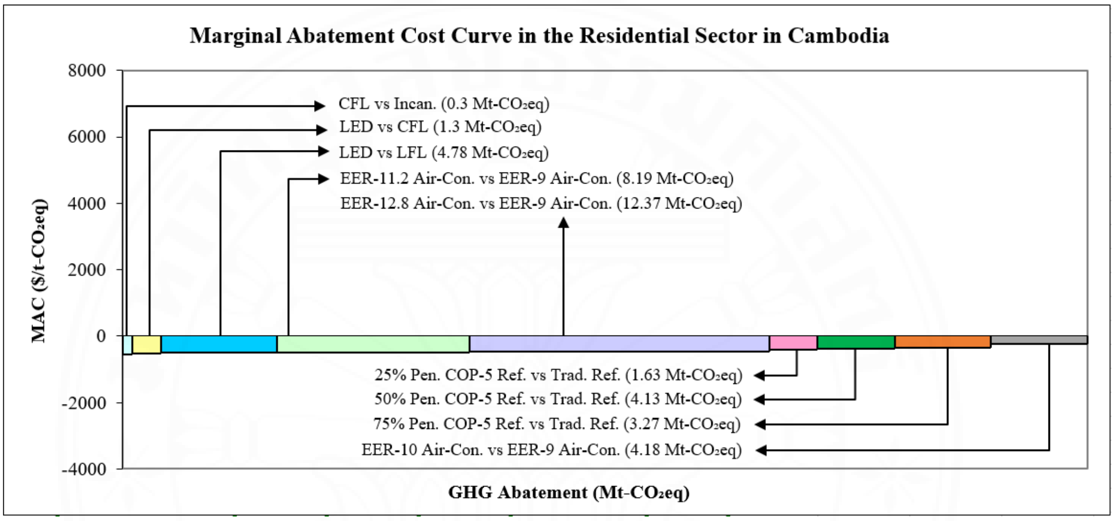

Figure 6.13 The cumulative MAC curve in the residential sector in Cambodia.

Table 6.1 Details of the cumulative MAC during 2015-2050 in the residential sector in Cambodia

Measures	GHG Abatement (Mt-CO_2eq)	MAC ($/t-$CO_2$eq)
CFL vs Incandescent lamp	0.3	-551.58
LED lamp vs CFL	1.3	-514.64
LED tube vs LFL	4.781	-488.35
EER-11.2 Air-Con. vs EER-9 Air-Con.	8.19	-480.42
EER-12.8 Air-Con. vs EER-9 Air-Con.	12.37	-471.16
25% Pen. COP-5 Ref. vs Trad. Ref.	1.63	-419.3
50% Pen. COP-5 Ref. vs Trad. Ref.	3.27	-382.92
75% Pen. COP-5 Ref. vs Trad. Ref.	4.13	-363.04
EER-10 Air-Con. vs EER-9 Air-Con.	4.18	-226.62

As can be seen from Table 6.1, the cumulative MACs of each measure in the residential sector in Cambodia have negative values which indicate that the proposed efficient technologies are more advantageous and preferable than the traditional equipment. Even though the investment cost of the new technologies is higher than that of the traditional technologies, the huge reduction in electricity cost will make the new technology equipment more preferable than the old ones as the results of the MAC analysis of this study suggest.

6.7.2 Commercial Sector

The MAC study for the commercial sector considering only the lighting system is chosen to be studied. When replacing 75% and 100% of the LFLs with LED lamps in the years 2035 and 2050 respectively, the cumulative GHG reduction is found to be 4.29 Mt-CO_2eq during 2015-2050 with the cumulative MAC of about -428.1 \$/t-CO_2eq. In addition, when replacing the CFLs with LED lamps at 75% and 100% in 2035 and 2050 accordingly, the cumulative GHG emissions mitigation during the same period is found to be 0.43 Mt-CO_2eq and the cumulative MAC would be -469.7 \$/t-CO_2eq. Figure 6.14 shows the cumulative MAC curve of the measures included in the commercial sector in Cambodia during 2015-2050. In addition, Table 6.2 lists the details of the cumulative MAC during 2015-2050 in the commercial sector in Cambodia.

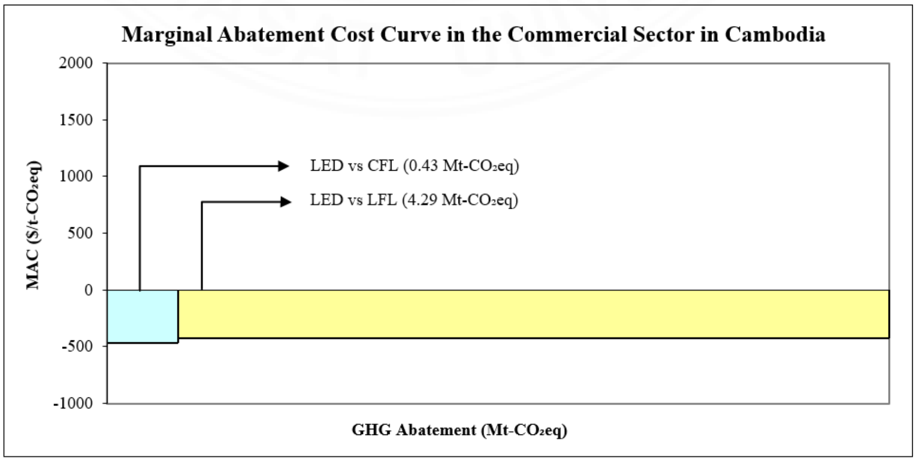

Figure 6.14 The cumulative MAC curve in the commercial sector in Cambodia.

Table 6.2 Details of the cumulative MAC during 2015-2050 in the commercial sector in Cambodia.

Measures	GHG Abatement (Mt-CO_2eq)	MAC (\$/t-CO_2eq)
LED lamp vs CFL	0.43	-469.73
LED tube vs LFL	4.29	-428.09

6.7.3 Transport Sector

The MAC study in the transport sector in Cambodia considers different end-use technologies such as electric vehicles and biofuel-powered vehicles. The efficient technologies would replace conventional vehicles such as gasoline-powered vehicles and diesel-powered vehicles. As described in the scenario setting section, the gasoline light-duty vehicles (LDV) are expected to be penetrated by electric LDVs and E20 LDVs at various rates and years. In addition, the gasoline motorcycles are to be replaced with electric motorcycles and E10 motorcycles. The diesel-powered buses would be penetrated by electric buses and B20 buses while the diesel-powered trucks would be replaced with B20 trucks and CNG trucks. Figure 6.15 and Table 6.3 represent the cumulative MAC curve of the measures considered in the transport sector in Cambodia during 2015-2050 and the details of the cumulative MAC in the transport sector in Cambodia during 2015-2050.

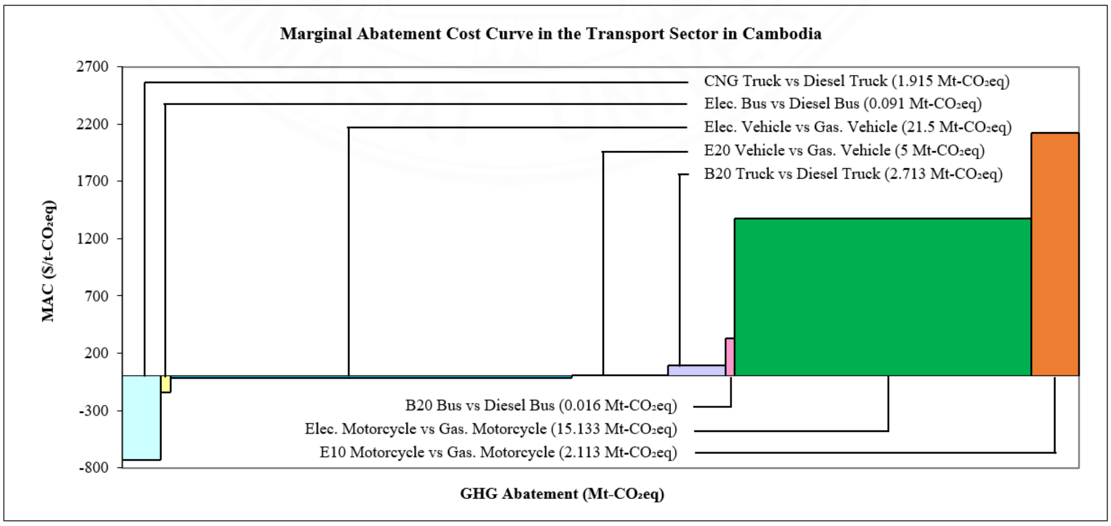

Figure 6.15 The cumulative MAC curve in the transport sector in Cambodia.

Table 6.3 Details of the cumulative MAC during 2015 in the transport sector in Cambodia.

Measures	GHG Abatement ($Mt-CO_2eq$)	MAC ($\$/t-CO_2eq$)
CNG Truck vs Diesel Truck	1.915	-731.66
Electric Bus vs Diesel Bus	0.091	-144.63
Electric Vehicle vs Gasoline Vehicle	21.496	-16.4
E20 Vehicle vs Gasoline Vehicle	5.004	5
B20 Truck vs Diesel Truck	2.713	91.01
B20 Bus vs Diesel Bus	0.016	331.17
Elec. Motorcycle vs Gasoline Motorcycle	15.133	1374
E10 Motorcycle vs Gasoline Motorcycle	2.113	2122.12

The results of the study indicate that the cumulative GHG emissions during 2015-2050 could be mitigated by about 21.5 $Mt-CO_2eq$ with the cumulative MAC of approximately -16.4 $\$/t-CO_2eq$ when introducing the electric LDVs into the transport sector in Cambodia. The cumulative GHG emissions during the same period that would be achieved from the penetration of E20 LDVs, electric motorcycles, E10 motorcycles, electric buses, B20 buses, B20 trucks, and CNG trucks over the conventional vehicles are found to be 5 $Mt-CO_2eq$, 15.13 $Mt-CO_2eq$, 2.11 $Mt-CO_2eq$, 0.01 $Mt-CO_2eq$, 0.02 $Mt-CO_2eq$, 2.71 $Mt-CO_2eq$, and 1.92 $Mt-CO_2eq$ respectively. The cumulative MAC of the CNG trucks over the diesel trucks during the same period appears to be the smallest among the other technologies penetrations which accounts for -731.7 $\$/t-CO_2eq$ whereas the biggest cumulative MAC is found in the replacement of gasoline motorcycles with E10 motorcycles.

6.7.4 Power Sector

In the power sector of Cambodia, different types of renewable energy sources for electricity generation are considered in order to phase out the conventional energy sources such as coal and natural gas for generating electricity. The marginal abatement cost study suggests that the energy source that best replaces coal and natural gas in the power sector is solar energy. Replacing coal and natural gas power plants by a total of 7,007 MW of solar power plants in 2050 would be able to reduce 19.73 $Mt-CO_2eq$ with a MAC of -73.97 $\$/t-CO_2eq$ in the same year. The least preferable energy source to replace coal and natural gas power plants in 2050 is nuclear as the replacement of 7,007 MW of coal and natural gas power plants will reduce 19.73 Mt-CO_2eq with a MAC of 49.83 \$/t-CO_2eq. Figure 6.16 illustrates the marginal abatement cost (MAC) curve of the power sector of Cambodia in 2050 and Table 6.4 details the MAC values of the measures in the power sector in 2050.

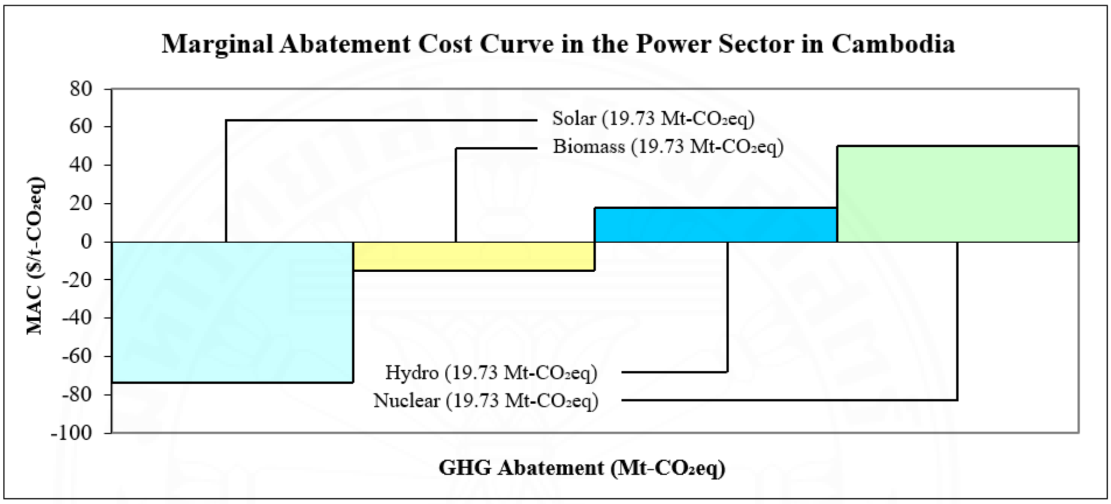

Figure 6.16 The MAC curve in the power sector of Cambodia in 2050.

Table 6.4 Details of the MAC in 2050 in the power sector in Cambodia.

Measures	GHG Abatement (Mt-CO_2eq)	MAC (\$/t-CO_2eq)
Solar	19.73	-73.97
Biomass	19.73	-15.16
Hydro	19.73	17.7
Nuclear	19.73	49.83

6.8 Emissions Gap

Cambodia's NDC targets show no signs of achieving the 2°C goal of the Paris Agreement or the 1.5°C target by 2050. Considering that Cambodia would fully achieve the conditional NDC target, it would still need to reduce additional emissions of 71 Mt-CO_2eq and 91 Mt-CO_2eq, respectively, to achieve the 2°C and 1.5°C targets in 2050. With the NDC-C-DOU scenario, the emissions of Cambodia would not still be able to go in line with the 2-D2050 scenario. In the NDC-C-TRI scenario, Cambodia's emissions would be able to go in line with the 2°C emissions pathway but would need to reduce more (13.6 Mt-CO_2eq) to reach the 1.5°C target. Figure 6.17 shows the emissions gaps between the adopted scenarios in Cambodia.

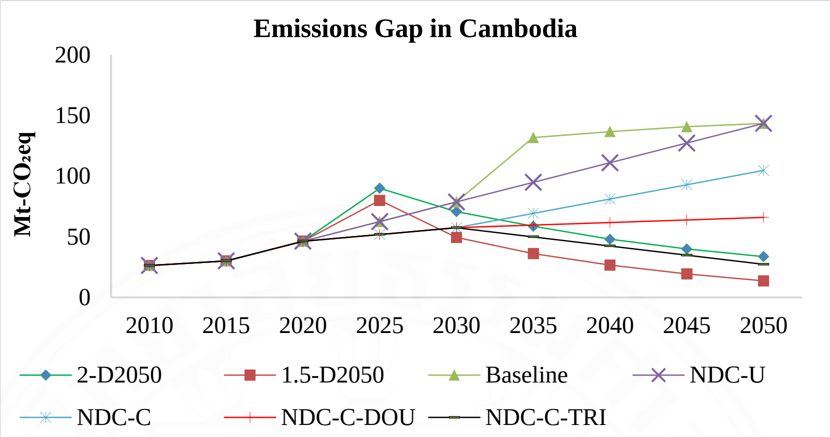

Figure 6.17 Emissions Gap in Cambodia.

6.9 Carbon Budgets

The carbon budgets analysis is done based on four approaches and focuses on both the 2°C goal of the Paris Agreement and the 1.5°C target. Based on the 2°C goal, among the four approaches, the GDR approach allows Cambodia to have the biggest cumulative carbon emissions during 2011-2050. The large budget is caused because Cambodia has small RCI values and high future emissions in the BAU case of the approach. On the contrary, the IEPC approach allows for the smallest budget during the same period due to the small population of the country. The cumulative carbon budgets for Cambodia in the GDR approach and the IEPC approach during 2011-2050 are 5.28 Gt-CO_2eq and 2.02 Gt-CO_2eq respectively. The carbon budgets based on the 1.5°C target would be even smaller than those based on the 2°C goal but show the same trend due to the same reasons. The cumulative carbon budgets in the GDR approach and the IEPC approach based on the 1.5°C target would be 5.24 Gt-CO_2eq and 1.75 Gt-CO_2eq respectively during 2011-2050. Figure 6.18 and Figure 6.19 show the cumulative carbon budgets for Cambodia in effort-sharing approaches based on the 2°C goal of the Paris Agreement and the 1.5°C target respectively. For comparison purposes, Figure 6.20 presents the cumulative carbon budgets for Cambodia based on both the 2°C and 1.5°C targets.

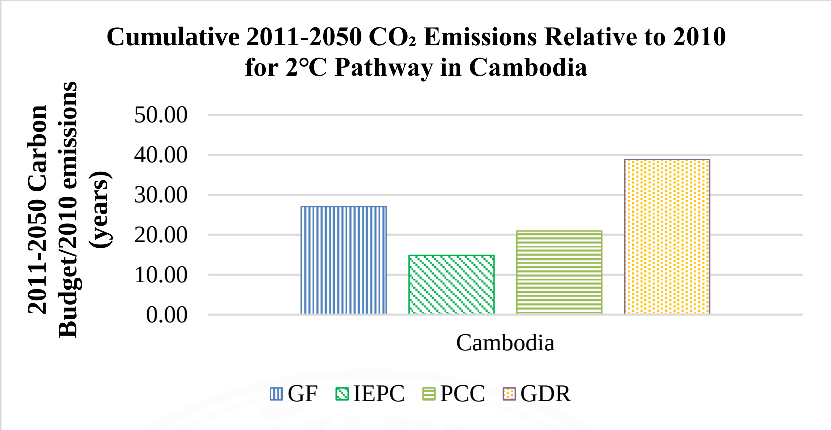

Figure 6.18 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 2°C pathway.

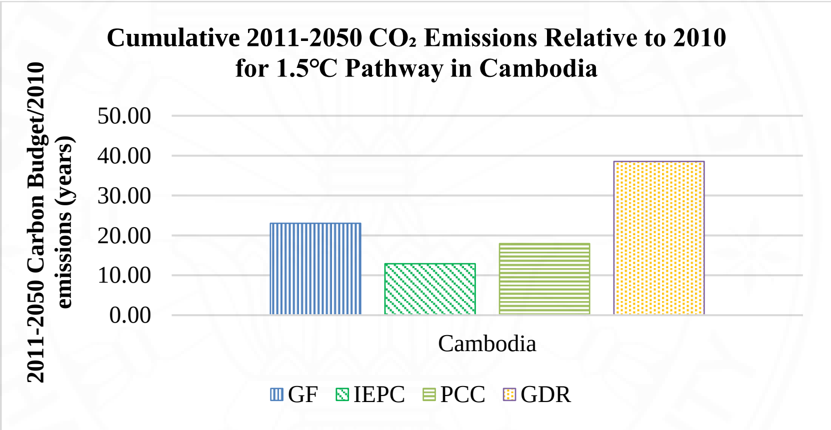

Figure 6.19 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 1.5°C pathway.

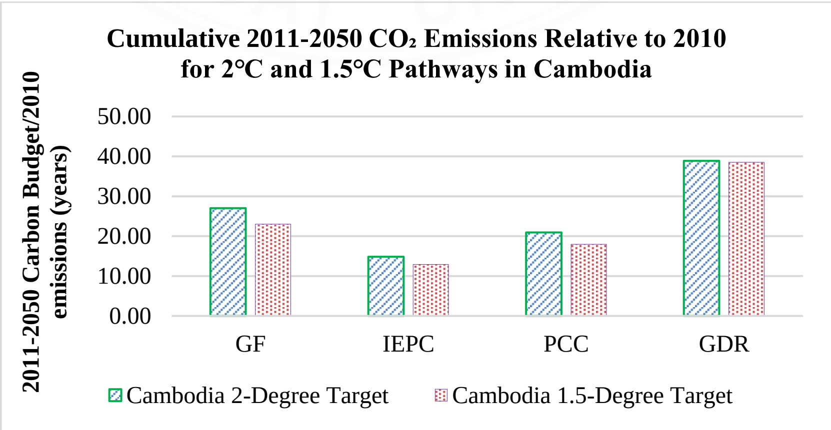

Figure 6.20 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 2°C and 1.5°C pathways.

6.10 Carbon Budgets Pathways

In addition to the carbon budget calculation, the 2-degree carbon budgets pathway of Cambodia during 2011-2100 is chosen to be illustrated in this study. In the results of the emissions pathway based on the four approaches, the CO_2 emissions in Cambodia are expected to be net-zero by the year 2065 in the GF, IEPC, and PCC approaches and by the year 2090 in the GDR approach. However, after reaching net-zero emissions, the CO_2 emissions in the GF, IEPC, and PCC will go up a little and stay near zero by 2100. This is due to the global trend of the CO_2 emissions in the 2-degree pathway. In contrast, in the GDR approach, the CO_2 emissions in Cambodia will keep decreasing even after reaching the net-zero in 2090 already as can be seen in Figure 6.21.

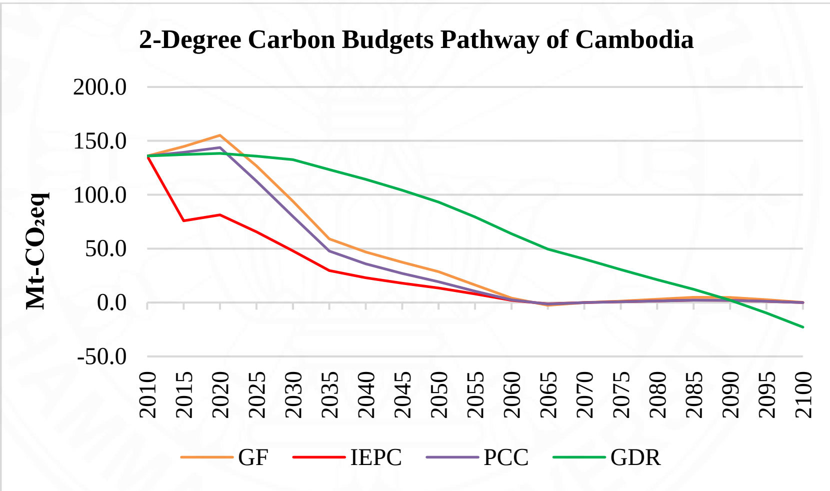

Figure 6.21 2-degree carbon budgets pathway of Cambodia based on the four approaches during 2010-2100.

On the other hand, the 1.5-degree carbon budgets pathways based on the four approaches of Cambodia show a similar but faster trend of reaching net-zero emissions. Figure 6.22 illustrates the 1.5-degree carbon budgets pathway of Cambodia during 2010-2100. The 1.5-degree carbon budgets pathway of Cambodia in the GF, IEPC, and PCC approaches will reach net-zero by the year 2045 due to the trend of global carbon emissions. In contrast, the pathway of Cambodia in the GDR approach will be net-zero by the year 2080 which is slower than the net-zero year of the other three approaches. This is due to the small RCI values of Cambodia that are assumed constant from 2030 onward. The RCI values are a function of the GDP per Capita and emissions mitigation capability index. Thus, in terms of fairness, the GDR approach is preferable to the other three approaches for Cambodia because of the slower rate of reaching net-zero emissions.

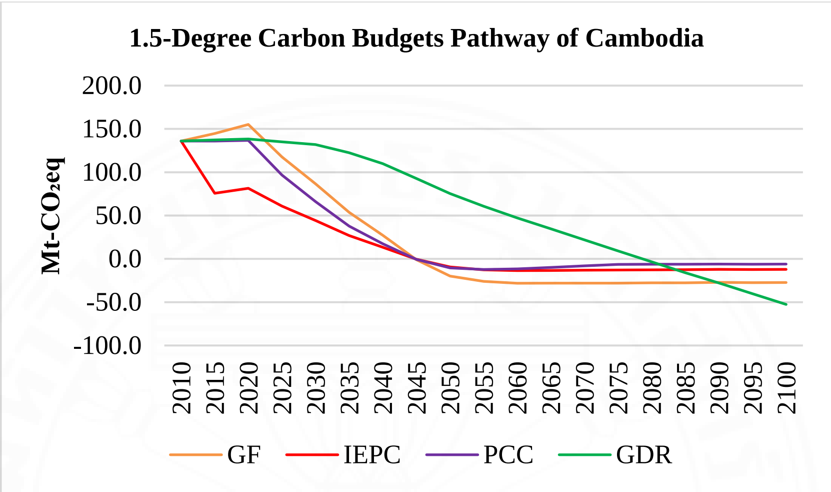

Figure 6.22 1 1.5-degree carbon budgets pathway of Cambodia based on the four approaches during 2010-2100.

CHAPTER 7
RESULTS OF LAO PDR

7.1 Electricity Demand

7.1.1 Business-as-Usual (BAU) Scenario

The electricity consumption in Lao PDR in 2015 was 4.2 TWh. The demand in Lao PDR in 2050 will be increased by 7.38 times from 2015. The industrial sector covers a big share of electricity demand, accounting for 41.5%. The residential sector, commercial sector, “other” sector, and transport sector take up shares of 37.1%, 20.6%, 0.8%, and 0% respectively. Slight changes will occur to the sectors sharing the electricity demand by 2050. In 2050, the sector consuming the majority of electricity demand would still be the industrial sector which accounts for 41.2% while the residential sector, commercial sector, “other” sector, and transport sector will account for 37.6%, 20.4%, 0.8%, and 0%, respectively. The electricity demand by type of sector in Lao PDR is shown in Figure 7.1.

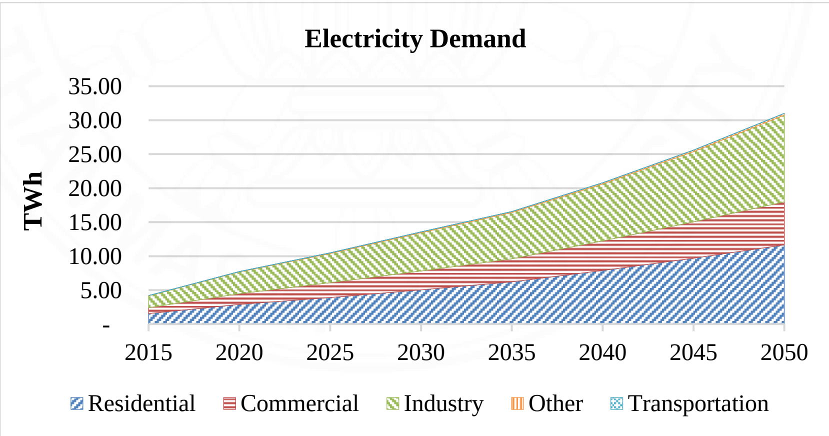

Figure 7.1 Electricity demand in Lao PDR in the BAU scenario.

7.1.2 Renewable Energy Technologies (RET) Scenario

The electricity demand in Lao PDR in the RET scenario is as much as that in the BAU scenario.

7.1.3 Improved Energy Efficiency (IEE) Scenario

As a result of the energy efficiency improvement and electric vehicle penetration, the electricity demand in Lao PDR in the IEE scenario will increase from 4.2 TWh in 2015 to 29.09 TWh in 2050. In comparison to the BAU scenario, energy demand will be lower by 1.92 TWh. Of the total demand in 2050, the industrial sector and the residential sector will have a share of 43.88% and 34.24%, respectively, while the transport sector will have an electricity demand of 0.14 TWh. Figure 7.2 presents the electricity demand by sector in Lao PDR in the IEE scenario.

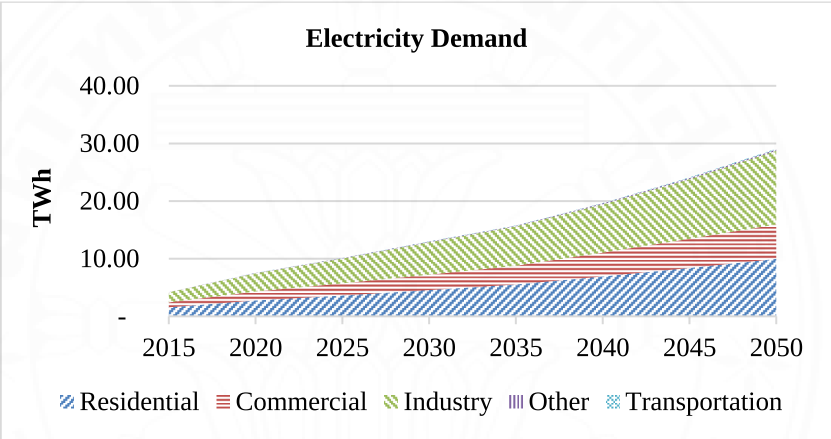

Figure 7.2 Electricity demand in Lao PDR in the IEE scenario.

7.2 Electricity Generation

7.2.1 Business-as-Usual (BAU) Scenario

Lao PDR generates 16.3 TWh of electricity in 2015, 74.23% of which are exported. By 2050, Lao PDR would be generating 214.16 TWh of electricity. The energy demand indicates an increase of 1,313.86% by 2050 in comparison to 2015. By 2050, Lao PDR would export 85.5% of its total electricity generation. The majority of the generated electricity would come from hydro which will account for 87.07% whereas the share of the bituminous coal, biomass, solar, and wind will account for 8.46%, 0.95%, 1.53%, and 1.99%, respectively. Figure 7.3 presents the electricity generation and its type of sources in Lao PDR during 2015-2050.

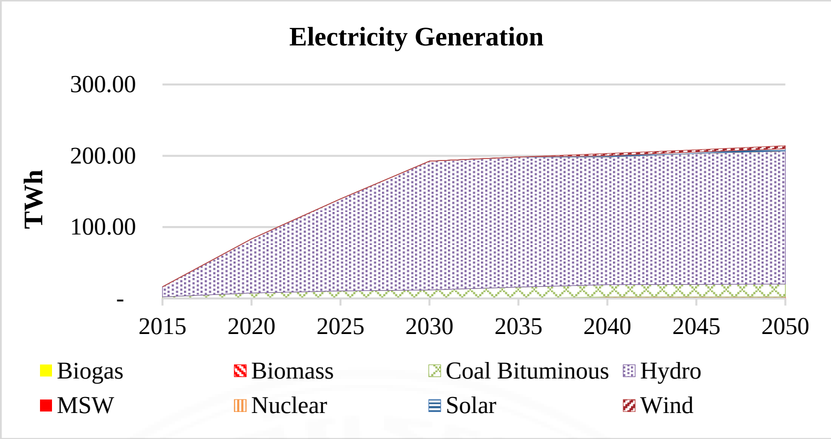

Figure 7.3 Electricity generation in Lao PDR in the BAU scenario.

7.2.2 Renewable Energy Technologies (RET) Scenario

The RET scenario has the same electricity demand as the BAU scenario. However, the differences are the shares of sources of electricity generation. In the RET scenario in 2050, the total electricity generation will be 214.16 TWh of which, the electricity outputs produced from hydro, bituminous coal, nuclear, wind, solar, biomass, MSW, and biogas account for 71.85%, 9.16%, 8.13%, 2.1%, 5.42%, 2.77%, 0.33%, and 0.24%, respectively, as shown in Figure 7.4.

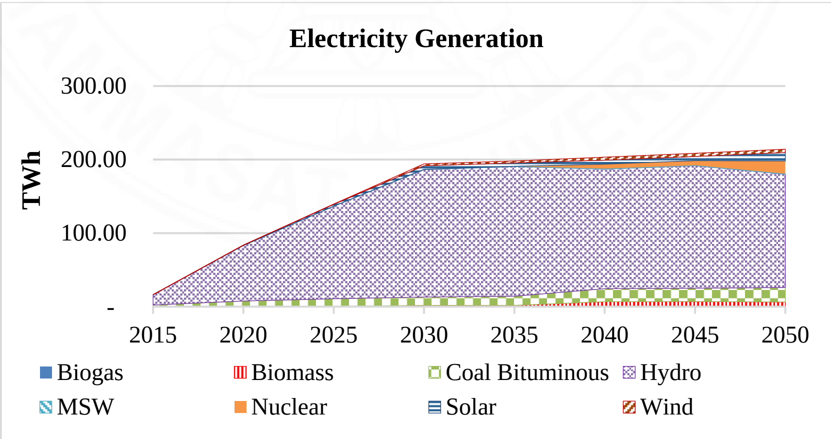

Figure 7.4 Electricity generation in Lao PDR in the RET scenario.

7.2.3 Improved Energy Efficiency (IEE) Scenario

In the IEE scenario, the total electricity generation in 2050 will drop from the BAU scenario by 2.08 TWh with the majority of electricity generated from hydro accounting for 87.33%, while the generation from other renewable energy sources will have a share of only 4.48%. Figure 7.5 presents the electricity generation by fuel type in Lao PDR in the IEE scenario.

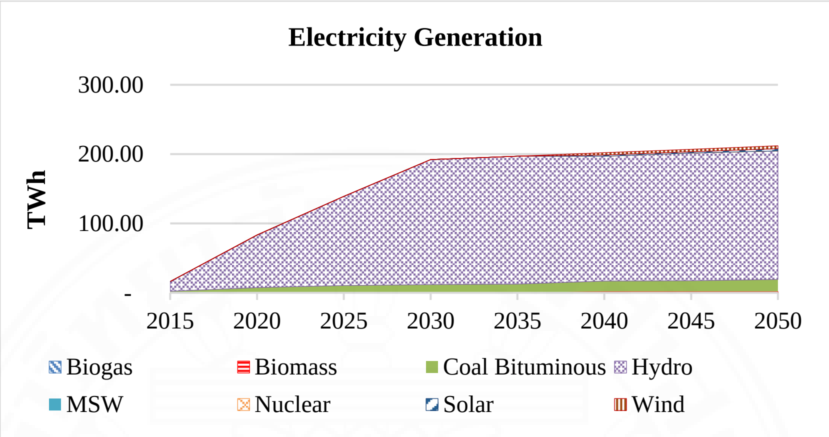

Figure 7.5 Electricity generation in Lao PDR in the IEE scenario.

7.3 Emissions in the Power Sector

The CO_2 emissions in the power sector in Lao PDR in the BAU scenario will increase from 1.98 Mt-CO_2eq in 2015 to 18.19 Mt-CO_2eq in 2050 of which the majority comes from the use of coal. The CO_2 emissions in the RET scenario will decrease to 9.71 Mt-CO_2eq in 2050 in comparison to the BAU scenario, indicating a drop of 8.48 Mt-CO_2eq. The CO_2 emissions in 2050 in the IEE scenario will decrease by 2.95 Mt-CO_2eq from 18.19 Mt-CO_2eq in the BAU scenario as presented in Figure 7.6.

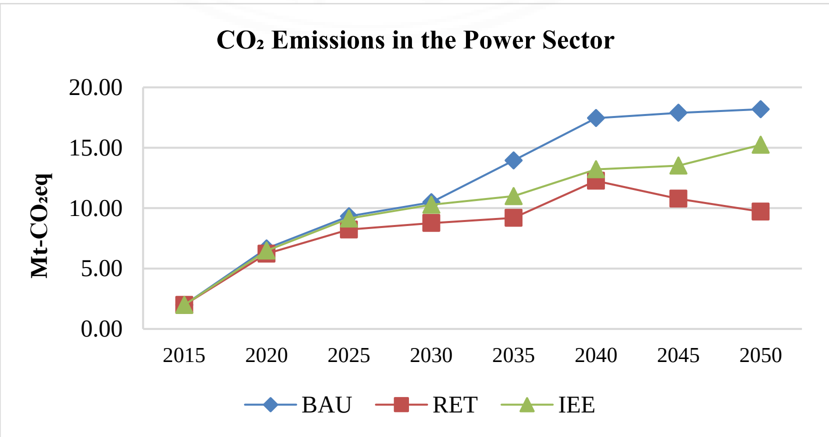

Figure 7.6 Carbon dioxide emissions in the power sector in Lao PDR.

In addition, the emissions of SO_2, NO_x, and CO in the power sector in Lao PDR in 2050 in each scenario are shown in Figure 7.7.

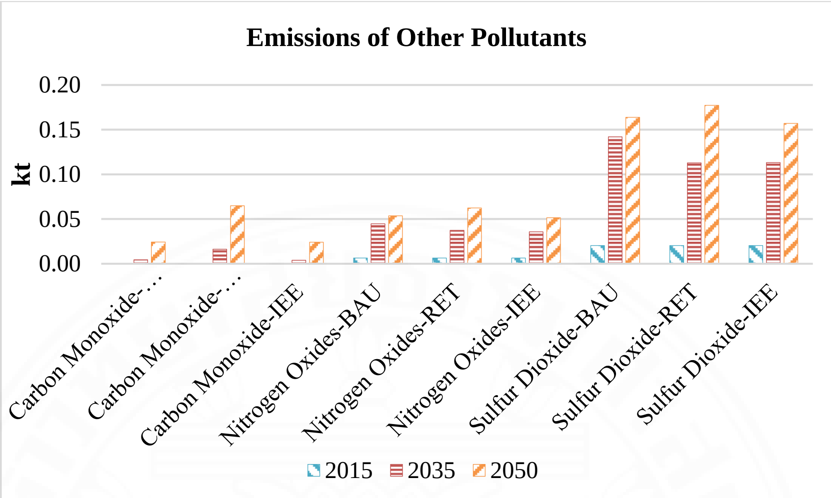

Figure 7.7 Emissions of other pollutants in the power sector in Lao PDR.

7.4 Energy Demand in the Transport Sector

The total energy demand in the transport sector in Lao PDR will increase from 48.93 ktoe in 2015 by 5.67 times, 5.59 times, and 2.56 times in the BAU scenario, RET scenario, and IEE scenario respectively by 2050. The energy demand in the road transport in 2015 covers 99.27% of the total energy demand for the transport sector and the rate in 2050 would be 99.28%, 99.27%, and 79.74% in the BAU scenario, RET scenario, and IEE scenario respectively. Road freight transport takes a share of 16.01% of the energy demand for road transport in 2015 and the share is estimated to be 17.72%, 17.91%, and 15.55% in the BAU scenario, RET scenario, and IEE scenario respectively in 2050. Within the energy demand for road passenger transport in 2015, light-duty vehicles consume 69.84%, the motorcycle and three-wheelers, and bus consume 22.2% and 7.96%, respectively. In the BAU scenario, the shares are expected to be the same by 2050, whereas, in the RET scenario, the shares would be 69.64%, 22.27%, and 8.1%, respectively. In the IEE scenario, the shares in 2050 would be 41.41%, 16.23%, and 27.48%, respectively. Figure 7.8 illustrates the energy demand in the transport sector in Lao PDR during 2015-2050 in all scenarios.

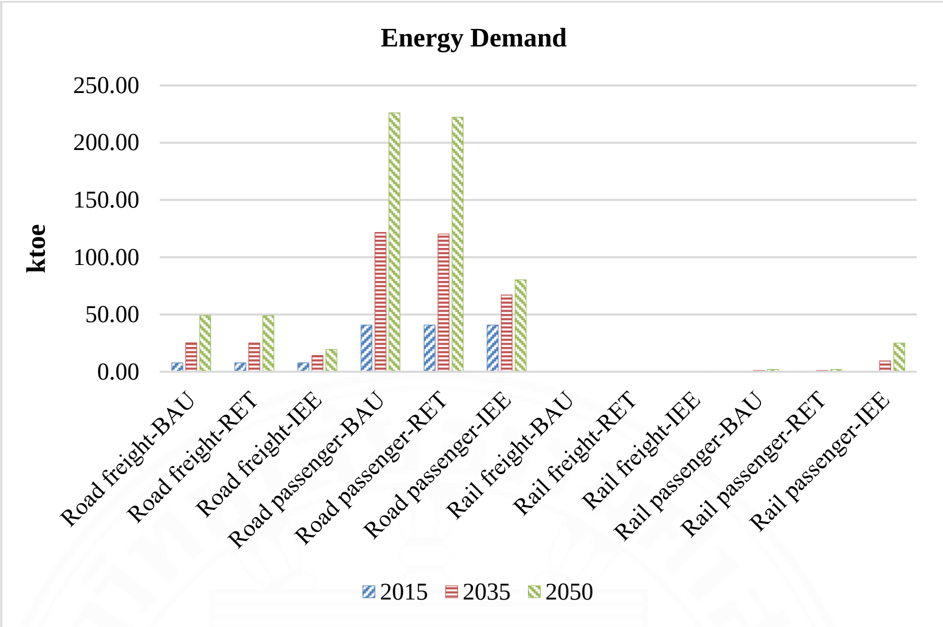

Figure 7.8 Energy demand in the transport sector in Lao PDR.

7.5 Emissions in the Transport Sector

In 2015, the GHG emissions in the transport sector in Lao PDR were 0.14 Mt-CO_2eq. The energy demand is expected to increase by 5.67 times, 5.6times, and 2.35 times by 2050 in the BAU scenario, RET scenario, and IEE scenario respectively. By 2050, the emissions from freight transport would account for 0.15 Mt-CO_2eq in the BAU scenario, while that in the RET scenario and IEE scenario would account for 0.15 Mt-CO_2eq and 0.06 Mt-CO_2eq, respectively. Figure 7.9 shows the emissions in the transport sector in Lao PDR from 2015-2050 in every scenario.

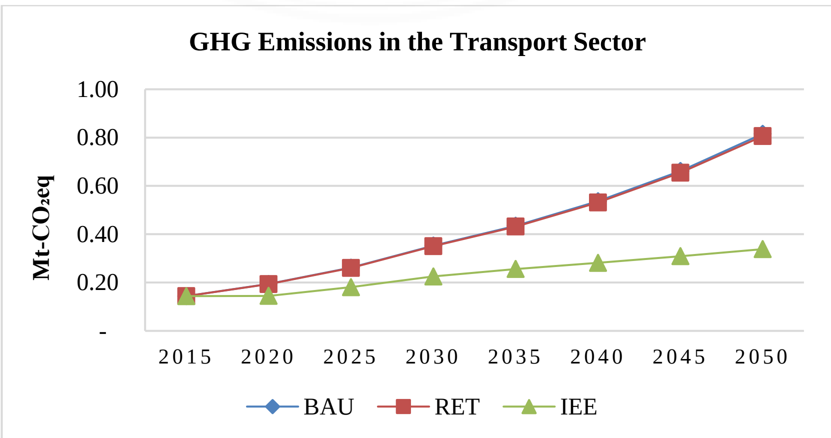

Figure 7.9 GHG emissions in the transport sector in Lao PDR.

7.6 Cost of Electricity Generation

In Lao PDR 2015, the cost of electricity production was 0.28 billion USD and it is expected to be 5.25 billion USD, 5.86 billion USD, and 5.22 billion USD in the BAU scenario, RET scenario, and IEE scenario, respectively, in 2050. Figure 7.10 shows the cost of electricity production in Lao PDR. In addition, the cost of externality in Lao PDR in 2015 was 0.02 billion USD and would be increased to 0.164 billion USD, 0.087 billion USD, and 0.137 billion USD in the BAU scenario, RET scenario, and IEE scenario, respectively, by 2050 as illustrated in Figure 7.11. The total cost of electricity generation by 2050 in the BAU scenario, RET scenario, and IEE scenario would be 5.41 billion USD, 5.95 billion USD, and 5.35 billion USD, respectively, as presented in Figure 7.12.

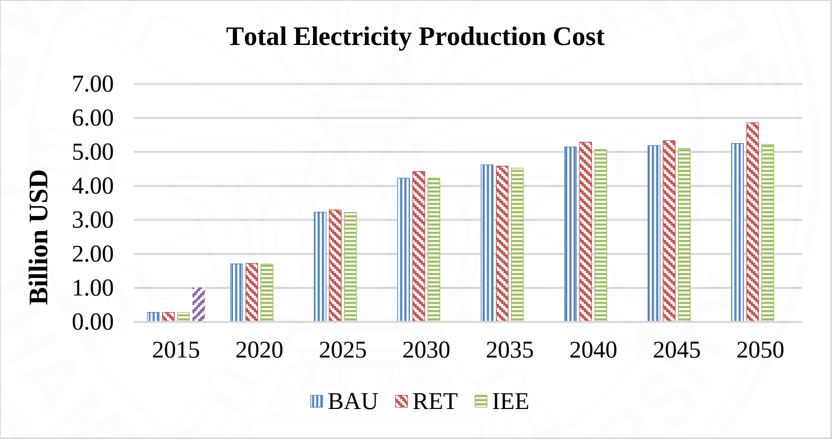

Figure 7.10 Total cost of electricity production in Lao PDR.

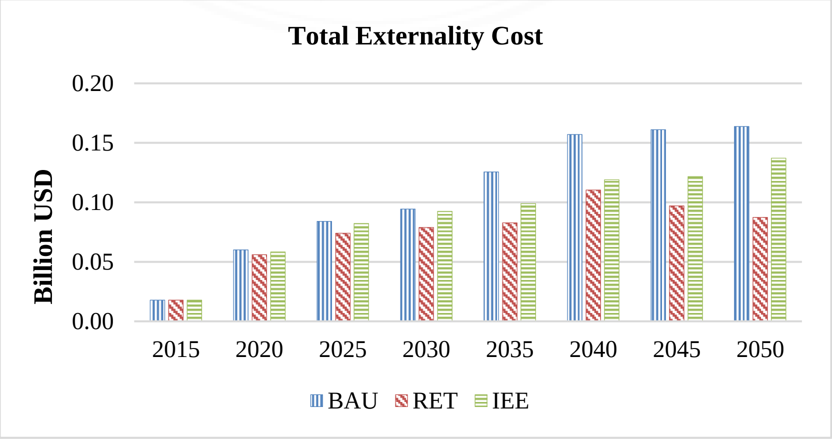

Figure 7.11 Total cost of externality in the power sector in Lao PDR.

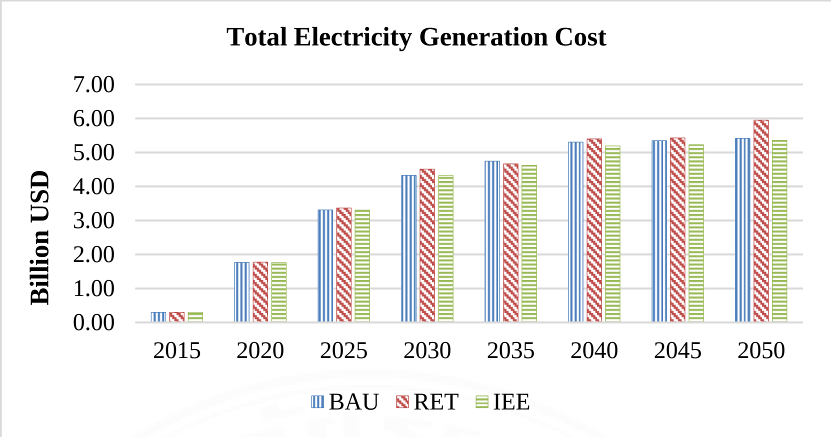

Figure 7.12 Total cost of electricity generation in Lao PDR.

7.7 Marginal Abatement Cost

7.7.1 Residential Sector

The MAC study in the residential sector considers the adoption of the three technologies namely, lighting system, air conditioning system, and refrigerating system that are considered in the Improved Energy Efficiency (IEE) scenario.

In the lighting system in Lao PDR, the penetrations of LED tubes over the LFLs in 2035 and 2050 by 75% and 100%, respectively, would result in the cumulative GHG emissions drop by about 0.84 Mt-CO_2eq with the cumulative MAC of -807.3 \$/t-CO_2 during 2015-2050. When replacing 75% and 100% of the incandescent lamps in 2035 and 2050, respectively, with CFLs, the cumulative GHG emissions during the same period that can be reduced as a result of the reduction in energy consumption would account for approximately 0.06 Mt-CO_2eq with the cumulative MAC of about -959.5 \$/t-CO_2eq. The cumulative GHG emissions mitigation and the cumulative MAC of the penetration of LED lamps over CFLs during the same period would be 0.02 Mt-CO_2eq and -3,273 \$/t-CO_2eq, respectively.

In the air conditioning system, the domestic air conditioners with an efficiency rating of EER-9 will be replaced by the air conditioners having higher efficiency ratings. The results show that when replacing the EER-9 air conditioners with EER-10 air conditioners at a penetration rate of 50% by 2020, the cumulative GHG emissions reduction during 2015-2050 would be 0.12 Mt-CO_2eq by 2050 with the cumulative MAC of 860.3 \$/t-CO_2eq. The replacement of EER-9 air conditioners with EER-11.2

air conditioners would result in a cumulative emissions reduction of about 0.23 Mt-CO_2eq with the cumulative MAC of 537.8 \$/t-CO_2eq during the same period. When considering replacing the EER-9 air conditioners with the EER-12.8 air conditioners, the cumulative emissions would be reduced by 0.35 Mt-CO_2eq with the cumulative MAC of -138.3 \$/t-CO_2eq during 2015-2050. Figure 7.13 and Table 7.1 present the cumulative MAC curve of the measures during 2015-2050 and the details of the cumulative MAC during 2015-2050 in the residential sector in Lao PDR respectively.

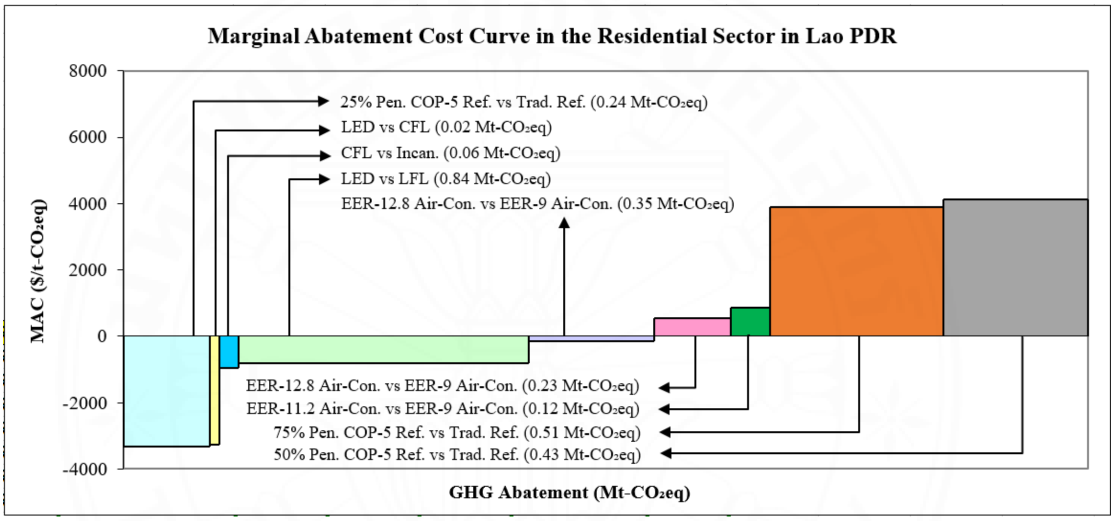

Figure 7.13 The MAC curve in the residential sector in Lao PDR.

Table 7.1 The MAC during 2015-2050 in the residential sector in Lao PDR.

Measures	GHG Abatement (Mt-CO_2eq)	MAC (\$/t-CO_2eq)
25% Pen. COP-5 Ref. vs Trad. Ref.	0.24	-3325.2
LED lamp vs CFL	0.02	-3273.02
CFL vs Incandescent lamp	0.06	-959.54
LED tube vs LFL	0.84	-807.33
EER-12.8 Air-Con. vs EER-9 Air-Con.	0.35	-138.33
EER-11.2 Air-Con. vs EER-9 Air-Con.	0.23	547.82
EER-10 Air-Con. vs EER-9 Air-Con.	0.12	860.31
75% Pen. COP-5 Ref. vs Trad. Ref.	0.51	3898.03
50% Pen. COP-5 Ref. vs Trad. Ref.	0.43	4130.6

Almost all of the MAC values in Table 7.1 show negative values except for the measures of EER-11.2 air conditioners, EER-10 air conditioners, 75% penetration of COP-5 refrigerator, and 50% penetration of COP-5 refrigerator. The negative values of MAC in the table are caused by the large reduction of electricity cost of the efficient technologies even though the investment cost of the new and efficient technology is higher than that of the old ones. The positive values of MAC indicate that the measures are not preferable in terms of finance. The reason for the positive values in the MAC study is that the saving in the electricity costs is not enough to make up for the high investment costs of the new and efficient technologies.

7.7.2 Commercial Sector

The MAC study for the lighting system in the commercial sector in Lao PDR suggests that the cumulative GHG emissions reduction and the corresponding cumulative MAC during 2015-2050 of approximately 0.07 Mt-CO_2eq and -9,865.2 \$/t-CO_2eq, respectively, would be achieved by replacing LFLs with LED tubes. However, if the replacement of the CFLs by LED lamps at the rate of 75% and 100% in 2035 and 2050 are done, the cumulative GHG emissions could be cut down by around 0.009 Mt-CO_2eq with the cumulative MAC of -18,309 \$/t-CO_2eq during the same period. Figure 7.14 represents the cumulative MAC curve of the measures included in the commercial sector in Lao PDR from 2015-2050. In addition, Table 6.2 lists the details of the cumulative MAC during 2015-2050 in the commercial sector in Lao PDR.

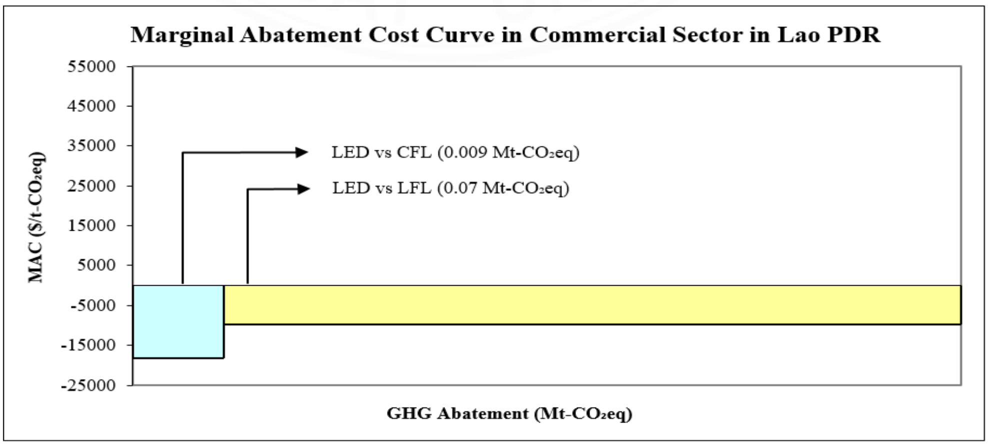

Figure 7.14 The cumulative MAC curve in the commercial sector in Lao PDR.

Table 7.2 Details of the cumulative MAC during 2015-2050 in the commercial sector in Lao PDR.

Measures	GHG Abatement (Mt-CO_2eq)	MAC (\$/t-CO_2eq)
LED lamp vs CFL	0.009	-18308.8
LED tube vs LFL	0.07	-9865.16

7.7.3 Transport Sector

The MAC study in the transport sector in Lao PDR considers different end-use technologies such as electric vehicles and biofuel-powered vehicles. The results of the analysis show that the replacement of gasoline LDVs with electric LDVs have the potential to reduce the cumulative GHG emissions of around 0.51 Mt-CO_2eq during 2015-2050. Figure 7.15 illustrates the cumulative MAC curve of the measures in the transport sector in Lao PDR during 2015-2050.

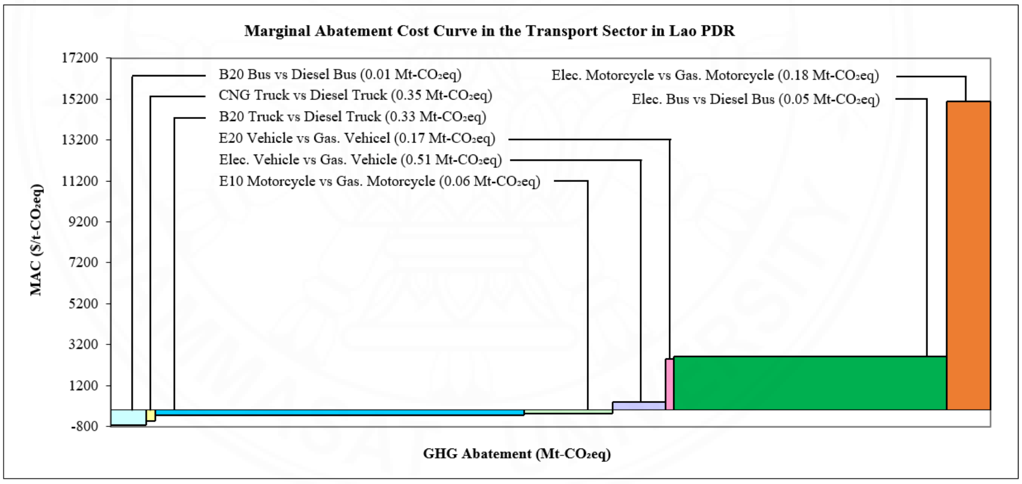

Figure 7.15 The cumulative MAC curve in the transport sector in Lao PDR.

The cumulative MAC corresponding to the GHG reduction during the same period would be 411.05 \$/t-CO_2eq. B20 buses would be a good option to replace diesel buses in Lao PDR in terms of finance because of its low cumulative MAC of approximately -741 \$/t-CO_2eq. However, its cumulative GHG emissions during 2015-2050 would be only 0.01 Mt-CO_2eq. The replacement of diesel trucks with both CNG trucks and B20 trucks in the transport sector would be effective as their cumulative GHG emissions reduction and corresponding cumulative MAC during the same period would be 0.35 Mt-CO_2eq and -547 \$/t-CO_2eq and 0.33 Mt-CO_2eq and -242 \$/t-CO_2eq respectively. The replacement of gasoline motorcycles with electric motorcycles results in low cumulative GHG emissions mitigation (0.18 Mt-CO_2eq) during 2015-2050 and high cumulative MAC (15,073 \$/t-CO_2eq). Table 7.3 shows the MAC during 2015-2050 in the transport sector in Lao PDR.

Table 7.3 The cumulative MAC during 2015-2050 in the transport sector in Lao PDR.

Measures	GHG Abatement (Mt-CO_2eq)	MAC (\$/t-CO_2eq)
B20 Bus vs Diesel Bus	0.01	-740.8
CNG Truck vs Diesel Truck	0.35	-546.74
B20 Truck vs Diesel Truck	0.33	-241.8
E10 Motorcycle vs Gasoline Motorcycle	0.06	-144.97
Electric Vehicle vs Gasoline Vehicle	0.51	411.05
E20 Vehicle vs Gasoline Vehicle	0.17	2500.2
Electric Bus vs Diesel Bus	0.05	2634.12
Elec. Motorcycle vs Gasoline Motorcycle	0.18	15070.72

7.7.4 Power Sector

The MAC study for the power sector in Lao PDR suggests that when coal power plants with a capacity of 500 MW are replaced by different sources in 2050, the most economical source turns out to be solar which would be able to reduce the GHG emissions of approximately 0.64 Mt-CO_2eq in the same year with a MAC of 148.34 \$/t-CO_2eq. Similar to the MAC study for Cambodia, the energy source with the biggest cost of MAC is nuclear, which accounts for 821.5 \$/t-CO_2eq and GHG emissions reduction of 0.32 Mt-CO_2eq in 2050. Figure 7.16 shows the MAC curve for the replacement of coal power plants by different types of power plants for Lao PDR in 2050. Table 7.4 details the MAC values of the measures in the power sector in 2050.

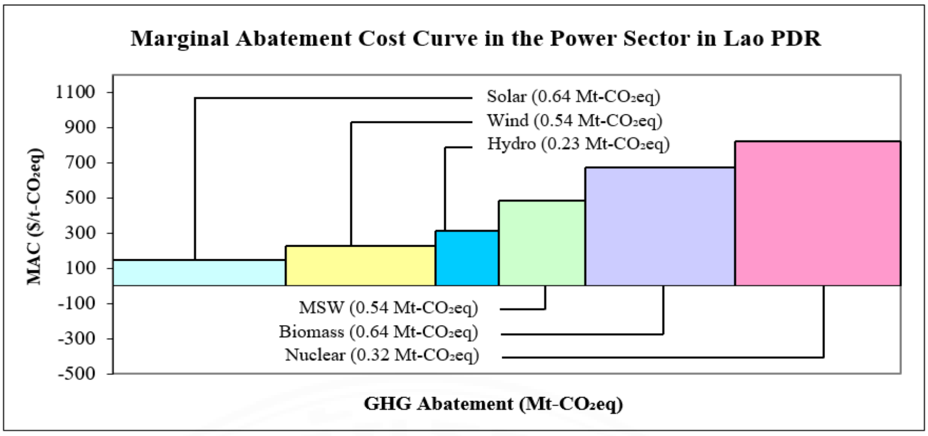

Figure 7.16 Marginal abatement cost curves of coal power plant replacement by different energy sources in the power sector of Lao PDR in 2050.

Table 7.4 Details of the MAC in 2050 in the power sector in Lao PDR.

Measures	GHG Abatement ($Mt\text{-}CO_2eq$)	MAC ($\$/t\text{-}CO_2eq$)
Solar	0.64	148.34
Wind	0.54	227.55
Hydro	0.23	314.55
MSW	0.54	482.19
Biomass	0.64	671.07
Nuclear	0.32	821.5

7.8 Emissions Gap

The full implementation of the unconditional and conditional NDCs targets of Lao PDR would not be still enough to achieve the emissions pathways of 2℃ and 1.5℃ in 2050. The emissions gaps between the conditional NDCs target and the 2℃ and 1.5℃ targets in 2050 are 48.8 $Mt\text{-}CO_2eq$ and 58.3 $Mt\text{-}CO_2eq$, respectively. Figure 7.17 shows the emissions gaps between different scenarios in Lao PDR.

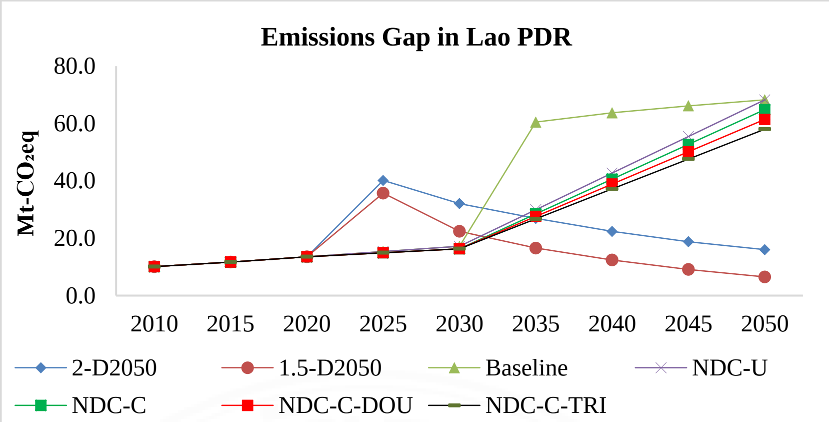

Figure 7.17 Emissions Gap in Lao PDR.

7.9 Carbon Budgets

The carbon budgets analysis for Lao PDR suggests that the GF approach allows for the least cumulative carbon budgets during 2011-2050 based on both the 2°C pathway and 1.5°C pathway. The cumulative 2011-2050 carbon budgets for Lao PDR based on the 2°C emissions pathway in the GF, IEPC, PCC and GDR approaches are 530.5 Mt-CO_2eq, 821.2 Mt-CO_2eq, 675.9 Mt-CO_2eq, and 1,334.8 Mt-CO_2eq, respectively. The large budget in the GDR approach is caused by small RCI values and high future emissions in the BAU case of the approach in Lao PDR. Figure 7.18 illustrates the cumulative carbon budgets for Lao PDR in effort-sharing approaches based on the 2°C goal of the Paris Agreement. Figure 7.19 represents the cumulative carbon budgets for Lao PDR in effort-sharing approaches based on the 1.5°C target.

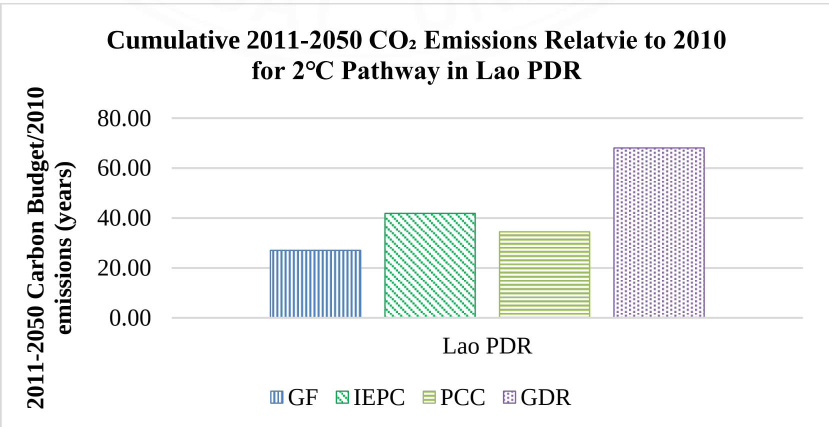

Figure 7.18 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 2°C pathway.

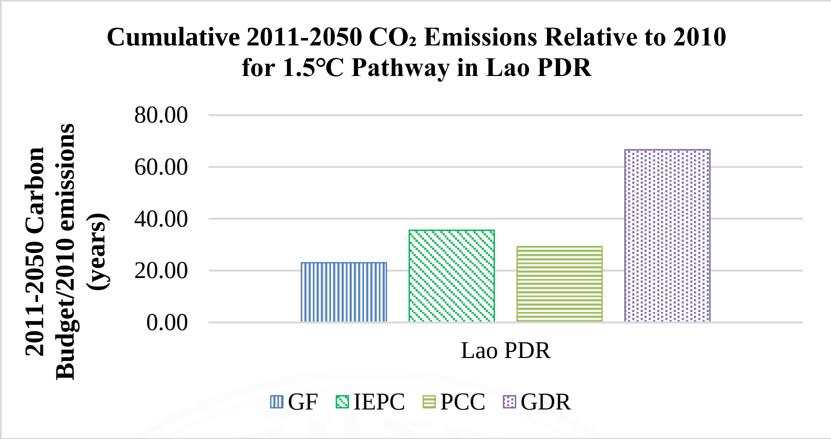

Figure 7.19 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 1.5°C pathway.

Based on the 1.5°C emissions pathway, the cumulative carbon budgets during 2011-2050 for Lao PDR in the GDR and GF approaches are 1,307.4 Mt-CO_2eq and 451.9 Mt-CO_2eq respectively. The carbon budgets for Lao PDR based on the 1.5°C target would be smaller than those in the 2°C target, however, the cumulative carbon budgets in Lao PDR will stay the same as in the 2°C target due to the same reasons. For the comparison purpose, Figure 7.20 presents the cumulative carbon budgets for Lao PDR based on both the 2°C and 1.5°C targets.

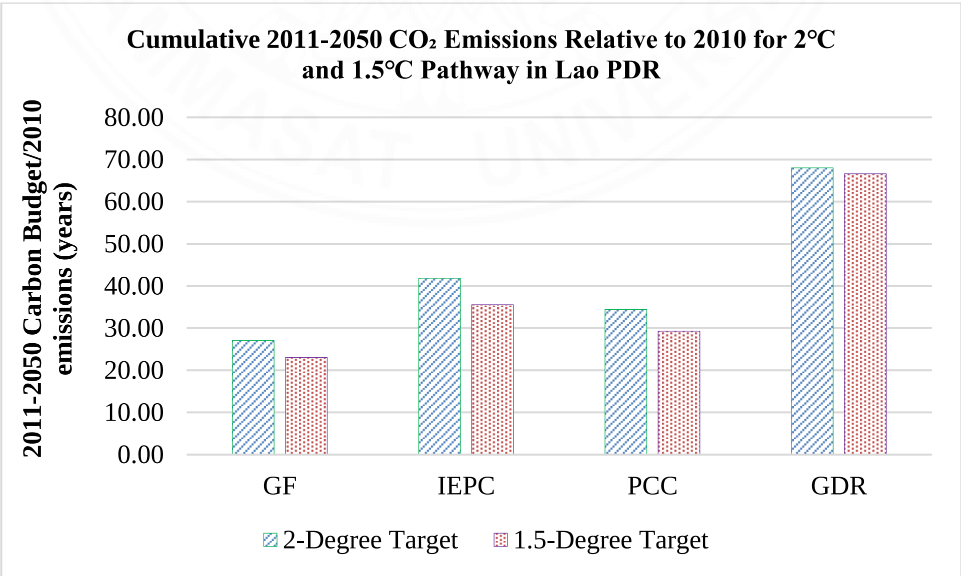

Figure 7.20 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 2°C and 1.5°C pathways.

7.10 Carbon Budgets Pathways

The 2-degree carbon budgets pathway of Lao PDR during 2011-2100 based on the four approaches is shown in Figure 7.21. The results indicate that the CO_2 emissions in Lao PDR are expected to be net-zero by the year 2060 in the GF, IEPC, and PCC approaches and by 2088 in the GDR approach. However, after reaching net-zero emissions, the CO_2 emissions in the GF, IEPC, and PCC will go up and down between the year reaching net-zero emissions and the year 2100. Finally, the emissions in Lao PDR will be zero in the GF and IEPC approaches in 2100. This is due to the global trend of the CO_2 emissions in the 2-degree pathway. In contrast, in the GDR approach, the CO_2 emissions in Lao PDR will keep decreasing even after reaching the net-zero in 2090.

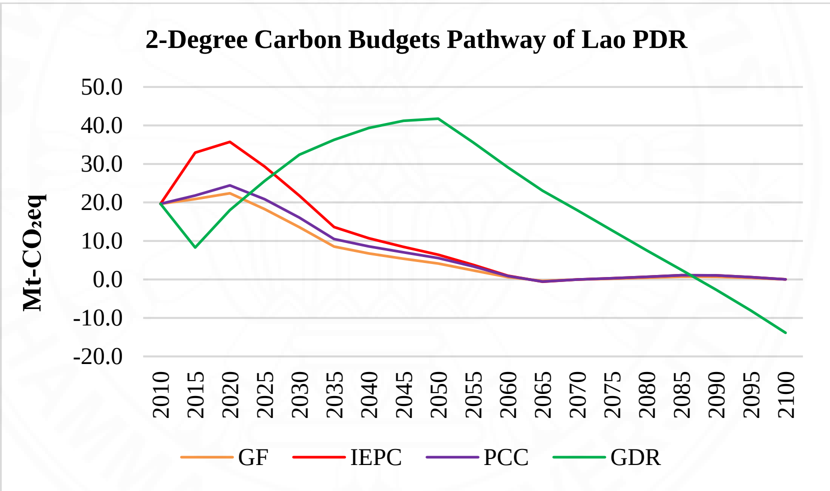

Figure 7.21 2-degree carbon budgets pathway of Lao PDR based on the four approaches during 2010-2100.

The 1.5-degree carbon budgets pathways based on the four approaches of Lao PDR show a faster trend of reaching net-zero emissions as can be seen from Figure 7.22. The 1.5-degree carbon budgets pathway of Lao PDR in the GF, IEPC, and PCC approaches will reach net-zero in the same year as Cambodia, which is 2045. This is due to the trend of global carbon emissions. On the other hand, the pathway of Lao PDR in the GDR approach will be net-zero by 2085, which is slower than the net-zero year of the other three approaches. This is due to the small RCI values of Lao PDR which is the index corresponding to the GDP per capita and emissions mitigation capability, and is assumed to be constant from 2030 onward. In addition, the GDR approach depends on the responsibility of a country over the historical emissions and the capability of a country to mitigate the emissions in the future. Thus, in terms of fairness, the GDR approach is more preferable to the other three approaches for Lao PDR because of the slower rate of reaching net-zero emissions.

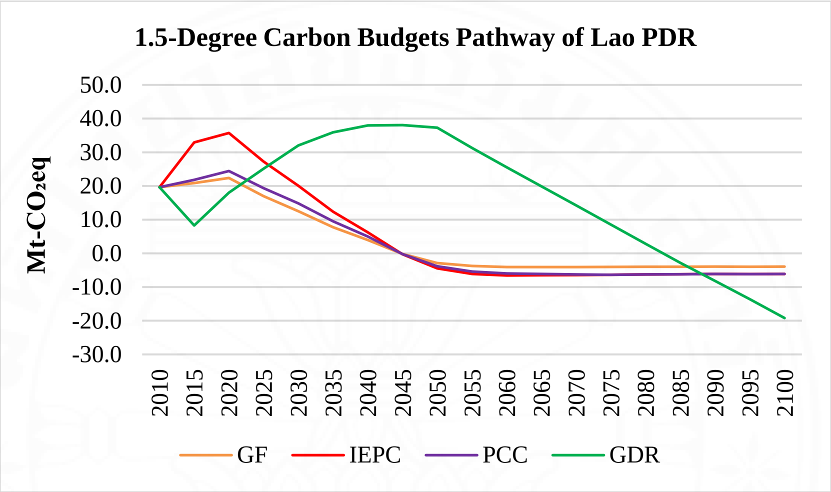

Figure 7.22 1.5-degree carbon budgets pathway of Cambodia based on the four approaches during 2010-2100.

CHAPTER 8
RESULTS OF THAILAND

8.1 Electricity Demand

8.1.1 Business-as-Usual (BAU) Scenario

The electricity demand in Thailand would increase from 174.99 TWh in 2015 to 705.4 TWh in 2050. In 2015, the industrial sector had a major share of electricity consumption accounting for 47.99%. The commercial sector, residential sector, governmental sector, transport sector, and other sector have shares of 24.27%, 23.59%, 0.1%, 0.09%, and 3.95% respectively. By 2050, the share of energy demand in the industry is estimated to be 48% while that of the commercial sector, residential sector, governmental sector, transport sector, and other sector will be 24.27%, 23.59%, 0.1%, 0.08%, and 3.95%, respectively. The shares of the electricity demand by type of sector are shown in Figure 8.1.

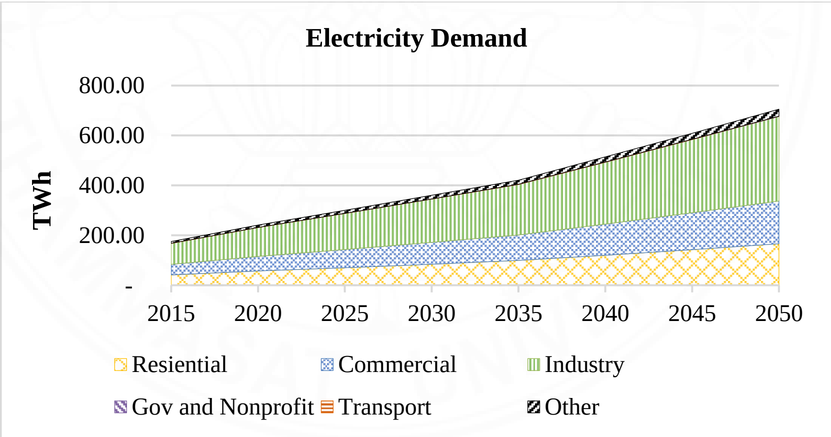

Figure 8.1 Electricity demand in Thailand in the BAU scenario.

8.1.2 Renewable Energy Technologies (RET) Scenario

The electricity demand in Thailand in the RET scenario is as much as that in the BAU scenario.

8.1.3 Improved Energy Efficiency (IEE) Scenario

As a result of the energy efficiency improvement and electric vehicle penetration, the electricity demand in Thailand in the IEE scenario will decrease by 20.7 TWh in 2050 in comparison to the BAU scenario. The industry sector will consume nearly half of the total demand in 2050 while the commercial sector, residential sector, governmental sector, transport sector, and other sector will have shares of 20.52%, 19.37%, 0.11%, 6.48%, and 4.07%, respectively, as presented in Figure 8.2.

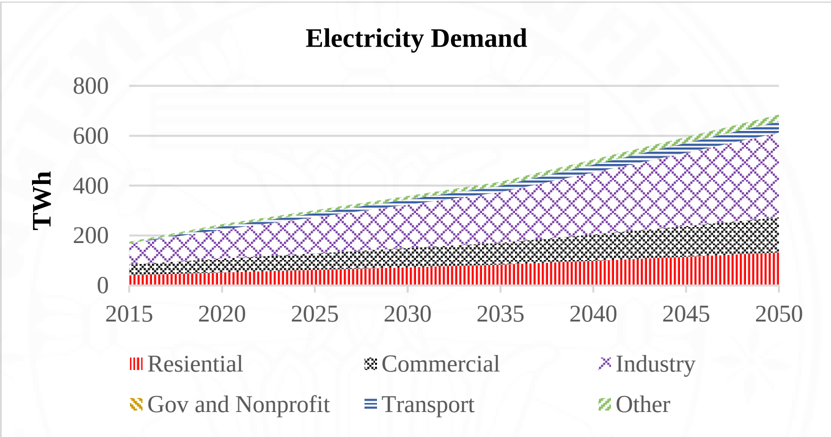

Figure 8.2 Electricity demand in Thailand in the IEE scenario.

8.2 Electricity Generation

8.2.1 Business-as-Usual (BAU) Scenario

In 2015, the total electricity generation in Thailand was 192.25 TWh, of which natural gas was the main source, accounting for 66.85%. Coal and lignite, hydro, biomass, MSW, solar, biogas, wind, oil, imported electricity, and diesel accounted for 17.99%, 8.2%, 4.12%, 0.27%, 1.23%, 0.56%, 0.17%, 0.48%, 0.07%, and 0.07%, respectively. The electricity generation is estimated to increase to 742.53 TWh by 2050. By 2050, the share of natural gas as the source of generation is expected to be decreased drastically to 33.33%. The shares of coal and lignite, hydro, biomass, MSW, solar, biogas, nuclear, wind, oil, imported electricity, and diesel as the sources of electricity generation are 14.25%, 21.29%, 8.76%, 2.08%, 9.39%, 3.71%, 2.96%, 3.93%, 0%, 0.3%, and 0%, respectively. Figure 8.3 shows the electricity generation by type of fuel in Thailand during 2015-2050.

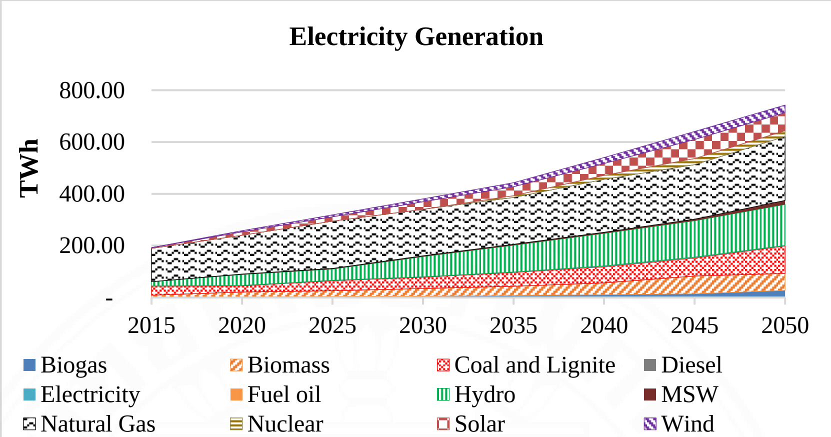

Figure 8.3 Electricity generation in Thailand in the BAU scenario.

8.2.2 Renewable Energy Technologies (RET) Scenario

The electricity generation in Thailand in the RET scenario is as much as that in the BAU scenario. However, the electricity generation in the RET is much cleaner because of renewable energy sources. In this scenario, the total electricity generation in 2050 will be 742.53 TWh, of which, the electricity generation from coal and lignite, hydro, biomass, MSW, solar, biogas, nuclear, wind, fuel oil, natural gas, imported electricity, and diesel will account for 8.36%, 15.74%, 12.6%, 3.24%, 17.33%, 6.27%, 3.91%, 10.45, 0%, 21.8%, 0.29%, and 0%, respectively, as shown in Figure 8.4.

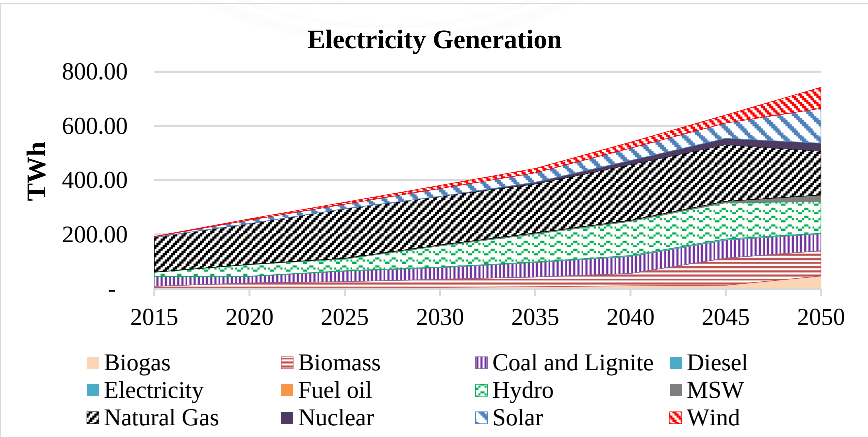

Figure 8.4 Electricity generation in Thailand in the RET scenario.

8.2.3 Improved Energy Efficiency (IEE) Scenario

In the IEE scenario, the total electricity generation in Thailand in 2050 will drop from the BAU scenario by 21.79 TWh with the majority of electricity generated from natural gas accounting for 33.33%, while the generation from other renewable energy sources will have a share of 27.87%, excluding hydro. Figure 8.5 presents the electricity generation by fuel type in Thailand in the IEE scenario.

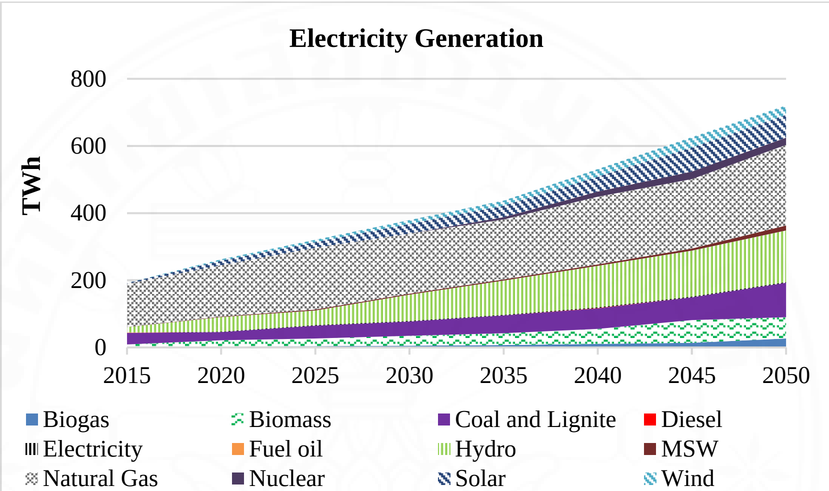

Figure 8.5 Electricity generation in Thailand in the IEE scenario.

8.3 Emissions in the Power Sector

Figure 8.6 represents CO_2 emissions from power generation in Thailand during 2015-2050.

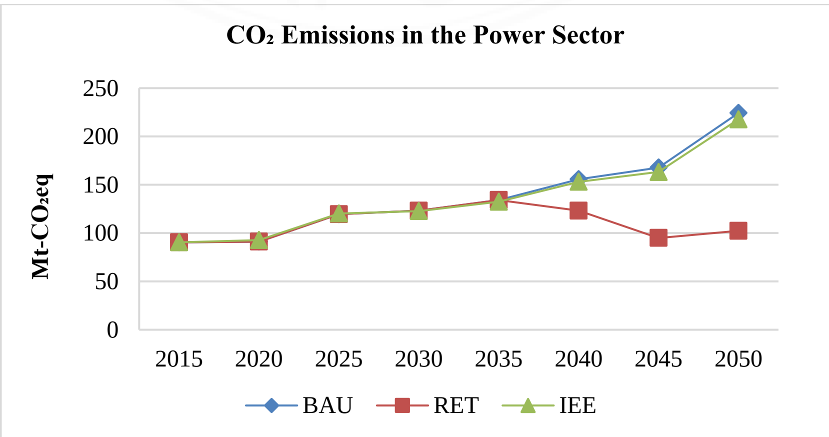

Figure 8.6 Carbon dioxide emissions in the power sector in Thailand.

The CO_2 emissions in the power sector in Thailand in the BAU scenario will increase from 90.4 Mt-CO_2eq in 2015 to 224.35 Mt-CO_2eq in 2050, of which the majority comes from the use of natural gas, and coal, and lignite. Because of a much cleaner electricity generation, the CO_2 emissions in the RET scenario will be reduced by 121.97 Mt-CO_2eq when compared to the BAU scenario. The CCS technology could reduce GHG emissions by 57.33 Mt-CO_2eq in 2050. The emissions in 2050 in the IEE scenario will decrease by 6.58 Mt-CO_2eq from the BAU. In addition, the emissions of other pollutants such as SO_2, NO_x, and CO in the power sector in Thailand in 2050 in each scenario are also shown in Figure 8.7.

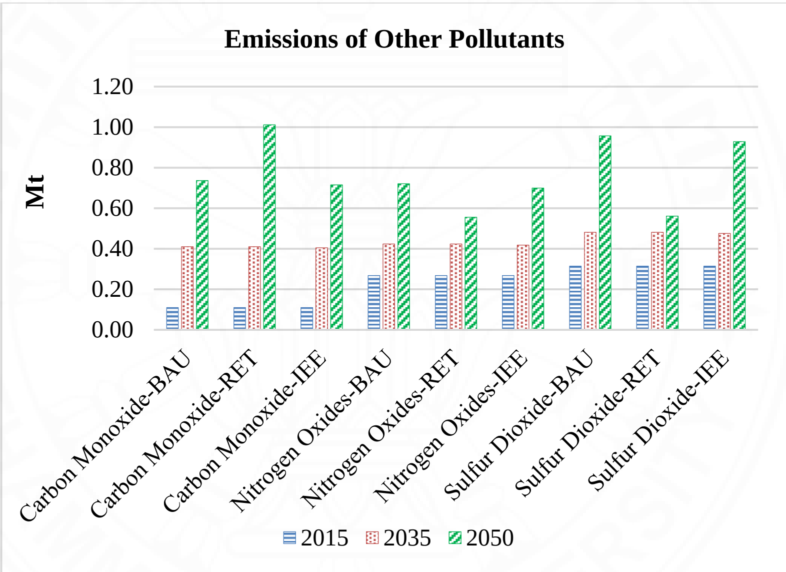

Figure 8.7 Emissions of other pollutants in the power sector in Thailand.

8.4 Energy Demand in the Transport Sector

In the BAU scenario, the transport sector in Thailand in 2015 consumed 18.82 Mtoe of energy and it is expected to be increased to 97.26 Mtoe by 2050 while that in the RET scenario, and IEE scenario are estimated to be 93.74 Mtoe, and 34.35 Mtoe, respectively by 2050. In 2015, road transport accounted for 74.69% of the total energy demand in the transport sector while rail transport, waterway transport, and aviation transport had shares of 0.46%, 4.43%, and 20.42%, respectively. The energy demand of waterway transport and aviation transport is covered by freight transport only. The share of energy demand for road transport is expected to be 77.74%, 75.88%, and

64.99% in the BAU scenario, RET scenario, and IEE scenario, respectively, by 2050. The share of energy demand for rail transport would be 0.35%, 0.37%, and 5.82% in the BAU scenario, RET scenario, and IEE scenario, respectively, by 2050; while the share of that for waterway transport would be 3.91%, 4.23%, and 3.51%, respectively, in the BAU scenario, RET scenario, and IEE scenario. The energy demand for road passenger transport in the BAU scenario will increase from 10.97 Mtoe in 2015 to 40.06 Mtoe in 2050, while in the RET scenario and IEE scenario the demand is expected to be 35.2 Mtoe and 10.67 Mtoe accordingly by 2050. Within the road passenger transport in 2015, the energy demand for light-duty vehicles is 6.95 Mtoe, while that for the bus, and motorcycle and three-wheelers were 2.72 Mtoe and 1.3 Mtoe, respectively. In the BAU scenario, the numbers are expected to be 25.36 Mtoe, 9.94 Mtoe, and 4.76 Mtoe, respectively, by 2050, whereas in the RET scenario the numbers would be 24.58 Mtoe, 9.94 Mtoe, and 4.66, Mtoe respectively. For the IEE scenario, the numbers are expected to be 3.72 Mtoe, 3.88 Mtoe, and 3.07 Mtoe, respectively. Figure 8.8 illustrates the energy demand in the transport sector in Thailand during 2015-2050.

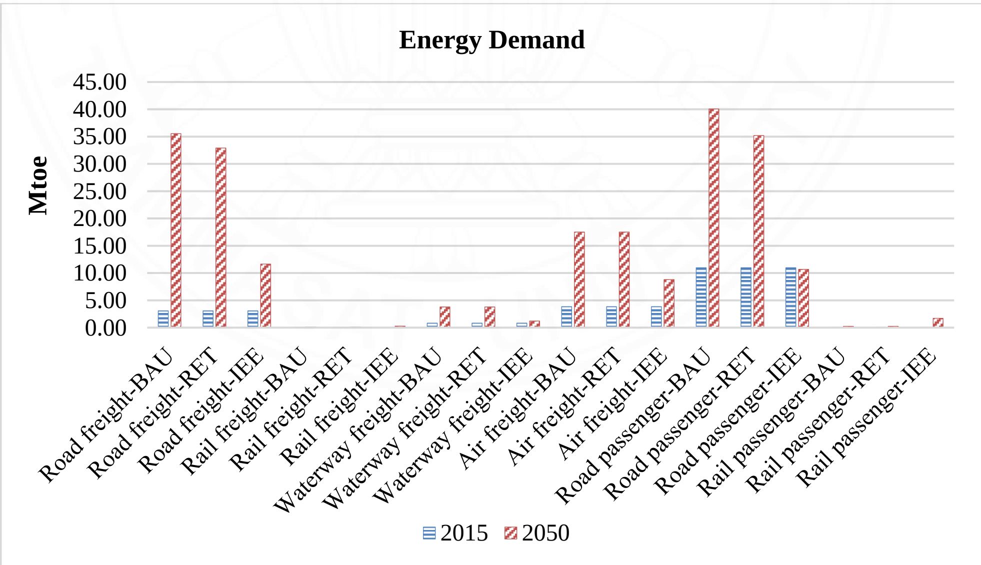

Figure 8.8 Energy demand in the transport sector in Thailand.

8.5 Emissions in the Transport Sector

The GHG emissions in the transport sector in Thailand in 2015 were 56.27 Mt-CO_2eq and the number is expected to increase to 292.76 Mt-CO_2eq, 281.95 Mt-CO_2eq, and 91.9 Mt-CO_2eq by 2050 in the BAU scenario, RET scenario, and IEE scenario, respectively. By 2050, the emissions from freight transport would account for 59.56%, 59.04%, and 72.09% of the total GHG emissions in the transport sector in the BAU, RET, and IEE scenarios, respectively. Figure 8.9 presents the GHG emissions in the transport sector in Thailand during 2015-2050 in all scenarios.

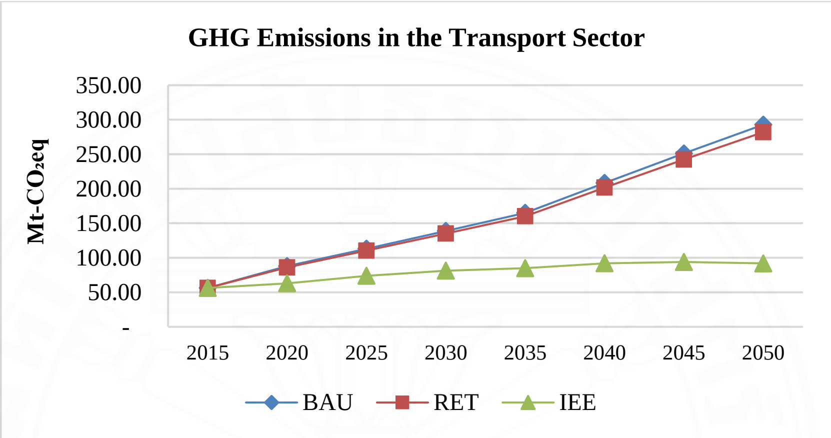

Figure 8.9 GHG emissions in the transport sector in Thailand.

8.6 Cost of Electricity Generation

In Thailand 2015, the cost of electricity production, externality, and total cost of electricity generation were 4.81 billion USD, 0.81 billion USD, and 5.63 billion USD respectively. By 2050, the cost of electricity production in the BAU scenario, RET scenario, and IEE scenario would be 35.01 billion USD, 31.35 billion USD, and 34.19 billion USD, respectively, as shown in Figure 8.10. On the other hand, the externality cost of electricity generation by 2050 in the BAU scenario, RET scenario, and IEE scenario will be 2.02 billion USD, 0.92 billion USD, and 1.96 billion USD, respectively. The total cost of electricity generation by 2050 in the BAU scenario would be 37.03 billion USD, whereas that in the RET scenario and IEE scenario will be 32.27 billion USD and 36.14 billion USD, respectively. Figure 8.11 and Figure 8.12 show the cost of externality and the total cost of electricity generation in Thailand in the four scenarios during 2015-2050.

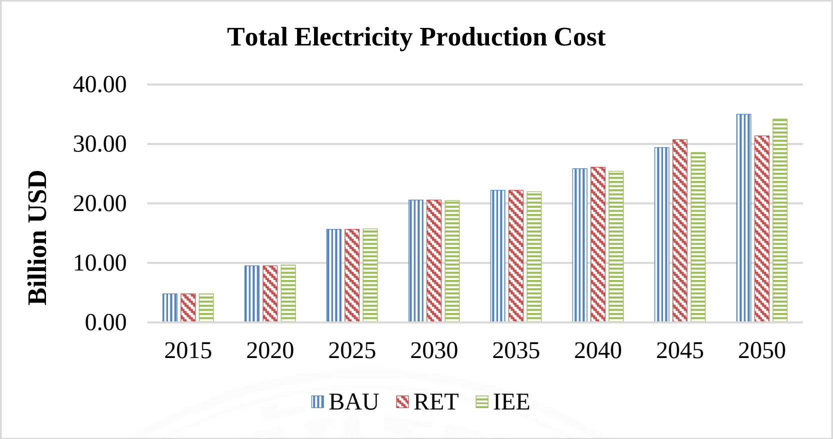

Figure 8.10 Total cost of electricity production in Thailand.

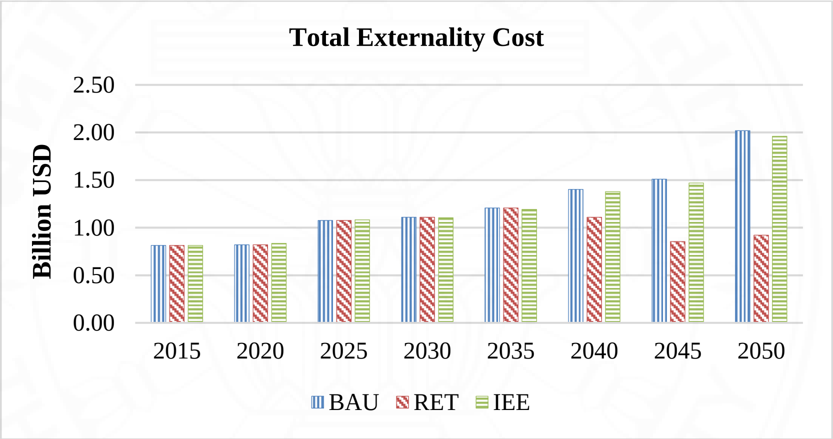

Figure 8.11 Total cost of externality in the power sector in Thailand.

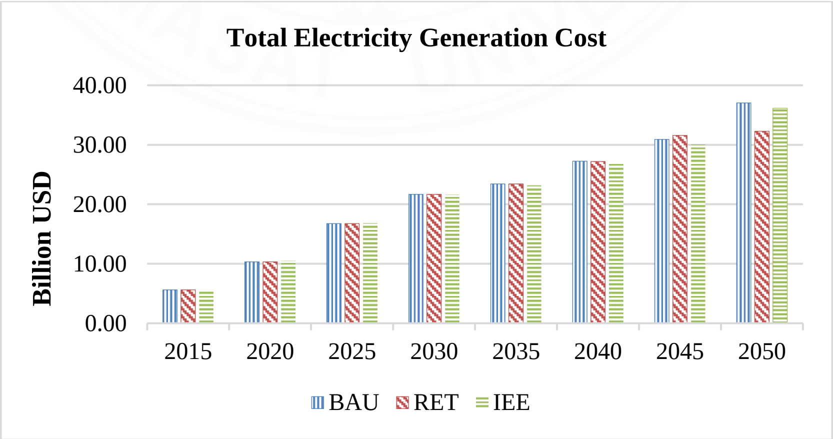

Figure 8.12 Total cost of electricity generation in Thailand.

8.7 Special Observation on the Impacts of Thailand's PDP2018

The PDP2018 of Thailand considers higher use of renewable energy in the electricity generation than that in the PDP2015. By following the PDP2018, the electricity generation as well as the GHG emissions in the BAU, RET, and IEE scenarios, are expected to differ from the case of adopting the PDP2015.

8.7.1 Electricity Generation

In 2015, the total electricity generation in the special observation case for Thailand was 192.25 TWh and it is expected to increase to 742.5 TWh, 742.5 TWh, and 720.7 TWh in the BAU, RET, and IEE scenarios, respectively, in 2050. As a result of using the PDP2018, the electricity generated from renewable energy (RE) in 2050 in Thailand in the BAU scenario would differ from that in the case of using the PDP2015 by about +1.15%, whereas the percentages in the RET and IEE scenarios would be -2.83% and +1.15%, respectively.

8.7.2 Emissions in the Power Sector

When considering the adoption of the PDP2018 into the power sector in Thailand, the impacts on the GHG emissions in the power sector in the BAU scenario in 20150 would be reduced by about 11.81 Mt-CO_2eq compared to the original case where the power generation in Thailand follows PDP2015. Even though the share of electricity generated from RE in the special observation case is lower than that of the original case in the RET scenario, the GHG emissions in the power sector in the special observation case in 2050 would be about 1.91% lower than the original case. On the other hand, in the IEE scenario in the special observation case, the GHG emissions in the power sector in Thailand in 2050 are expected to be reduced from that in the original case by around 5.3%. Therefore, the PDP2018 of Thailand has the potential to lead Thailand to have a cleaner power system which will likely make Thailand's ability to achieve the NDC targets even stronger.

8.8 Marginal Abatement Cost

8.8.1 Residential Sector

The MAC study in the residential sector in Thailand considers the adoption of the lighting, air conditioning, and refrigerating systems that are considered in the Improved Energy Efficiency (IEE) scenario.

In the lighting system in Thailand, the replacement of LFLs with LED tubes would results in the cumulative GHG emissions drop during 2015-2050 by 49.88 Mt-CO_2eq with the corresponding cumulative MAC of -314.2 \$/t-CO_2eq. The MAC study of the lighting system in Thailand suggests that the replacement of incandescent lamps with CFLs would mitigate the cumulative GHG emissions of around 10.77 Mt-CO_2eq with the corresponding MAC of -371.8 \$/t-CO_2eq. The replacement of CFLs with LED lamps in the residential sector would result in the least cumulative GHG emissions during the same period, accounting for 7.28 Mt-CO_2eq with the corresponding MAC of -324.2 \$/t-CO_2eq, compared to the other two replacement perspectives.

The domestic air conditioners with an efficiency rating of EER-11.6 are replaced by the air conditioners having different efficiency ratings. The results show that when replacing the EER-11.6 air conditioners with EER-12.9 air conditioners at a rate of 50% by 2020, the cumulative GHG emissions that could be reduced during 2015-2050 would be 18.36 Mt-CO_2eq with the cumulative MAC of -174.07 \$/t-CO_2eq. The replacement of EER-11.6 air conditioners with EER-14.5 air conditioners with a rate of 75% by 2030 would result in a cumulative emissions reduction of 27.1 Mt-CO_2eq with the corresponding MAC of -112.6 \$/t-CO_2eq during the same period. When replacing 100% of the EER-11.6 air conditioners with the EER-16.6 air conditioners by 2050, the cumulative emissions that could be reduced would be 36.14 Mt-CO_2eq with the cumulative MAC of 204.7 \$/t-CO_2eq. Figure 8.13 shows the cumulative MAC curve of the measures in the residential sector in Thailand during 2015-2050. More details of the cumulative MAC during 2015-2050 in the residential sector in Thailand can be found in Table 8.1.

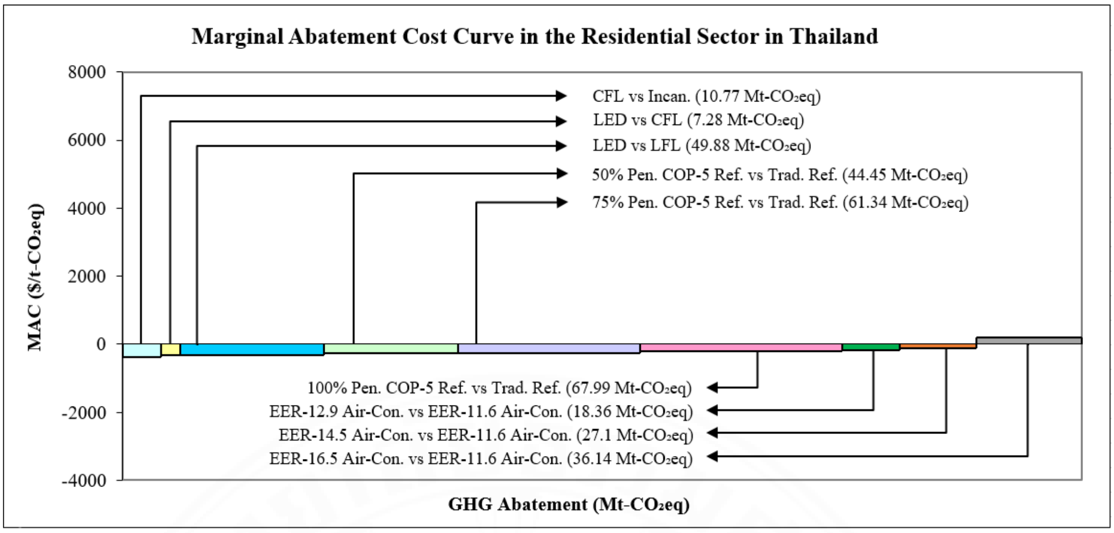

Figure 8.13 The cumulative MAC curve in the residential sector in Thailand.

Table 8.1 Details of the cumulative MAC during 2015-2050 in the residential sector in Thailand.

Measures	GHG Abatement ($Mt-CO_2eq$)	MAC ($\$/t-CO_2eq$)
CFL vs Incandescent lamp	10.77	-371.81
LED lamp vs CFL	7.28	-324.24
LED tube vs LFL	49.88	-314.16
50% Pen. COP-5 Ref. vs Trad. Ref.	44.45	-262.69
75% Pen. COP-5 Ref. vs Trad. Ref.	61.34	-249.55
100% Pen. COP-5 Ref. vs Trad. Ref.	67.99	-203.89
EER-12.9 Air-Con. vs EER-11.6 Air-Con.	18.36	-174.07
EER-14.5 Air-Con. vs EER-11.6 Air-Con.	27.1	-112.56
EER-16.5 Air-Con. vs EER-11.6 Air-Con.	36.14	204.68

Nearly all of the MAC values in Table 8.1 are negative which proves that the new and efficient technologies are desirable to be implemented. The negative cumulative MACs are caused by the large savings in electricity costs by using the new technologies over the old ones. Generally, the high investment cost of the efficient technologies would make the MAC values positive; however, when the electricity cost is included, the MAC values become negative. It is proof of the advantages of using efficient technologies.

8.8.2 Commercial Sector

In the MAC study for the commercial sector in Thailand, the results show that by phasing out the LFLs at the rate of 75% in 2035 and 100% by 2050 with LED tubes, there could be a cumulative GHG emissions cut of about 3.16 Mt-CO_2eq with the corresponding MAC of -256 \$/t-CO_2eq during 2015-2050. The penetration of LED lamps over CFLs in Thailand in the commercial sector could result in cumulative GHG emissions mitigation of about 4.35 Mt-CO_2eq with the cumulative MAC of -376.4 \$/t-CO_2eq during the same periods. Figure 8.14 indicates the cumulative MAC curve of the measures included in the commercial sector in Thailand during 2015-2050. The details of the cumulative MAC study in the commercial sector in Thailand are listed in Table 8.2.

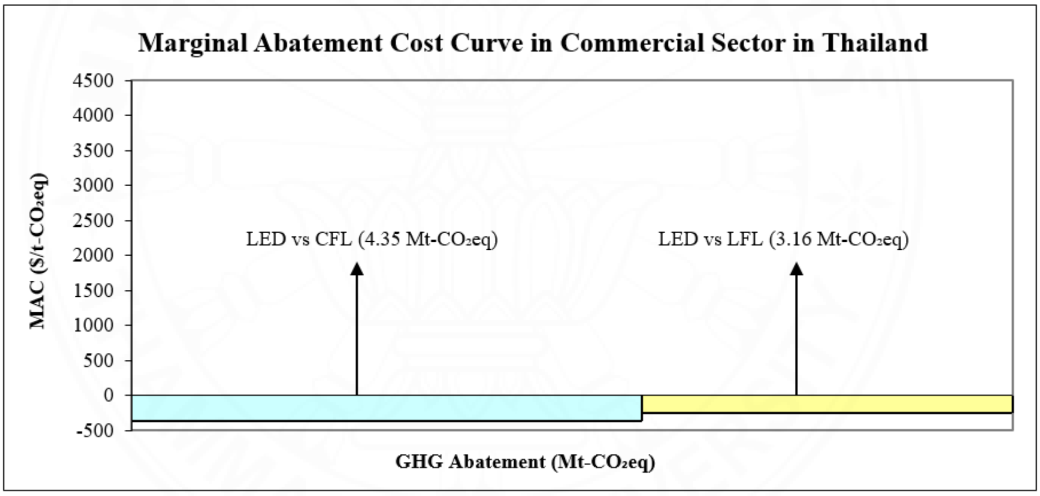

Figure 8.14 The cumulative MAC curve in the commercial sector in Thailand.

Table 8.2 The cumulative MAC during 2015-2050 in the commercial sector in Thailand.

Measures	GHG Abatement (Mt-CO_2eq)	MAC (\$/t-CO_2eq)
LED lamp vs CFL	4.35	-376.4
LED tube vs LFL	3.16	-255.97

8.8.3 Transport Sector

The findings of the MAC study in Thailand's transport sector indicate that the electric LDVs have the potential to mitigate a huge amount of cumulative GHG emissions during 2015-2050 with the corresponding MAC of negative value when slowly phased in over the gasoline LDVs. The cumulative GHG reduction resulting from the increase of electric LDVs during 2015-2050 would be 159.24 Mt-CO_2eq with the cumulative MAC of -451 \$/t-CO_2eq. The penetration of CNG trucks over diesel trucks would result in the desirable MAC of -2,089.2 \$/t-CO_2eq. Nonetheless, the corresponding cumulative GHG emissions cut that could be obtained would be only 4.43 Mt-CO_2eq during 2015-2050. The phase-in of the electric motorcycles over the gasoline motorcycle and the phase-in of the electric bus over the diesel bus show a big GHG mitigation potential during the same period. Their cumulative GHG emissions reductions and corresponding MACs would be 46.46 Mt-CO_2eq and 1,610 \$/t-CO_2eq and 56.17 Mt-CO_2eq and -272 \$/t-CO_2eq respectively. The cumulative GHG emissions mitigations and the corresponding MACs of the E10 motorcycles, B20 buses, E20 LDVs, and B20 trucks during 2015-2050 would be 5.23 Mt-CO_2eq and -1.826 \$/t-CO_2eq, 11.14 Mt-CO_2eq and -530 \$/t-CO_2eq, 42.59 Mt-CO_2eq and 1548 \$/t-CO_2eq, and 9.45 Mt-CO_2eq and -172.3 \$/t-CO_2eq respectively. Figure 8.15 and Table 8.3 represent the cumulative MAC curve of the measures during 2015-2050 and the cumulative MAC during 2015-2050 in the transport sector in Thailand respectively.

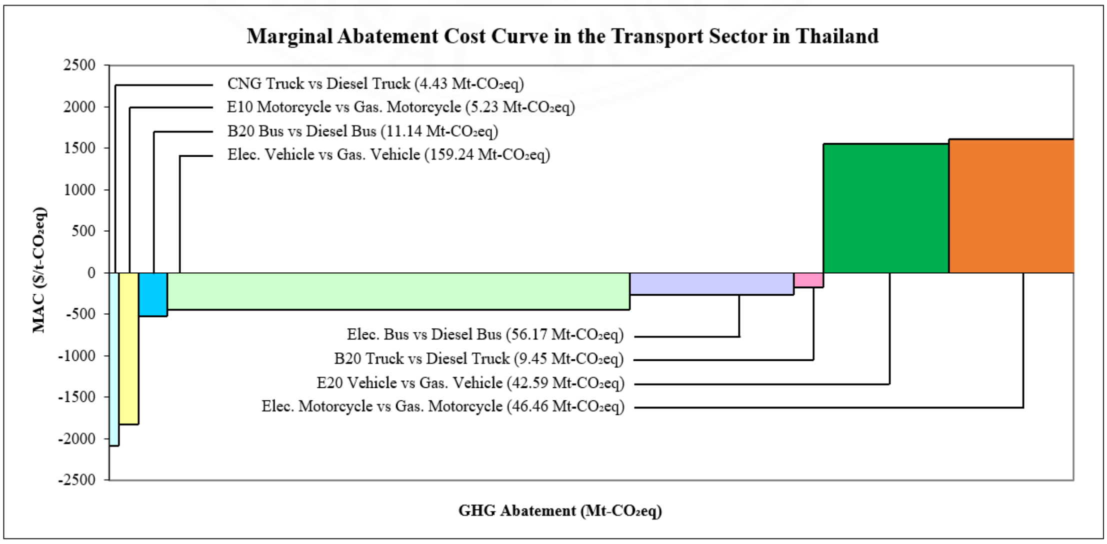

Figure 8.15 The cumulative MAC curve in the transport sector in Thailand.

Table 8.3 Details of the cumulative MAC during 2015-2050 in the transport sector in Thailand.

Measures	GHG Abatement ($Mt-CO_2eq$)	MAC ($\$/t-CO_2eq$)
CNG Truck vs Diesel Truck	4.43	-2089.23
E10 Motorcycle vs Gasoline Motorcycle	5.23	-1825.75
B20 Bus vs Diesel Bus	11.14	-529.87
Electric Vehicle vs Gasoline Vehicle	159.24	-450.86
Electric Bus vs Diesel Bus	56.17	-271.91
B20 Truck vs Diesel Truck	9.45	-172.34
E20 Vehicle vs Gasoline Vehicle	42.59	1548.02
Elec. Motorcycle vs Gasoline Motorcycle	46.46W	1609.66

8.8.4 Power Sector

In Thailand, coal and natural gas are two main sources of GHG emissions in the power sector. The results of the MAC study in Thailand show that by replacing coal and natural gas power plants of 17,400 MW in 2050, solar would be the most economical energy source with an ability to mitigate approximately 76.35 $Mt-CO_2eq$ and a MAC of -163.33 $\$/t-CO_2eq$. Wind energy could be another potential energy source to replace coal and natural gas power plants in 2050. Wind energy would be able to reduce around 76.35 $Mt-CO_2eq$ of GHG emissions in the power sector in 2050 when replacing 17,400 MW of coal and natural gas; however, its MAC is a little bit higher than that of the solar energy which accounts for -157.89 $\$/t-CO_2eq$. The least economical energy source to replace the main GHG emitters in the power sector in 2050 would be the municipal solid waste (MSW) which would have a MAC of -59.35 $\$/t-CO_2eq$. Figure 8.16 represents the marginal abatement cost curves of several energy sources replacing coal and natural gas in the power sector of Thailand in 2050. The values of the cumulative MAC study during 2015-2050 in the power sector in Thailand in detail are presented in Table 8.4 below.

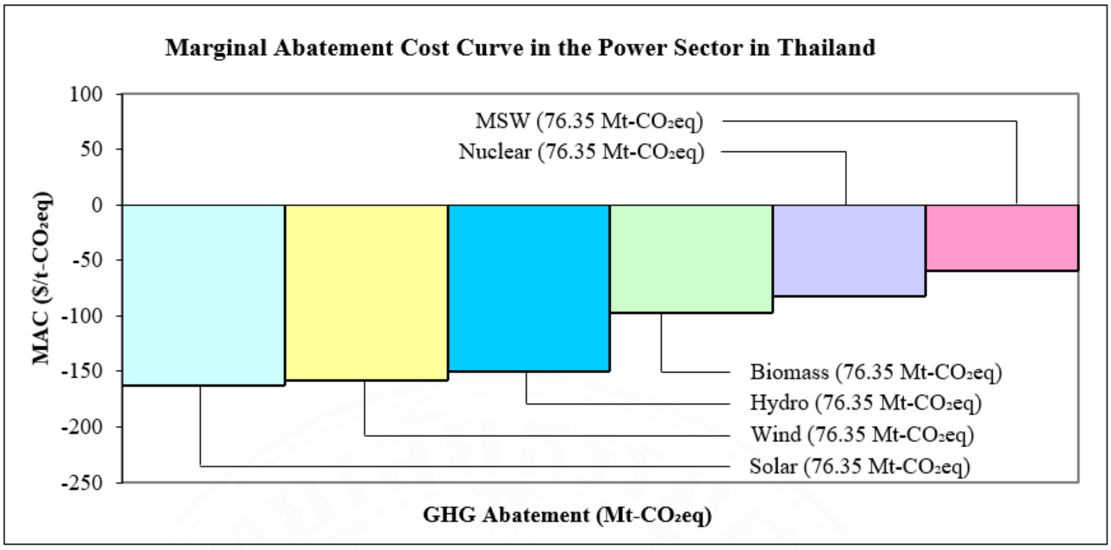

Figure 8.16 The MAC curve of coal and natural gas power plants replacement by several energy sources in the power sector in Thailand in 2050.

Table 8.4 The cumulative MAC during 2015-2050 in the power sector in Thailand.

Measures	GHG Abatement ($Mt\text{-}CO_2eq$)	MAC ($\$/t\text{-}CO_2eq$)
Solar	76.35	-163.33
Wind	76.35	-157.89
Hydro	76.35	-150.71
Biomass	76.35	-97.31
Nuclear	76.35	-82.16
MSW	76.35	-59.35

8.9 Emissions Gap

Thailand would have big emissions gaps to achieve the 2°C and 1.5°C emissions pathways by 2030 and 2050. When the full implementation of the unconditional and conditional NDCs targets are considered, the emissions gaps to achieve the 2-D2050 scenario in 2030 would be 124.5 $Mt\text{-}CO_2eq$ and 152.3 $Mt\text{-}CO_2eq$, respectively. If compared to the 1.5°C emissions pathway, the emissions gap in the unconditional and conditional NDCs targets in 2030 are 212.3 $Mt\text{-}CO_2eq$ and 240.1 $Mt\text{-}CO_2eq$, accordingly. Figure 8.17 shows the emissions gaps in all scenarios in Thailand.

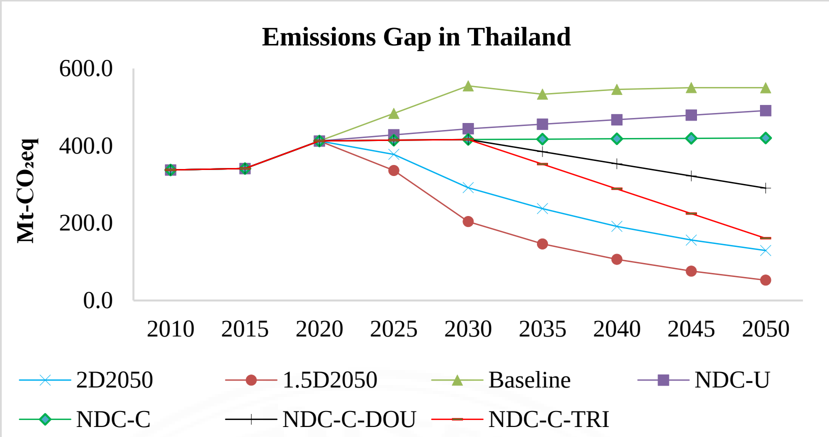

Figure 8.17 Emissions gap in Thailand.

8.10 Carbon Budgets

Thailand emitted the most emissions in the past when compared to Cambodia, Lao PDR, and Vietnam. The carbon budgets analysis in this study suggests that the GDR approach allows for cumulative carbon budgets during 2011-2050 of approximately 10.1 Gt-CO_2eq and 9.98 Gt-CO_2eq based on the 2℃ and 1.5℃ emissions pathways, respectively. Figure 8.18 and Figure 8.19 represent the cumulative carbon budgets for Thailand in effort-sharing approaches based on the 2℃ goal of the Paris Agreement and the 1.5℃ target, respectively.

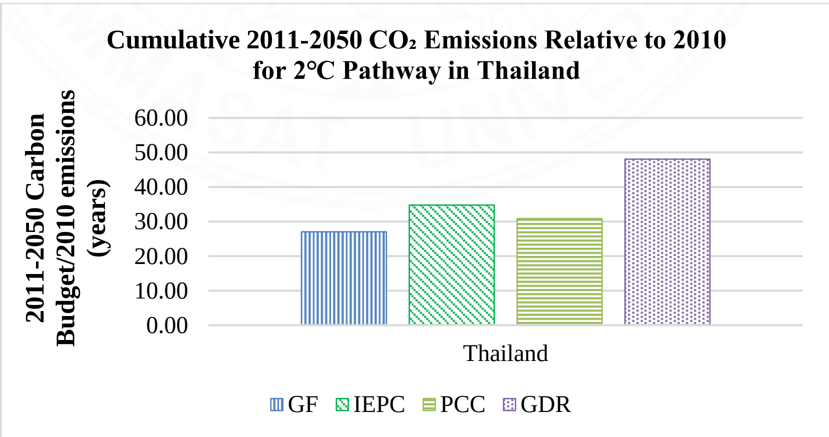

Figure 8.18 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 2℃ pathway.

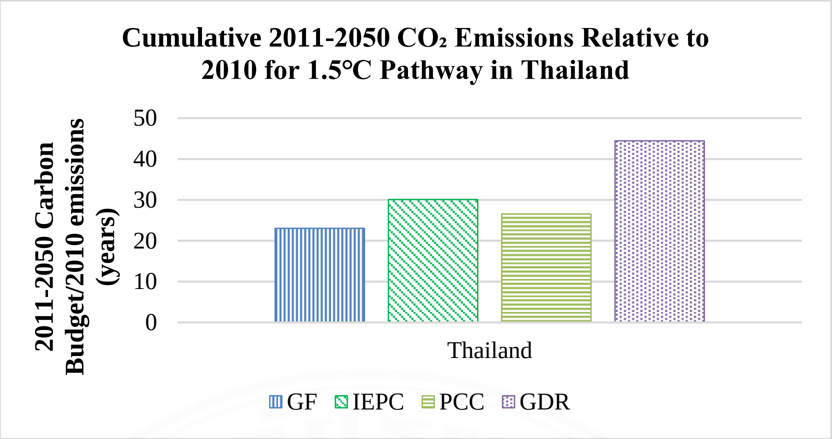

Figure 8.19 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 1.5°C pathway.

The approach that allows for the least cumulative carbon budgets during the same period is the GF approach. The budgets would be around 6.07 Gt-CO_2eq and 5.17 Gt-CO_2eq based on the 2°C and 1.5°C emissions pathways accordingly. The largest carbon budget among the four approaches for Thailand is found in the GDR approach because of the RCI values and the high future emissions in the country. On the other hand, the GF approach has the smallest budget due to the current emissions share of Thailand. For illustration purposes, Figure 8.20 shows the cumulative carbon budgets during 2011-2050 for Thailand based on both the 2°C and 1.5°C targets.

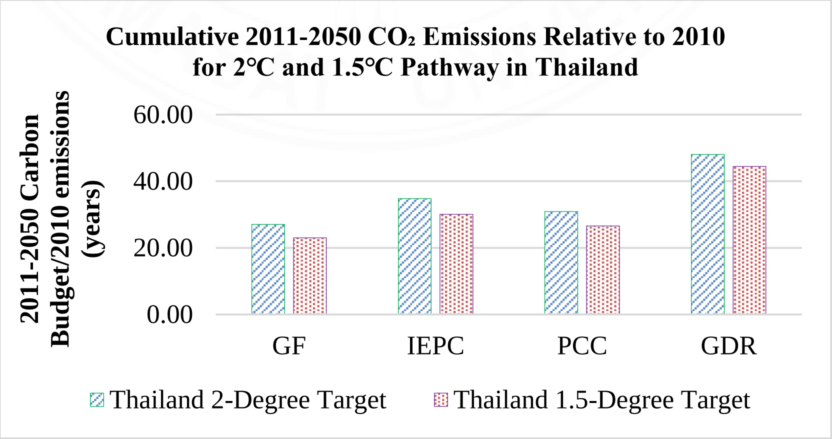

Figure 8.20 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 2°C and 1.5°C pathways.

8.11 Carbon Budgets Pathways

Figure 8.21 illustrates the 2-degree carbon budgets pathway based on the GF, IEPC, PCC, and GDR approaches in Thailand during 2010-2100. In addition to the carbon budget calculation, the 2-degree carbon budgets pathway of Thailand during 2011-2100 is also determined. The results of the emissions pathway based on the four approaches show that the CO_2 emissions in Thailand are expected to be net-zero by 2064 in the GF, IEPC, and PCC approaches and 2054 in the GDR approach. However, after reaching net-zero emissions, the CO_2 emissions in the GF, IEPC, and PCC will go up a little and stay near zero by 2100. This is due to the global trend of the CO_2 emissions in the 2-degree pathway. In contrast, in the GDR approach, the CO_2 emissions in Thailand will keep decreasing even after reaching the net-zero in 2054. The reasons for the continuous decrease of CO_2 emissions in Thailand in the GDR are that the RCI value, which is the index corresponding to the GDP per capita and the emissions mitigation capability, after the year 2030 is assumed to stay constant and the assumption of a linear convergence to PCC outcomes after 2030.

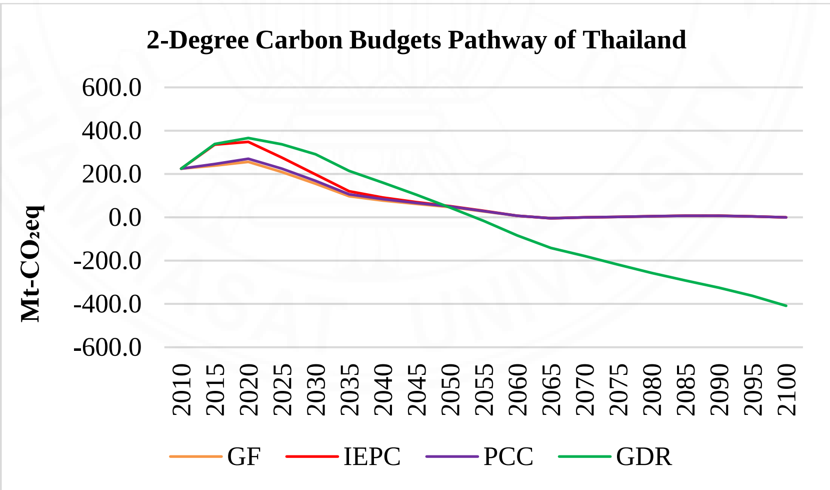

Figure 8.21 2-degree carbon budgets pathway of Thailand based on the four approaches during 2010-2100.

In addition to the 2-degree carbon budgets pathway, the 1.5-degree carbon budgets pathways based on the four approaches of Thailand are also shown for the comparison between the two trends. In the 1.5-degree carbon budgets pathways of

Thailand, the net-zero years of the national emissions (only CO_2) would be faster than that in the 2-degree carbon budgets pathway.

Just like Cambodia and Lao PDR, the 1.5-degree carbon budgets pathway of Thailand in the GF, IEPC, and PCC approaches will reach net-zero in the year 2045. This is due to the trend of global carbon emissions. On the other hand, the pathway of Thailand in the GDR approach will be net-zero by 2048 which is only three years slower than the net-zero year of the other three approaches. Compared to Cambodia and Lao PDR, the RCI values of Thailand are bigger, thus the emissions year of reaching net-zero would likely be faster than that of Cambodia and Lao PDR. In addition, the GDR approach depends on the responsibility of a country over the historical emissions and the capability of a country to mitigate the emissions in the future. Thus, in terms of fairness, the GDR approach is more preferable to the other three approaches for Thailand because of the slower rate of reaching net-zero emissions. Figure 8.22 presents the 1.5-degree carbon budgets pathway of Thailand based on the four approaches during 2010-2100.

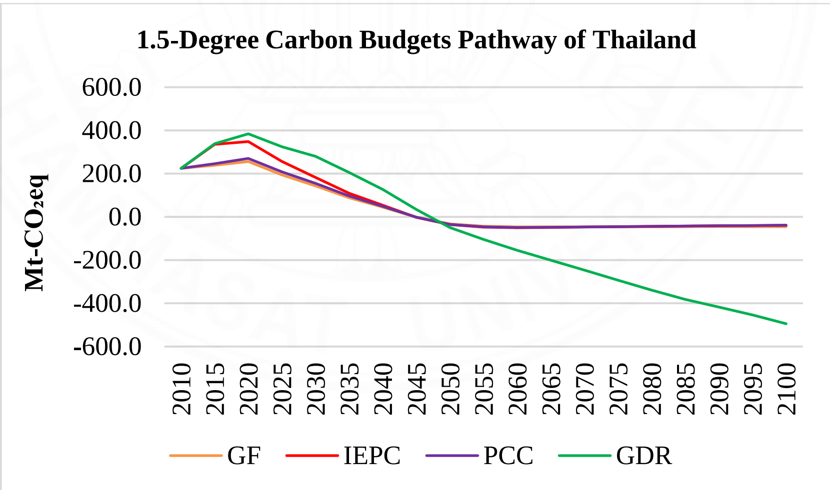

Figure 8.22 1.5-degree carbon budgets pathway of Thailand based on the four approaches during 2010-2100.

CHAPTER 9
RESULTS OF VIETNAM

9.1 Electricity Demand

9.1.1 Business-as-Usual (BAU) Scenario

The electricity consumption in Vietnam in 2015 was 141.25 TWh. The electricity demand in Vietnam in 2050 will be increased by 5.785 times from that in 2015. The industry sector generated 57.01% of electricity demand while the residential sector, commercial sector, and “other” sector took up the shares of 35.42%, 5.92%, and 1.65% respectively. In 2050, the sector consuming the majority of electricity demand would be the industry sector which accounts for 56.87%, while the residential sector, commercial sector, and “other” sector will account for 35.58%, 5.91%, and 1.64%, respectively. There will be no electricity demand in the transport sector in the BAU scenario. The electricity demand by type of sector in Vietnam is shown in Figure 9.1.

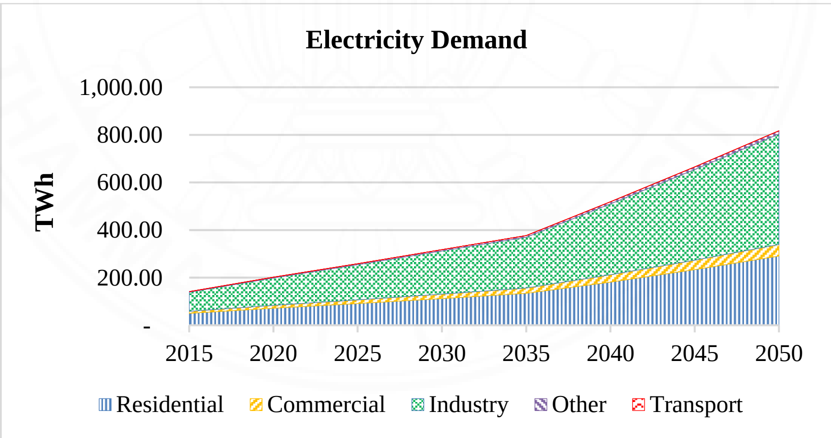

Figure 9.1 Electricity demand in Vietnam in the BAU scenario.

9.1.2 Renewable Energy Technologies (RET) Scenario

The electricity demand in Vietnam in the RET scenario is as much as that in the BAU scenario.

9.1.3 Improved Energy Efficiency (IEE) Scenario

The electricity demand in Vietnam in the IEE scenario will be decreased by 51.56 TWh from the BAU scenario in 2050. By 2050, the electricity demand in the residential sector, commercial sector, industry sector, transport sector, and "other" sector will account for 30.68%, 5.85%, 60.70%, 1.01%, and 1.75%, respectively, of the total electricity demand. The penetration of electric vehicles in the transport sector in the IEE scenario would increase the electricity demand in the transport sector in Vietnam by 7.76 TWh from the BAU scenario in 2050. Figure 9.2 presents the electricity demand by sector in Vietnam in the IEE scenario.

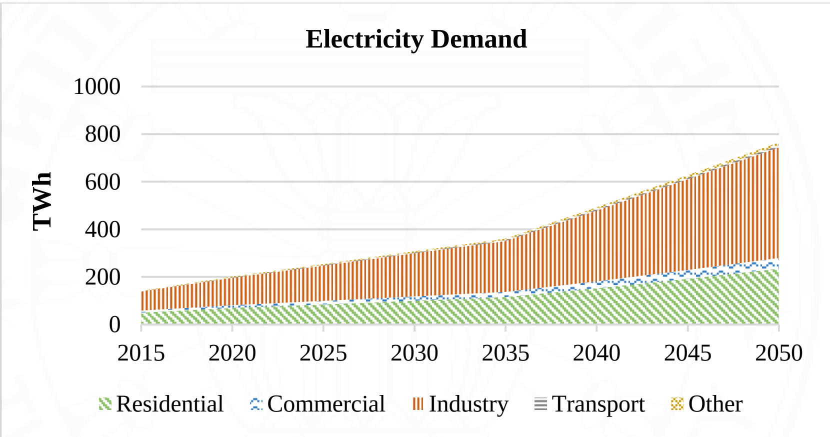

Figure 9.2 Electricity demand in Vietnam in the IEE scenario.

9.2 Electricity Generation

9.2.1 Business-as-Usual (BAU) Scenario

The electricity generation in Vietnam in 2015 was 164.18 TWh and will be increased to 860.19 TWh by 2050. The energy demand indicates an increase of 523.93% in comparison to 2015. The majority of the generated electricity in 2050 would come from bituminous coal (58.64%), hydro (15.12%), biomass (1.59%), solar (2.01%), nuclear (3.67%), wind (2.67%), natural gas (12.17%), and imported electricity will cover the rest of the shares. Figure 9.3 presents the electricity generation and its sources in Vietnam during 2015-2050 in the BAU scenario.

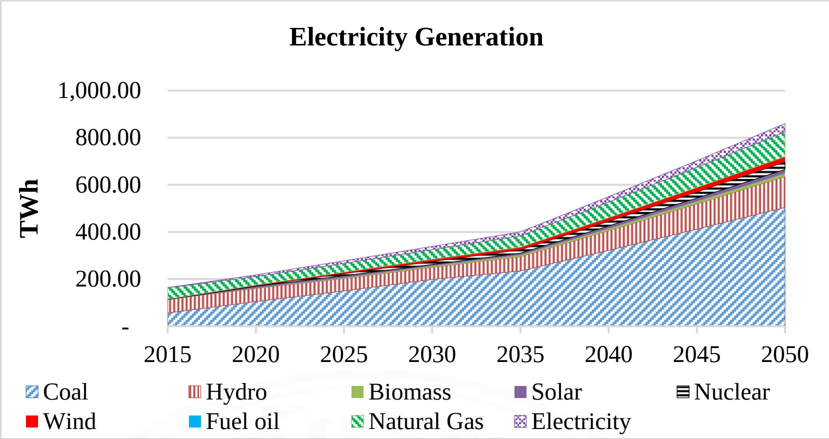

Figure 9.3 Electricity generation in Vietnam in the BAU scenario.

9.2.2 Renewable Energy Technologies (RET) Scenario

The amount of total electricity generation in Vietnam in the RET scenario is as much as that in the BAU scenario, except for the share of energy sources for the generation. With the integration of more renewable energy sources in the RET scenario, the shares of the electricity generation from biomass, bituminous coal, imported electricity , fuel oil, hydro, natural gas, nuclear, solar, and wind in 2050 are 5.6%, 32.66%, 1.2%, 0%, 21.47%, 10.04%, 3.55%, 17.76%, and 7.72%, respectively while the shares in 2015 were 0.04%, 34.39%, 0.55%, 0.79%, 34.82%, 29.33%, 0%, 0%, and 0.08%, respectively, as shown in Figure 9.4.

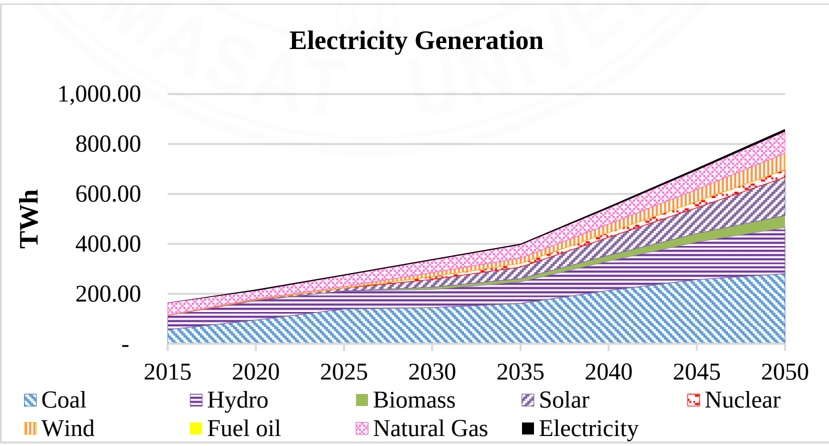

Figure 9.4 Electricity generation in Vietnam in the RET scenario.

9.2.3 Improved Energy Efficiency (IEE) Scenario

In the IEE scenario, the total electricity generation will be increased from 164.18 TWh in 2015 to 805.92 TWh in 2050, indicating a reduction of 54.27 TWh when compared to the BAU scenario because of the decreasing electricity demand from efficiency improvement. The shares of the electricity generation from bituminous coal, hydro, biomass, solar, nuclear, wind, fuel oil, natural gas, and imported electricity in 2050 are 58.64%%, 15.12%, 1.59%, 2.01%, 3.67%, 2.67%, 0%, 12.17%, and 4.13%, respectively. Figure 9.5 illustrates the electricity generation by type of fuel in Vietnam from 2015 to 2050 in the IEE scenario.

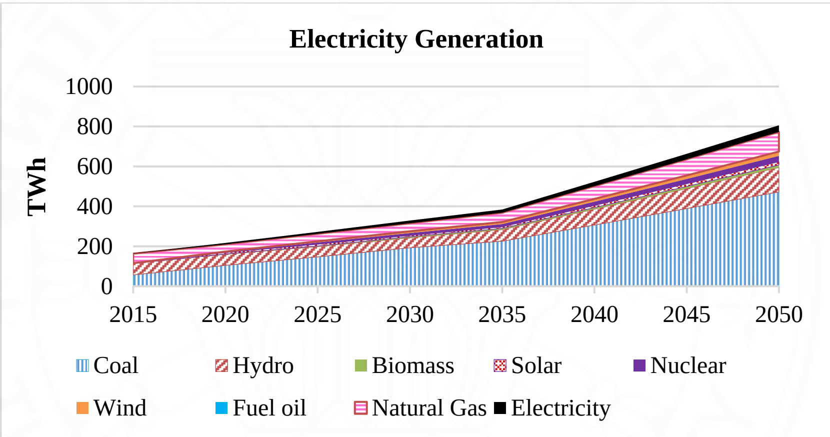

Figure 9.5 Electricity generation in Vietnam in the IEE scenario.

9.3 Emissions in the Power Sector

The CO_2 emissions in the power sector in Vietnam by 2050 will be increased by 6.77 times from 2015, which accounts for 490.52 Mt-CO_2eq. The RET scenario would cut down the emissions to 157.54 Mt-CO_2eq in 2050 as a result of the usage of renewable energy sources and efficient technologies. A 30.95 Mt-CO_2eq of CO_2 emissions reduction from the BAU scenario will be made in the IEE scenario by 2050. The CCS technology will be able to reduce the CO_2 emissions in the power sector by 128.48 Mt-CO_2eq in 2050. Figure 9.6 shows the CO_2 emissions in the power sector in Vietnam during the study period.

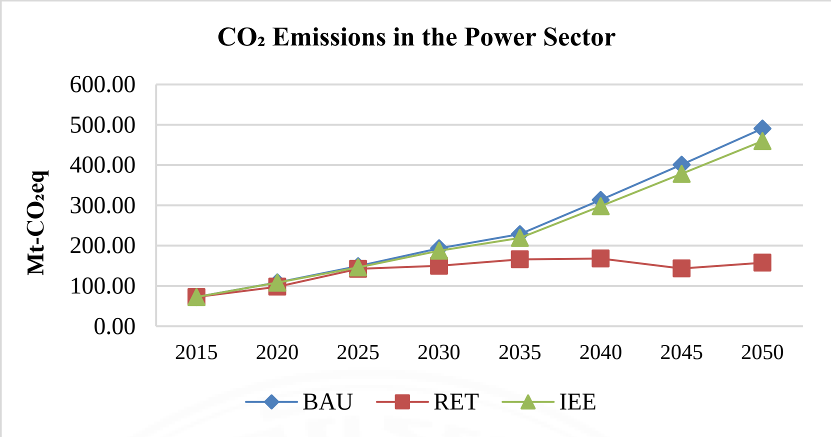

Figure 9.6 Carbon dioxide emissions in the power sector in Vietnam.

In addition, the emissions of other pollutants such as SO_2, NO_x, and CO in the power sector in Vietnam in 2050 in each scenario are also shown in Figure 9.7.

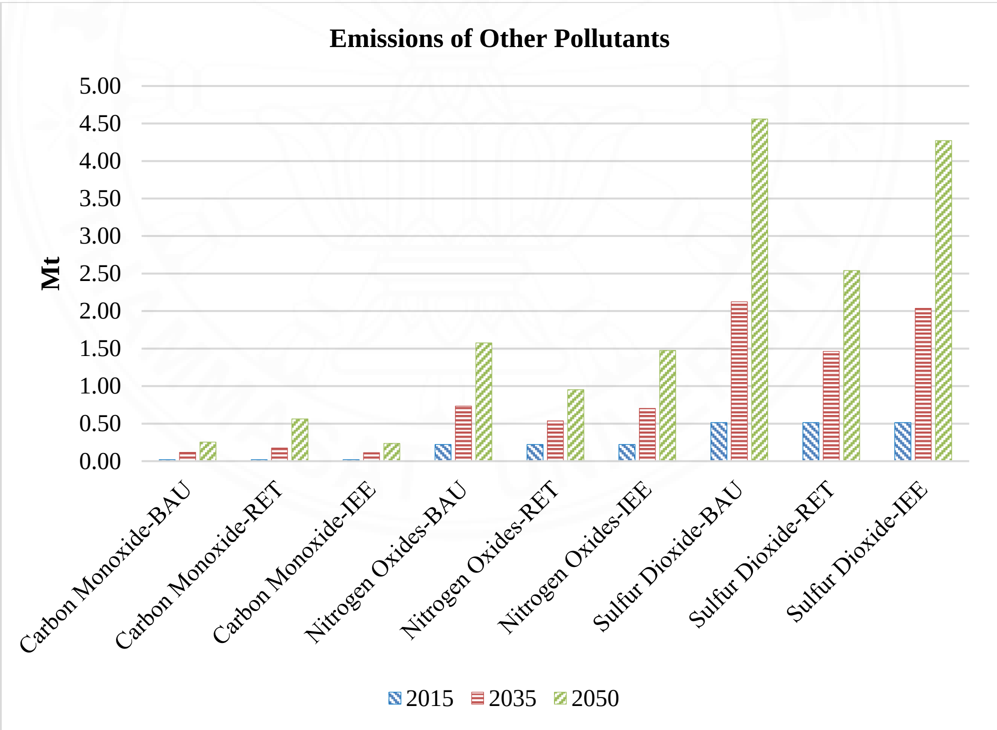

Figure 9.7 Emissions of other pollutants in the power sector in Vietnam.

9.4 Energy Demand in the Transport Sectors

The energy demand in the transport sector in Vietnam in 2015 was 5.46 Mtoe. It is expected to increase to 26.73 Mtoe, 26.73 Mtoe, and 7.01 Mtoe in the BAU scenario, RET scenario, and IEE scenario, respectively, by 2050. Of all the energy demand in the transport sector, waterway transport consumes 2.28 Mtoe in 2015 while road transport, aviation transport, and rail transport consume 2.03 Mtoe, 1.08 Mtoe, and 0.07 Mtoe respectively. The energy demand of waterway transport and aviation transport is covered by freight transport only. The energy demand for waterway transport and aviation transport in 2050 would be 12.33 Mtoe and 5.87 Mtoe respectively in the BAU. In the RET scenario and IEE scenario, the number would be 12.33 Mtoe and 5.87 Mtoe and 0.81 Mtoe and 0.97 Mtoe. The energy demand for road transport in 2050 would increase to 8.2 Mtoe, 8.2 Mtoe, and 4.76 Mtoe in the BAU scenario, RET scenario, and IEE scenario respectively. Road passenger transport will consume a share of the energy of 72.18% of the total energy demand for road transport in 2050 in the BAU scenario while the shares would be 71.4% and 35.38% in the RET scenario and IEE scenario. Figure 9.8 shows the energy demand in the transport sector in Vietnam during 2015-2050 in every scenario.

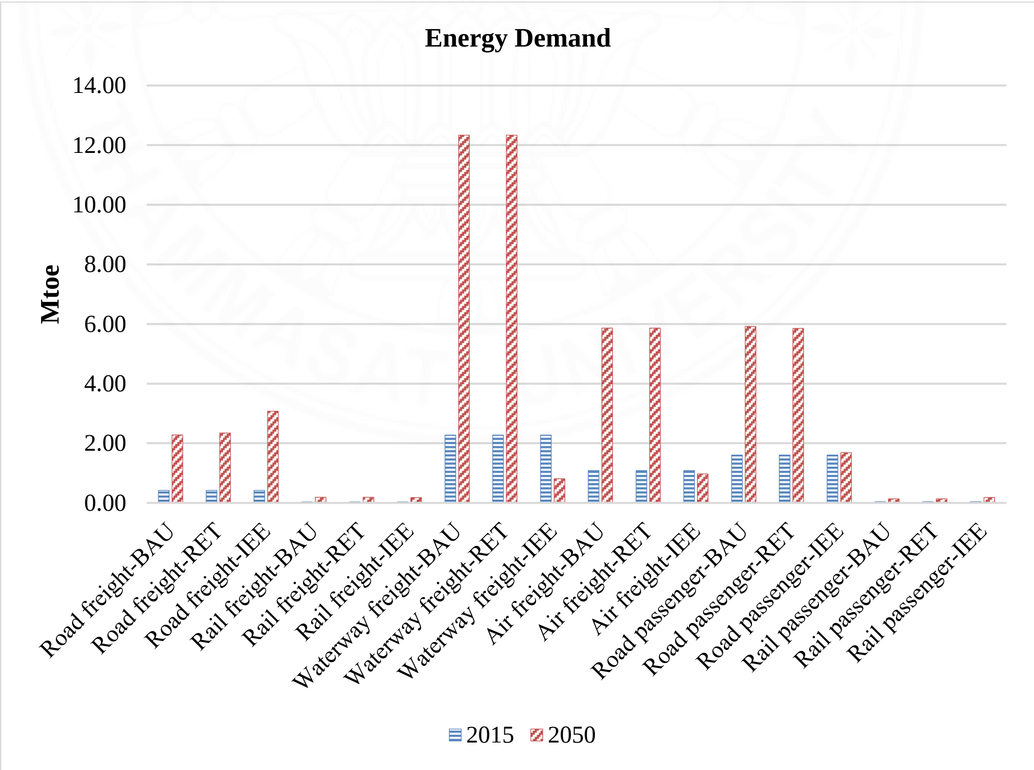

Figure 9.8 Energy demand in the transport sector in Vietnam.

Among the amount of energy used for road passenger transport in 2015, light-duty vehicles consumed only 2.06% when motorcycle and three-wheelers, and buses had shares of 20.33% and 77.61%, respectively, and the numbers are expected to be the same in 2050 in the BAU scenario. In the RET scenario in 2050, the shares are expected to be 2.04%, 20.55%, 77.41%, respectively. For the IEE scenario, the shares in 2050 would be 14.13%, 16.66%, and 45.89% respectively.

9.5 Emissions in the Transport Sector

The transport sector in Vietnam in 2015 released 16.5 Mt-CO_2eq of GHG and the number is expected to increase to 80.99 Mt-CO_2eq, 80.93 Mt-CO_2eq, and 18.9 Mt-CO_2eq by 2050 in the BAU scenario, RET scenario, and IEE scenario respectively. By 2050, the emissions from freight transport will account for 78.03% of the total GHG emissions in the transport sector in the BAU scenario while those from the RET scenario and IEE scenario would account for 78.34% and 79.75%, respectively. Figure 9.9 shows the emissions in the transport sector in Vietnam from 2015-2050 in every scenario.

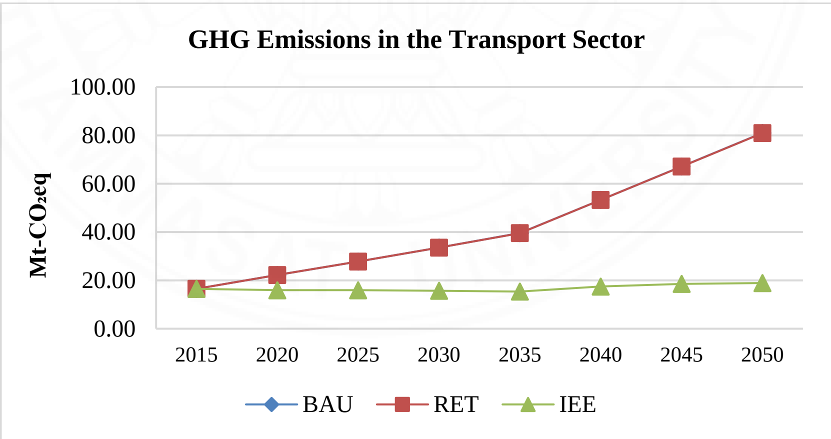

Figure 9.9 GHG emissions in the transport sector in Vietnam.

9.6 Cost of Electricity Generation

In Vietnam in 2015, the cost of electricity production was 3.51 billion USD and it is expected to be 28 billion USD, 26.57 billion USD, and 26.65 billion USD in the BAU scenario, RET scenario, and IEE scenario, respectively, in 2050 as shown in

Figure 9.10. Moreover, the cost of externality in Vietnam in 2015 was 0.65 billion USD and would be increased to 4.41 billion USD, 1.42 billion USD, and 4.14 billion USD in the BAU scenario, RET scenario, and IEE scenario, respectively, by 2050 as illustrated in Figure 9.11.

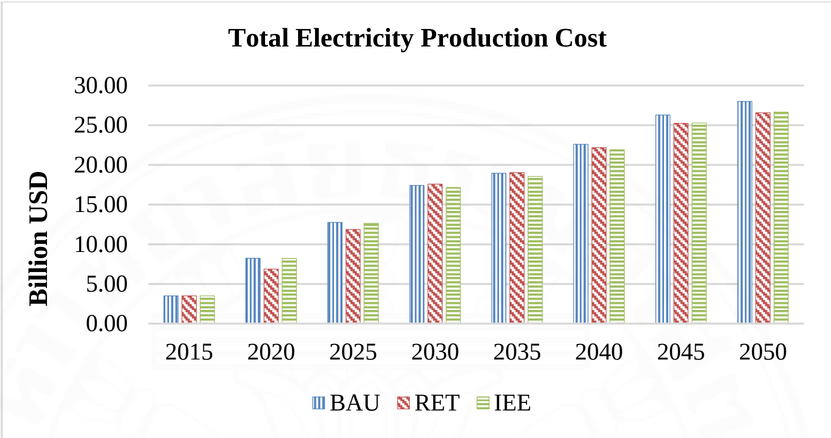

Figure 9.10 Total cost of electricity production in Vietnam.

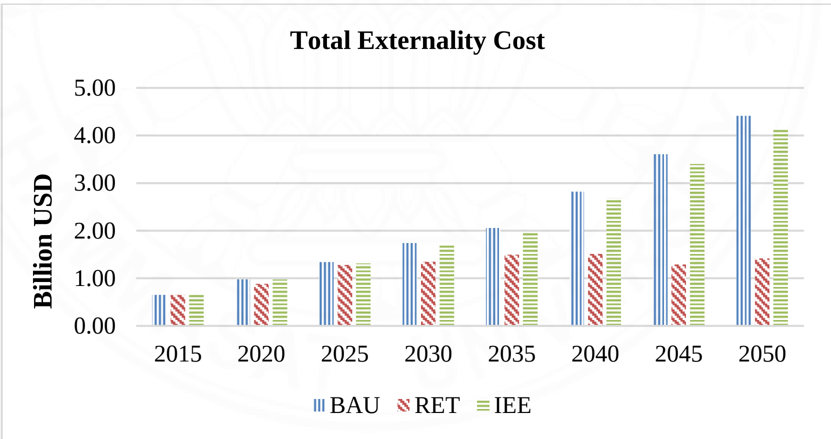

Figure 9.11 Total cost of externality in the power sector in Vietnam.

The total cost of electricity generation by 2050 in the BAU scenario, RET scenario, and IEE scenario would be 32.42 billion USD, 27.99 billion USD, and 30.79 billion USD, respectively, as shown in Figure 9.12.

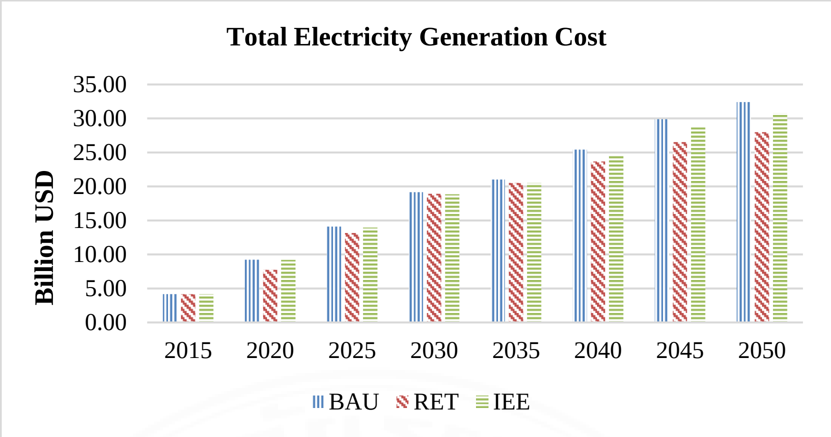

Figure 9.12 Total cost of electricity generation in Vietnam.

9.7 Marginal Abatement Cost

9.7.1 Residential Sector

The MAC study in the residential sector considers the lighting, air conditioning, and refrigerating systems. In the lighting system in Vietnam, the penetration of LED tubes to replace the LFL would mitigate the most cumulative GHG emissions when compared to the other options within the lighting system considered in the MAC study. The outcomes suggest that by replacing 75% and 100% of the incandescent lamps in 2035 and 2050, respectively, by CFLs, the cumulative GHG emissions that can be reduced as a result of the reduction in energy consumption during 2015-2050 would account for approximately 100.39 Mt-CO_2eq with the corresponding MAC of -166 \$/t-CO_2eq. The penetrations of LED tubes over the LFLs result in the cumulative GHG emissions drop by 141.67 Mt-CO_2eq along with the cumulative MAC of -139.3 \$/t-CO_2eq during the same period. The cumulative emissions mitigation and MAC of the LED lamps phase-in over the CFLs would be 58.12 Mt-CO_2eq and -88.3 \$/t-CO_2eq, respectively.

In air conditioning systems, the domestic air conditioners with an efficiency rating of EER-11 are replaced with the air conditioners having different efficiency ratings. The results show that when replacing the EER-11 air conditioners with EER-12.2 air conditioners at a penetration rate of 50% by 2020, the cumulative GHG emissions that could be reduced during 2015-2050 would be 48.92 Mt-CO_2eq with the cumulative MAC of -82 \$/t-CO_2eq. The replacement of EER-11 air conditioners with

EER-13.8 air conditioners would result in the cumulative emissions reduction of 73.07 Mt-CO_2eq with the corresponding MAC of -92 \$/t-CO_2eq by 2050. When considering replacing 100% of the EER-11 air conditioners with the EER-15.7 air conditioners by 2050, the cumulative emissions would be reduced by 95.31 Mt-CO_2eq with the corresponding cumulative MAC of -88 \$/t-CO_2eq during the same period. Figure 9.13 and Table 9.1 present the cumulative MAC curve of the measures and the details of the cumulative MAC during 2015-2050 in the residential sector in Vietnam, respectively.

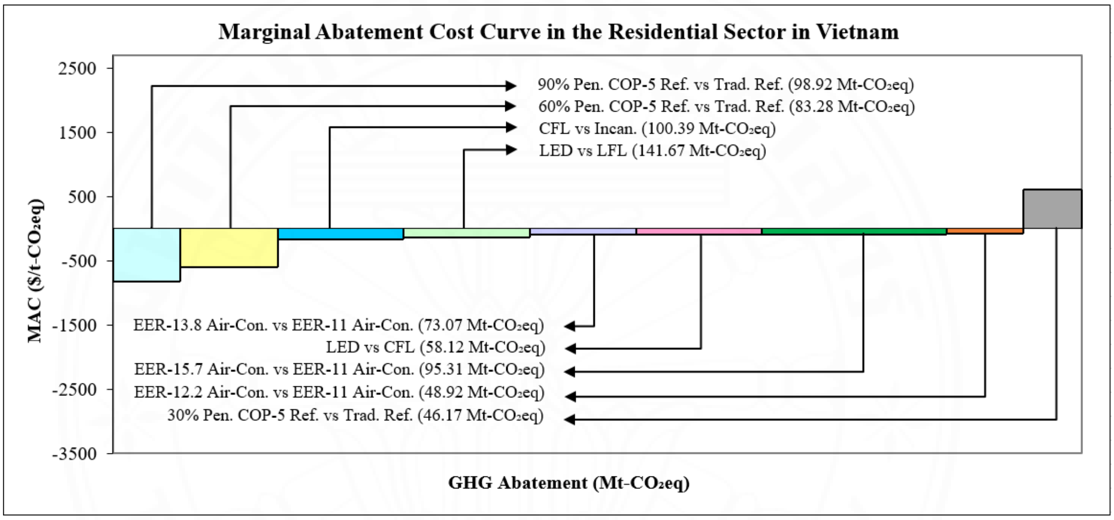

Figure 9.13 The cumulative MAC curve in the residential sector in Vietnam.

Table 9.1 The MACs during 2015-2050 in the residential sector in Vietnam.

Measures	GHG Abatement (Mt-CO_2eq)	MAC (\$/t-CO_2eq)
90% Pen. COP-5 Ref. vs Trad. Ref.	98.92	-819.93
60% Pen. COP-5 Ref. vs Trad. Ref.	83.28	-600.47
CFL vs Incandescent lamp	100.39	-165.97
LED tube vs LFL	141.67	-139.25
EER-13.8 Air-Con. vs EER-11 Air-Con.	73.07	-91.85
LED lamp vs CFL	58.12	-88.3
EER-15.7 Air-Con. vs EER-11 Air-Con.	95.31	-88.11
EER-12.2 Air-Con. vs EER-11 Air-Con.	48.92	-81.7
30% Pen. COP-5 Ref. vs Trad. Ref.	46.17	612.72

The cumulative MACs and GHG emissions reductions during 2015-2050 as the results of penetrating 30% of COP-5 refrigerators, 60% of COP-5 refrigerators, and

90% of COP-5 refrigerators over the traditional refrigerators would be 46.17 Mt-CO_2eq and 612.7 \$/t-CO_2eq, 83.28 Mt-CO_2eq and -600 \$/t-CO_2eq, and 98.92 Mt-CO_2eq and -820 \$/t-CO_2eq, respectively. According to the results of the MAC analysis, all of the measures in the residential sector except for the 30% penetration of COP-5 refrigerator show negative cumulative MAC values. It indicates that the measures are desirable to implement. The cause of the negative MAC values is the large reduction of electricity cost when using efficient technologies over the traditional ones. Therefore, the potential to reduce GHG emissions in the residential sector by using new and efficient technologies is considerably strong.

9.7.2 Commercial Sector

In Vietnam, the MAC study for the commercial sector includes only the lighting systems. The results of the analysis indicate that by penetrating 75% and 100% of LED lamps over the LFLs in 2035 and 2050, respectively, the cumulative GHG emissions could be reduced by around 18 Mt-CO_2eq with the corresponding MAC of -144.8 \$/t-CO_2eq. The difference between the GHG emissions reduction that can be achieved from replacing the LFLs with LED lamps and replacing CFLs with LED lamps would be 17.24 Mt-CO_2eq. The cumulative MAC to replace the CFLs with LED lamps would be -165 \$/t-CO_2eq. Figure 9.14 presents the cumulative MAC curve of the measures in the commercial sector in Vietnam during 2015-2050. The values of the MAC during 2015-2050 in the commercial sector in Vietnam are shown in Table 9.2.

Table 9.2 The MACs during 2015-2050 in the commercial sector in Vietnam.

Measures	GHG Abatement (Mt-CO_2eq)	MAC (\$/t-CO_2eq)
LED lamp vs CFL	0.76	-164.58
LED tube vs LFL	18	-144.8

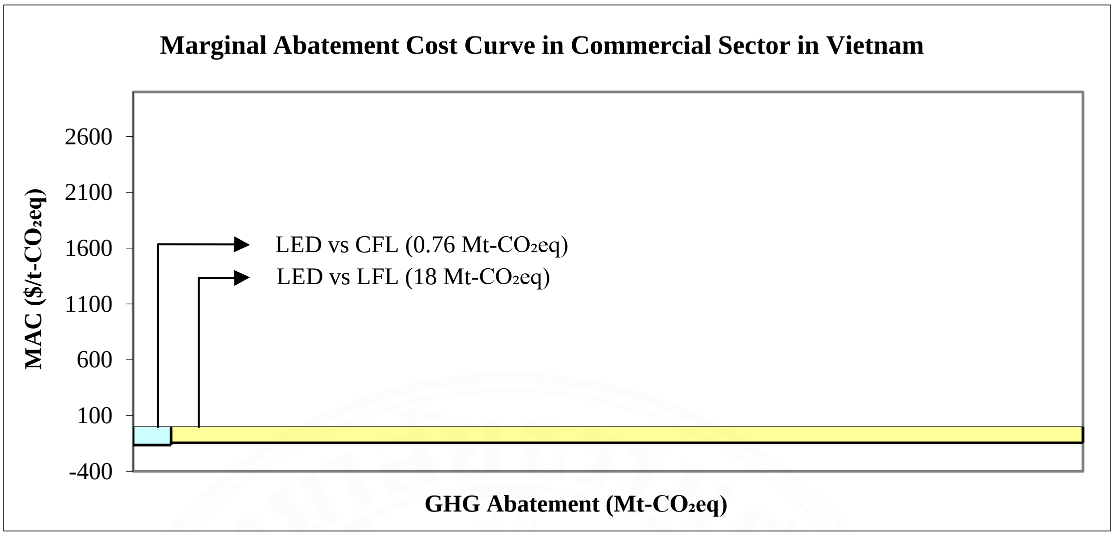

Figure 9.14 The cumulative MAC curve in the commercial sector in Vietnam.

9.7.3 Transport Sector

The phase-in of electric motorcycles over gasoline motorcycles would have the biggest potential to reduce the cumulative GHG emissions during 2015-2050 over the other options considered in the MAC study in the transport sector in Vietnam. Nevertheless, its cumulative MAC value is the second highest compared to the options. The cumulative GHG emissions reduction and the corresponding MAC of the electric motorcycles penetration would be 42.31 Mt-CO_2eq and 4,976 \$/t-CO_2eq, respectively. In Vietnam, the replacement of diesel trucks with CNG trucks would prove desirable in terms of finance with the cumulative MAC of -2,139 \$/t-CO_2eq. However, its corresponding cumulative GHG emissions cut during the same period would be only 0.17 Mt-CO_2eq. The cumulative GHG emissions savings and corresponding MACs of the electric LDVs, B20 buses, E10 motorcycles, B20 trucks, electric buses, and E20 vehicles during 2015-2050 would be 0.37 Mt-CO_2eq and -1,634 \$/t-CO_2eq, 0.96 Mt-CO_2eq and -566 \$/t-CO_2eq, 3.51 Mt-CO_2eq and -458 \$/t-CO_2eq, 0.25 Mt-CO_2eq and -209 \$/t-CO_2eq, 7.36 Mt-CO_2eq and -108 \$/t-CO_2eq, and 0.14 Mt-CO_2eq and 17,267 \$t-CO_2eq, respectively. Figure 9.15 illustrates the cumulative MAC curve of the measures in the transport sector in Vietnam during 2015-2050. Table 9.3 lists the values of the cumulative MAC of the measures in the transport sector during 2015-2050 in Vietnam.

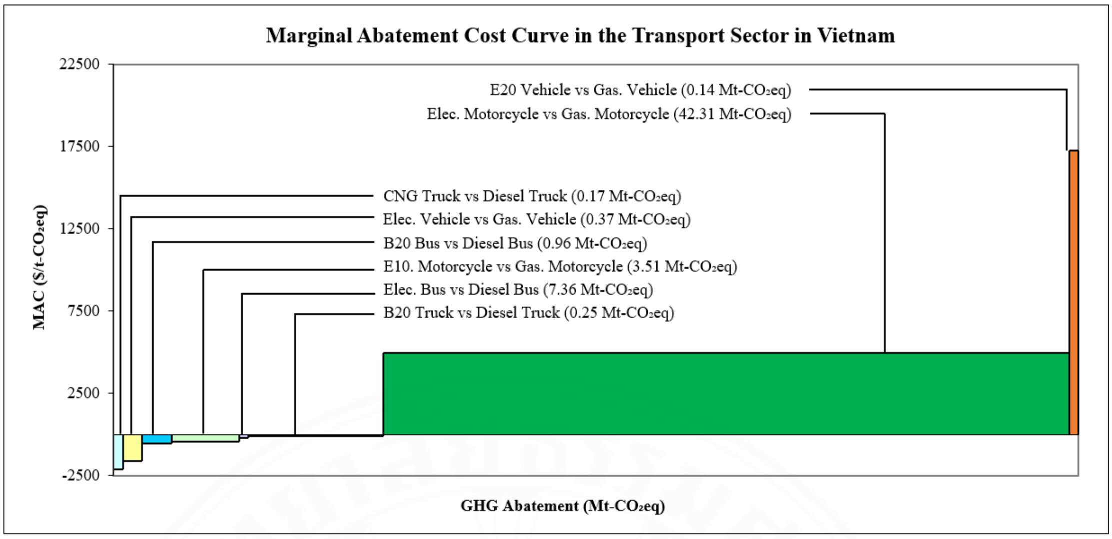

Figure 9.15 The cumulative MAC curve in the transport sector in Vietnam.

Table 9.3 The MACs in the transport sector during 2015-2050 in Vietnam.

Measures	GHG Abatement ($Mt-CO_2eq$)	MAC ($\$/t-CO_2eq$)
CNG Truck vs Diesel Truck	0.17	-2138.8
Electric Vehicle vs Gasoline Vehicle	0.37	-1634.1
B20 Bus vs Diesel Bus	0.96	-565.7
E10 Motorcycle vs Gasoline Motorcycle	3.51	-457.76
B20 Truck vs Diesel Truck	0.25	-209.21
Electric Bus vs Diesel Bus	7.36	-107.95
Elec. Motorcycle vs Gasoline Motorcycle	42.31	4975.7
E20 Vehicle vs Gasoline Vehicle	0.14	17267

9.7.4 Power Sector

The MAC study for Vietnam in the year 2050 considers replacing a capacity of 33,700 MW of coal and natural gas power plants with different types of energy sources in the year 2050. The results show that solar would be the most preferred energy source to phase out coal and natural gas for Vietnam. The solar technology would be able to mitigate approximately 207.07 $Mt-CO_2eq$ and would have a MAC of -41.28 $\$/t-CO_2eq$ in 2050. Compared to solar technology in the MAC study, nuclear would have a MAC of 18.94 $\$/t-CO_2eq$ making it the least economical energy source to phase out coal and natural gas in the electricity generation in the year 2050 as can be seen in Figure 9.16.

Table 9.3 lists the values of the MAC of the measures in the power sector in 2050 in Vietnam.

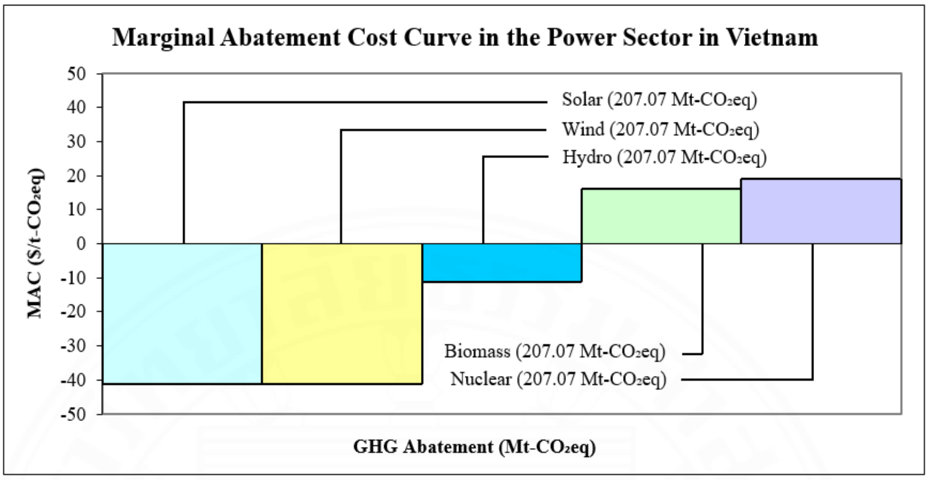

Figure 9.16 Marginal abatement cost curves of coal and natural gas power plants replaced by different energy sources in Vietnam in 2050.

Table 9.4 The MACs in the power sector in Vietnam in 2050.

Measures	GHG Abatement ($Mt\text{-}CO_2eq$)	MAC ($\$/t\text{-}CO_2eq$)
Solar	207.07	-41.28
Wind	207.07	-41.24
Hydro	207.07	-11.11
Biomass	207.07	16.11
Nuclear	207.07	18.94

9.8 Emissions Gap

The total GHG emissions (excluding LULUCF) in Vietnam would reach 977 $Mt\text{-}CO_2eq$ in 2030 and 810.5 $Mt\text{-}CO_2eq$ in 2050 in the baseline scenario. Vietnam's emissions gaps in the year 2030 between the full achievements of the NDC-U and NDC-C scenarios to the 2-D2050 would be 486.7 $Mt\text{-}CO_2eq$ and 320.6 $Mt\text{-}CO_2eq$, respectively. When compared to the 1.5-D2050 scenario, the emissions gaps would be 610.7 $Mt\text{-}CO_2eq$ and 444.6 $Mt\text{-}CO_2eq$. Figure 9.17 shows the emissions gaps in all scenarios in Vietnam.

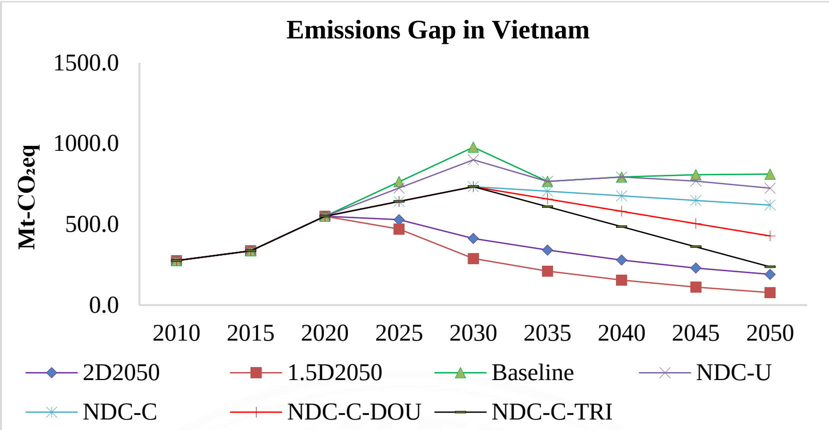

Figure 9.17 Emissions gap in Vietnam.

9.9 Carbon Budgets

Vietnam will be allowed a cumulative carbon budget during 2011-2050 of about 10.52 Gt-CO_2eq in the IEPC approach based on the 2°C emissions pathway. However, in the GF approach, Vietnam's cumulative carbon budget during the same period would be only 3.43 Gt-CO_2eq based on the 2°C emissions pathway. The cumulative carbon budgets during 2011-2050 for Vietnam based on the 1.5°C emissions pathway in the IEPC and GF approaches would be around 9 Gt-CO_2eq and 2.92 Gt-CO_2eq, respectively. Figure 9.18 and Figure 9.19 show the cumulative carbon budgets for Vietnam in different approaches based on the 2°C goal of the Paris Agreement and 1.5°C target, respectively. For illustration purposes, Figure 9.20 shows the cumulative carbon budgets during 2011-2050 for Vietnam based on both the 2°C and 1.5°C targets.

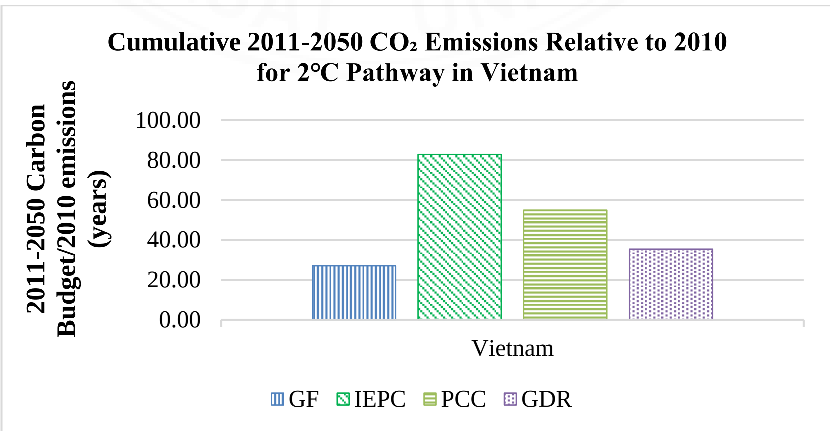

Figure 9.18 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 2°C pathway.

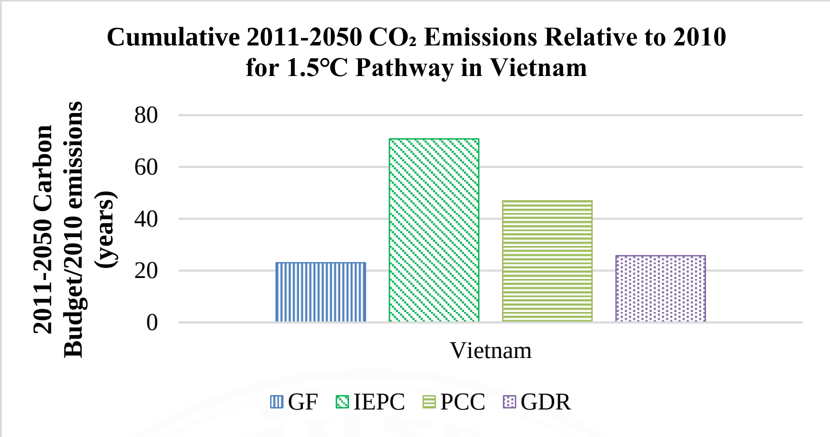

Figure 9.19 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 1.5°C pathway.

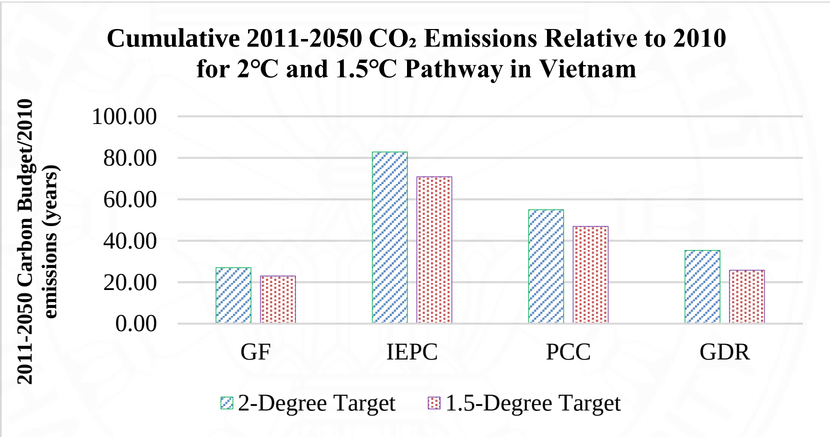

Figure 9.20 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 2°C and 1.5°C pathways.

9.10 Carbon Budgets Pathways

Figure 9.21 illustrates the 2-degree carbon budgets pathway based on the GF, IEPC, PCC, and GDR approaches in Vietnam during 2010-2100. After the carbon budgets estimation, the possibility of estimating the 2-degree carbon budgets pathway of Vietnam during 2011-2100 can also be illustrated. According to the results of the emissions pathway based on the GF, IEPC, PCC, and GDR approach, the CO_2 emissions in Vietnam are expected to be net-zero by 2064 in the GF, IEPC, and PCC approaches and 2051 in the GDR approach. However, after reaching net-zero emissions, the CO_2 emissions in the four approaches will go up a little and stay near zero by 2100. This is due to the global trend of the CO_2 emissions in the 2-degree pathway. In contrast, in the GDR approach, the CO_2 emissions in Vietnam will keep decreasing even after reaching the net-zero in 2051 already. The reasons for the continuous decrease of CO_2 emissions in Vietnam in the GDR are that the RCI values after the year 2030 are assumed to stay constant and the assumption of a linear convergence to PCC outcomes after 2030.

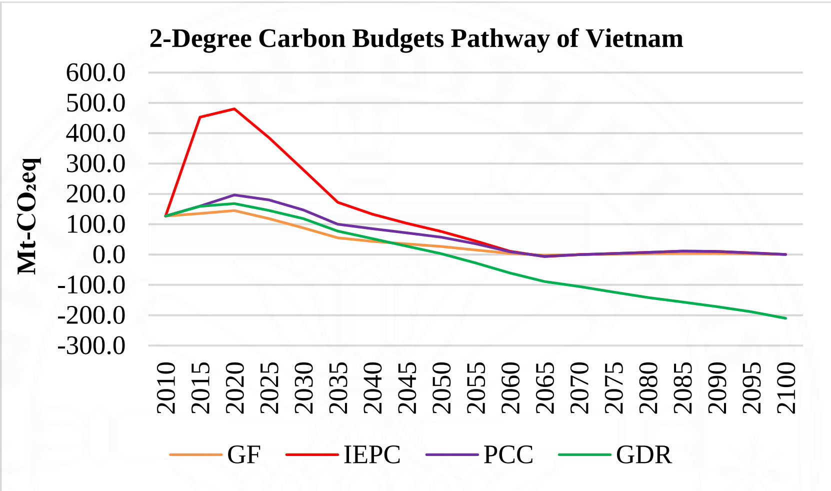

Figure 9.21 2-degree carbon budgets pathway of Vietnam based on the four approaches during 2010-2100.

The 1.5-degree carbon budgets pathways based on the four approaches of Vietnam also show a faster trend of reaching net-zero than that in the 2-degree carbon budgets pathway. Figure 9.22 shows the trend of the 1.5-degree carbon budgets pathway of Vietnam during 2010-2100 based on the GF, IEPC, PCC, and GDR approaches. Due to the trend in the global emissions, the net-zero emissions year of Vietnam based on the 1.5-degree target would be in the year 2045 in the GF, IEPC, and PCC approaches. However, the pathway of Vietnam in the GDR approach will reach net-zero in 2044 which is even faster than that in the other three approaches. Compared to Thailand, the RCI values of Vietnam are not significantly smaller. Plus, the historical emissions of Vietnam are nearly two times smaller than Thailand which would cause the emissions of Vietnam in the GDR approach to reach net-zero even faster than Thailand. In terms of emissions budgets and economic development in the country, the

IEPC approach is more preferable to the other three approaches for Vietnam because of the large carbon budgets.

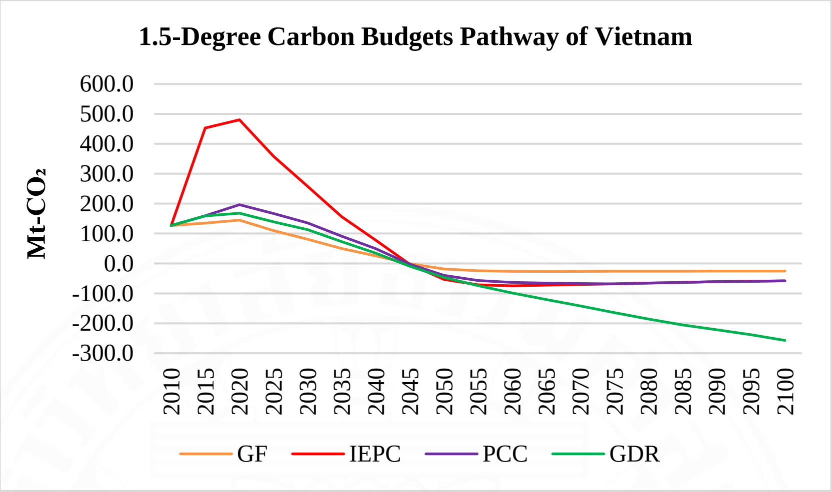

Figure 9.22 1.5-degree carbon budgets pathway of Vietnam based on the four approaches during 2010-2100.

CHAPTER 10
COMPARATIVE ANALYSIS

10.1 Electricity Demand

The total electricity demand in the selected GMS countries in 2015 was 325.67 TWh of which the industry sectors accounted for more than 50%. In the BAU scenario, the electricity demand in the selected GMS countries is expected to be increased to 1,624.12 TWh by 2050. The industry sector would still generate more than half of the total demand; however, the share of electricity demand in the residential sector would increase by 1% from 2015. The electricity demand in the transport sector would be 0.04% of the total demand and the share solely belongs to Thailand. The electricity demand in the RET scenario would be the same as in the BAU scenario in both 2015 and 2050. In 2050, the share of electricity demand in the industry in the IEE scenario would stay the same as in the BAU scenario. Nonetheless, the shares of the residential sector and commercial sectors would decrease from that in the BAU scenario by 5.89% and 2.15%, respectively. The share of electricity demand in the transport sector in the IEE scenario would increase to 3.83% by 2050. Figure 10.1 represents the electricity demand in the selected GMS countries in 2015 and 2050.

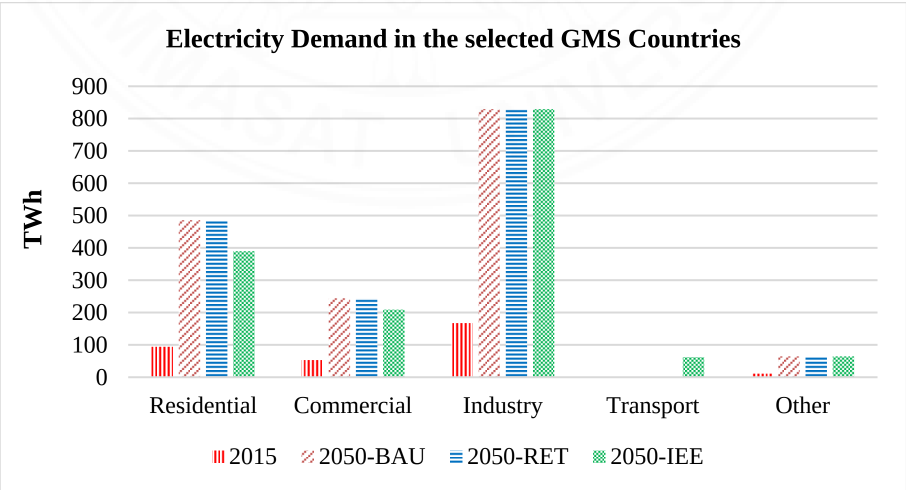

Figure 10.1 Electricity demand in the selected GMS countries by type of sector.

As the total electricity demand in the selected GMS countries increases, the electricity demand per capita would also increase. In 2015, the electricity demand per capita in Cambodia, Lao PDR, Thailand, and Vietnam was 337 kWh/capita, 631 kWh/capita, 2,549 kWh/capita, and 1,510 kWh/capita, respectively. In the BAU scenario, the electricity demand in Cambodia, Lao PDR, Thailand, and Vietnam would see an increase of about 9.6 times, 5.2 times, 4.2 times, and 4.9 times respectively in 2050. In the RET scenario, where the total electricity demand is the same as the BAU scenario, the electricity demand per capita also increases to the same value as in the BAU scenario. However, in the IEE scenario, the electricity demand per capita in each of the selected GMS countries will increase at different rates. Table 10.1 lists the value of electricity demand per capita of each country of the selected GMS countries in the three scenarios in 2015 and 2050.

Table 10.1 Electricity demand per capita of each country of the selected GMS countries.

Country	2015 (kWh/capita)	BAU-2050 (kWh/capita)	RET-2050 (kWh/capita)	IEE-2050 (kWh/capita)
Cambodia	337	3,227	3,227	3,463
Lao PDR	631	3,270	3,270	3,068
Thailand	2,549	10,698	10,698	10,384
Vietnam	1,510	7,455	7,455	6,985

10.2 Electricity Generation

In 2015, coal and natural gas accounted for nearly three-quarters of the total electricity generation in the selected GMS countries. The shares of RE sources such as hydro, biomass, solar, wind, biogas, and MSW amounted to 26.81% in the electricity generation. An increase of 5 times the total electricity generation from 2015 is expected to happen in 2050 in the BAU scenario in the selected GMS countries. By 2050, the share of coal usage in the power generation in the selected GMS countries would see an increase of around 36.77% from 2015. More than half of the total share of coal usage in the electricity generation in the selected GMS countries in 2050 will come from Vietnam, and followed by Thailand. The shares of RE sources in the electricity generation in 2050 would see an increase of about 54.5% from the shares in 2015.

Thailand would lead the four countries in terms of having the highest shares of usage of biomass, solar, and wind in the electricity generation in 2050 compared to Cambodia, Lao PDR, and Vietnam. Figure 10.2 represents the total electricity generation in the selected GMS countries in 2015 and 2050.

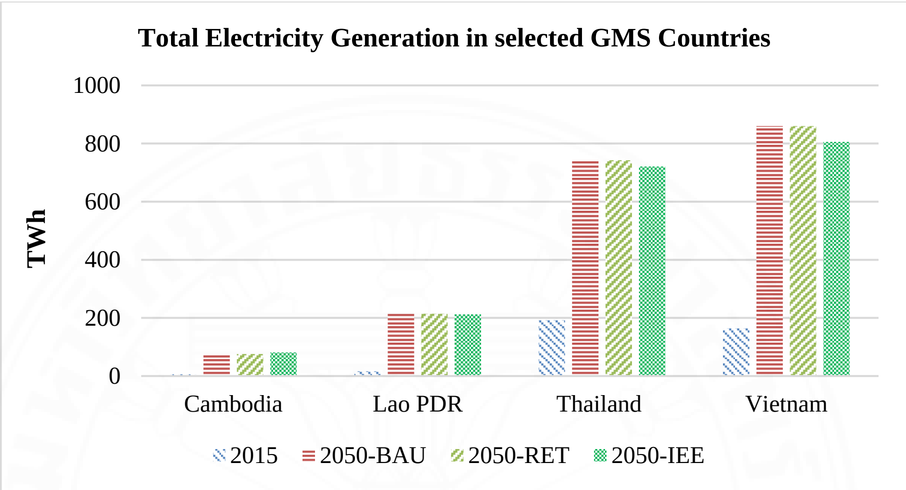

Figure 10.2 Total electricity generation in selected GMS countries.

The results of increasing the use of RE in the power sector in the RET scenario suggest that by 2050, the shares of RE sources in the electricity generation in the selected GMS countries would be increased by 2.31 times from 2015. More than half of the shares of RE sources in the electricity generation in 2050 would belong to biomass, solar, and wind. In 2050, Thailand would lead the four countries in terms of having the highest shares of biomass and wind in electricity generation, while Vietnam would have the highest share of solar in the electricity generation among the four countries. The coal and natural gas usage would see a decrease of 20.88% in 2050 in the RET scenario when compared to the BAU scenario. The coal and natural use in the electricity generation in Thailand and Vietnam would be decreased by more than 60% when compared to the BAU. However, the shares of coal and natural gas of Thailand among the four countries would only slightly be decreased, while those of Vietnam would be slightly increased. Figure 10.3 and Figure 10.4 present the share of RE sources in electricity generation and the share of RE sources (excluding hydro) in electricity generation in the selected GMS countries, respectively, in 2015 and 2050.

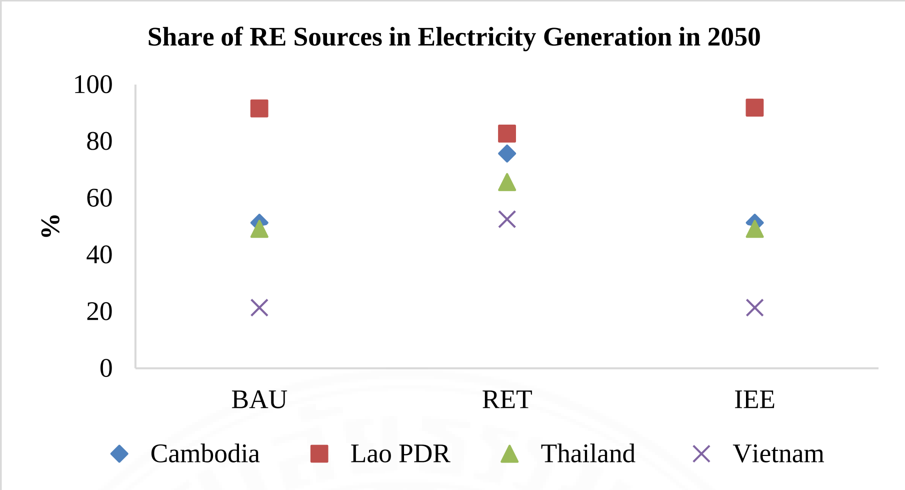

Figure 10.3 Share of RE sources in the electricity generation in selected GMS countries.

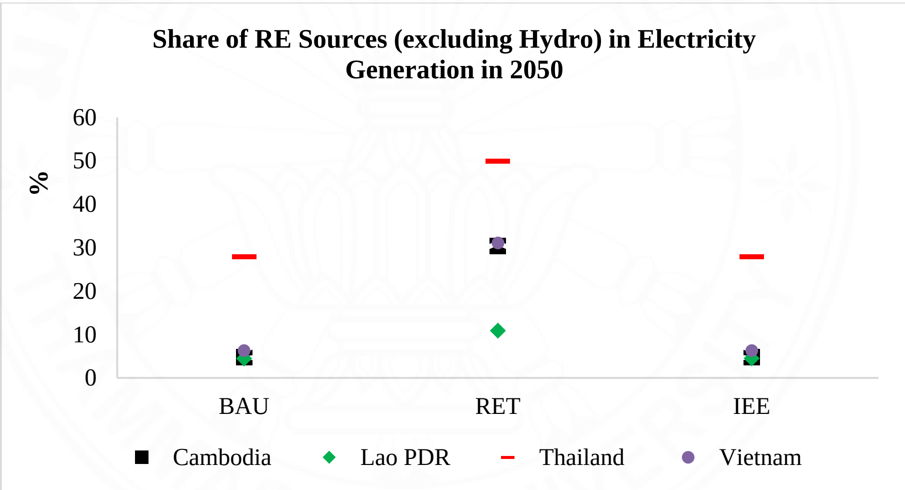

Figure 10.4 Share of RE sources (excluding hydro) in the electricity generation in the selected GMS countries.

In the IEE scenario, the total electricity generation in the selected GMS countries would see a reduction of 72.59 TWh when compared to the BAU scenario in 2050. This would lead to a tiny reduction (less than 1%) of the shares of coal and natural gas use in the electricity generation in the selected GMS countries and a small increase (less than 1%) of the shares of the RE sources in 2050. Nonetheless, the electricity generation from coal, natural gas, hydro, and other energy sources would decrease from the BAU scenario by about 33.91 TWh, 12.93 TWh, 11.53 TWh, and 14.22 TWh, respectively, in 2050. Thailand would lead the four countries in 2050 in terms of having the highest share of natural gas usage in the electricity generation whereas Vietnam would have the highest share of coal usage.

10.3 Emissions from the Power Sector

In 2015, the total CO_2 emissions in the power sector in the selected GMS countries amounted to 166.91 Mt-CO_2. Among the selected GMS countries, Thailand was the main contributor of CO_2 emissions in the power sector in 2015 followed by Vietnam and Cambodia. By 2050, the total CO_2 emissions in the selected GMS countries will be increased by 4.55 times when compared to the BAU scenario in 2050, among which, Thailand and Vietnam would account for approximately 94%.

In the RET scenario, the total CO_2 emissions in the selected GMS countries would see a reduction of 486.59 Mt-CO_2 in 2050 when compared to the BAU scenario. Vietnam would have the biggest emissions reduction which would account for 332.98 Mt-CO_2. The tremendous CO_2 reduction in Vietnam is caused by the phase-out of coal and natural gas use in the power generation. Nearly 40% of the CO_2 emissions reduction in Vietnam comes from the implementation of CCS technologies in the coal and natural gas power plants. Second to Vietnam, Thailand would be able to reduce CO_2 emissions by about 121.97 Mt-CO_2 in the RET scenario in 2050. Nearly half of the total CO_2 emissions reduction in Thailand results from the CCS technologies in the coal and natural gas power plants. Cambodia and Lao PDR would be able to reduce 3.14 Mt-CO_2 and 7.74 Mt-CO_2 of CO_2 emissions, respectively, in 2050 as a result of implementing CCS technologies in the coal and natural gas power plants.

In the IEE scenario, as a result of energy reduction, CO_2 emissions in the power sector would be decreased by 38.5 Mt-CO_2 from the BAU scenario in 2050. Lao PDR, Thailand, and Vietnam would have CO_2 emissions mitigation of about 2.95 Mt-CO_2, 6.58 Mt-CO_2, and 30.95 Mt-CO_2, respectively, in 2050. In contrast, CO_2 emissions in the power sector in 2050 in Cambodia would be increased around 1.98 Mt-CO_2 due to the increasing electricity demand in the transport sector. Figure 10.5 illustrates CO_2 emissions in the power sector in the selected GMS countries in 2050, while Figure 10.6 presents CO_2 emissions in the power sector without the CCS technologies in the selected GMS countries in 2050.

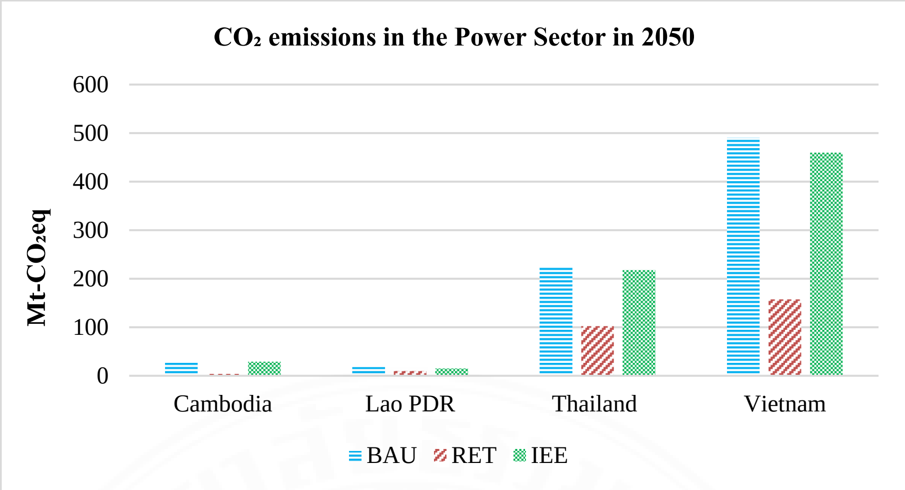

Figure 10.5 Total CO_2 emissions in the power sector in the selected GMS countries.

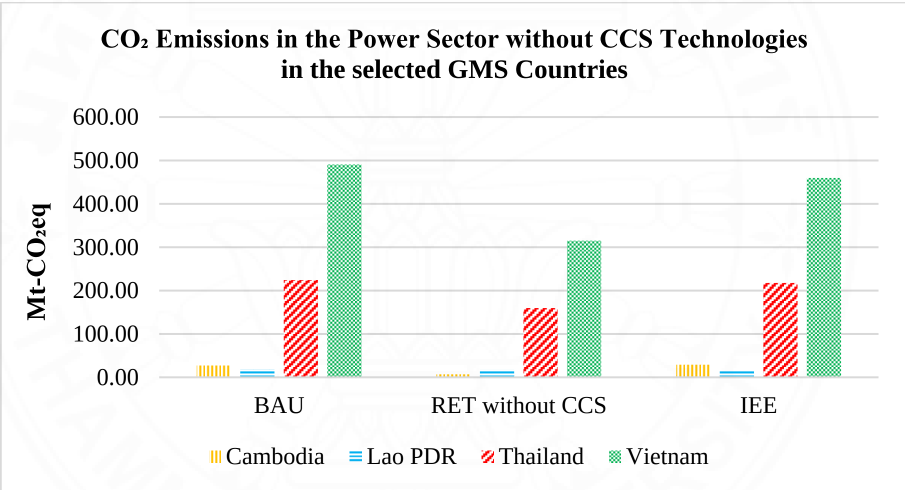

Figure 10.6 Total CO_2 emissions in the power sector without CCS technologies in the selected GMS countries.

Other than CO_2 emissions, the power sectors in the selected GMS countries also emits other pollutants such as NO_x, CO, and SO_2. Nonetheless, the emissions of these pollutants are small when compared with the emissions of CO_2. Table 10.2 indicates the density of the emission in the power sector in each of the selected GMS countries in the three scenarios in 2015 and 2050.

Table 10.2 The density of the emissions in the power sector in the selected GMS countries in the three scenarios.

	Cambodia	Lao PDR	Thailand	Vietnam
2015 (t-CO_2eq/MWh)	0.3388	0.0012	0.4742	0.4459
BAU-2050 (t-CO_2eq/MWh)	0.3608	0.00009	0.3054	0.5777
RET-2050 (t-CO_2eq/MWh)	0.0781	0.00006	0.1407	0.1879
IEE-2050 (t-CO_2eq/MWh)	0.3608	0.00007	0.3054	0.5777

10.4 Energy Demand in the Transport Sector

Total energy demand in the transport sector in the selected GMS countries in 2015 amounted to 26.13 Mtoe of which, Thailand had the most demand accounting for around 72%. In 2015, the electricity demand in the transport sector in the selected GMS countries came solely from Thailand which accounted for approximately 0.01 Mtoe. Passenger transport, which is divided into road passenger transport and rail passenger transport, account for 54.76% of the total energy demand in the transport sector. The waterway freight and airway freight shared about 18.96% and 18.86% of the total energy demand, respectively, in 2015.

By 2050, the total energy demand in the transport sector in the selected GMS countries is expected to have around five-fold incerase in the RET scenario which indicates that the total energy demand would be reduced from the BAU scenario by about 2.52 Mtoe. Thailand would still be the main contributor to the total energy demand among the four countries. In the RET, passenger transport would cover 46.2% of the total energy demand, of which, the road passenger transport and rail passenger transport would share 99.39% and 0.71% respectively. Thailand and Vietnam would have a road passenger transport energy demand of 45.63 Mtoe and 5.86 Mtoe, respectively, while the energy demand in Cambodia and Lao PDR would collectively amount to 9.63 Mtoe. The energy demand in freight transport in the selected GMS countries would be increased by 4.7 times from 2015. The energy demand in waterway freight, road freight, and airway freight transport in 2050 will go up by about 8.92 Mtoe, 5.13 Mtoe, and 18.52 Mtoe respectively from 2015. The electricity demand in the transport sector in 2050 in the RET scenario would increase by 5 times from 2015 and would belong solely to Thailand.

In the IEE scenario, the energy demand in the transport sector in the selected GMS countries is expected to be reduced by about 88.67 Mtoe in 2050 when compared to the BAU scenario. In the IEE scenario, the electricity demand in the transport sector in 2050 would increase 107 times compared to the demand in 2015. The energy demand of rail freight transport would surprisingly take nearly 11% of the total energy demand in the IEE scenario. The share of energy demand in road passenger transport would decrease by nearly half in the IEE scenario as a result of fuel economy improvements and transport mode shifts. Figure 10.7 shows the energy demand in the transport sector in the selected GMS countries in 2050 by type of transport mode.

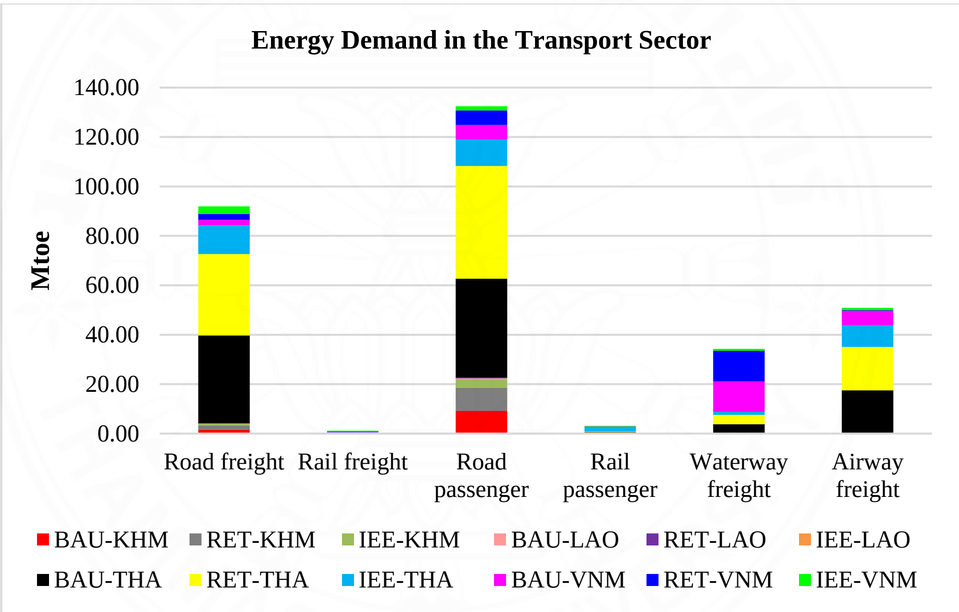

Figure 10.7 Energy demand in the transport sector in the selected GMS countries.

Note: KHM=Cambodia, LAO=Lao PDR, THA=Thailand, VNM=Vietnam.

10.5 Emissions in the Transport Sector

The GHG emissions in the transport sector in the selected GMS countries come from the use of petroleum products and the use of fuels to generate electricity. In 2015, the total GHG emissions in the transport sector in these countries amounted to 78.22 Mt-CO_2eq. LDVs are the main GHG emitters in the selected GMS countries and amounted to 30.21% of the total GHG emissions in 2015. The GHG emissions from the road freight trucks and trailers accounted for 14.44% of the total GHG emissions while air-way freight and waterway freight collectively emitted 29.73% of the total

GHG emissions. The GHG emissions by types of vehicle in the selected GMS countries in 2015 and 2050 are presented in Table 10.3 and are expressed as units of Mt-CO_2eq. Figure 10.8 shows the total GHG emissions in the transport sector in the selected GMS countries in all scenarios in 2015 and 2050.

Table 10.3 GHG emissions in the transport sector by types of vehicles in the selected GMS countries in 2015 and 2050.

Selected GMS Countries	2015	2050-BAU	2050-RET	2050-RET
Freight-Airway	15.09	71.65	71.65	30.00
Freight-Rail	0.19	0.99	0.99	1.45
Freight-B20 Trailer	0.00	0.00	24.20	0.00
Freight-B20 Truck	0.00	0.00	18.53	0.00
Freight-CNG Truck	0.15	2.34	2.34	5.69
Freight-Trailer	9.46	97.00	44.67	31.20
Freight-Truck	1.68	21.70	23.60	9.20
Freight-Waterway	9.49	49.19	49.19	6.16
Passenger-Rail	0.27	0.99	0.99	5.83
*Passenger-Electric Rail	0.08	0.18	0.08	1.92
Passenger-B20 Bus	0.00	0.00	12.10	0.00
Passenger-Bus	9.42	34.46	21.26	12.13
*Passenger-Electric Bus	0.00	0.00	0.00	2.88
Passenger-E20 LDV	0.00	0.00	31.55	0.00
Passenger-LDV	23.63	93.11	59.76	13.46
*Passenger-Electric LDV	0.00	0.00	0.00	6.21
Passenger-E10 MC	0.00	0.00	9.85	0.00
Passenger- MC and Three wheeler	8.77	34.88	24.48	7.11
*Passenger-Electric MC	0.00	0.00	0.00	10.59

Note: * The emissions are included in the power sector.

In the BAU scenario, the total GHG emissions in the transport sector in the selected GMS countries are expected to shoot up to 406.49 Mt-CO_2eq in 2050. Thailand would dominate nearly three-quarters of the total GHG emissions. The GHG emissions from the use of buses in the selected countries would amount to 8.48% in 2050, whereas the emissions from the LDVs and motorcycles would be 22.91% and 8.58%, respectively. The GHG emissions in the transport sector in 2050 caused by the generation of electricity for the electric vehicles would be 0.18 Mt-CO_2eq, which would only belong to the electric rail of Thailand.

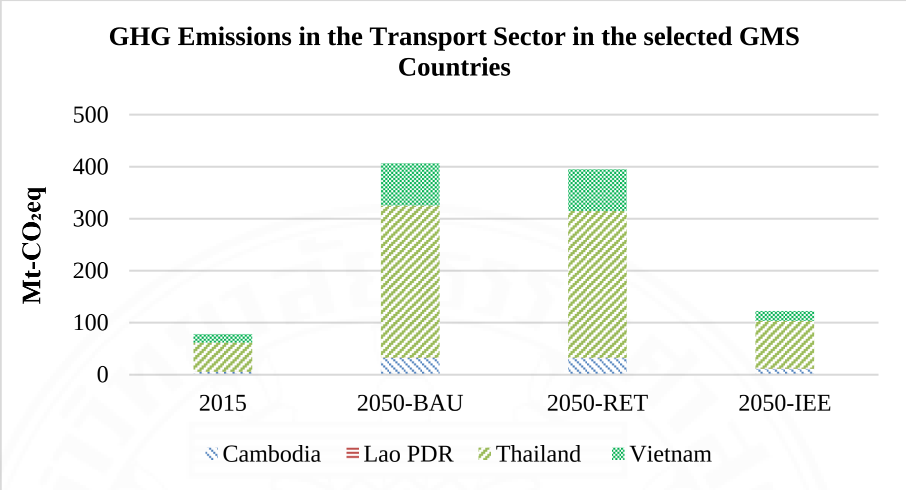

Figure 10.8 Total GHG emissions in the transport sector in the selected GMS countries in 2015 and 2050.

By 2050, the total GHG emissions in the transport sector in the four countries would see a reduction of about 11.27 Mt-CO_2eq in the RET scenario when compared to the BAU scenario. Compared to the BAU scenario, by introducing the biofuel-fired vehicles into the transport sector, the GHG emissions from the use of LDVs, motorcycles, trucks, and buses would be cut down by approximately 1.81 Mt-CO_2eq, 0.56 Mt-CO_2eq, 7.7 Mt-CO_2eq, and 1.11 Mt-CO_2eq, respectively, in 2050. Biofuel vehicles would reduce the GHG emissions of 0.3 Mt-CO_2eq, 0.01 Mt-CO_2eq, 10.81 Mt-CO_2eq, and 0.05 Mt-CO_2eq in Cambodia, Lao PDR, Thailand, and Vietnam which indicates that the measure is found to be most effective in Thailand.

On the other hand, the total GHG emissions in the transport sector in the selected GMS countries in the IEE scenario would be drastically cut down to 124.15 Mt-CO_2eq in 2050. The penetration of electric vehicles, fuel economy improvements, and transport mode shifting would prove to be more desirable than the penetration of biofuel in the transport sector in terms of GHG emissions abatement. However, the GHG emissions that would be cut down by use of electric LDVs, electric buses, and electric motorcycles over the conventional vehicles in 2050 would be 73.43 Mt-CO_2eq, 19.45 Mt-CO_2eq, and 17.18 Mt-CO_2eq, respectively, when compared to the BAU scenario.

10.6 Costs of Electricity Generation

The costs of electricity generation in the selected GMS countries are divided into production cost, externality cost, and total electricity generation cost. The externality cost is calculated using the carbon tax of 9 $/t-CO_2eq. In 2015, the total production cost of electricity in the selected countries amounted to 8.72 billion USD, of which, Thailand accounted for more than 50%. The costs of electricity production from natural gas and coal and lignite collectively accounted for 6.68 billion USD in 2015. The costs of electricity production from other fossil fuel resources collectively equaled only 0.26 billion USD. Figure 10.9 illustrates the total electricity production, total externality, and total electricity generation costs in the selected GMS countries in 2015 and 2050 in the three scenarios.

In the BAU scenario, the total electricity production cost and the total electricity generation cost in the selected GMS countries would be increased to 71.96 billion USD and 78.8 billion USD, respectively, in 2050. Nearly three-quarters of the total electricity production cost in the four countries would be spent on natural gas and coal and lignite power plants in 2050. Vietnam would have the highest electricity production cost from coal and lignite, whereas Thailand would spend most of the electricity production cost on natural gas power plants. The expenditure on electricity production from hydro and other renewable energy sources would amount to 14.86% and 12.42% of the total production cost of the selected countries. The total externality cost resulting from taxing the carbon emissions in the selected GMS countries would be 6.84 billion USD in 2050.

In the RET scenario, where the RE sources have penetrated the power sector at a higher rate than in the other scenarios, the total electricity production in the selected GMS countries is expected to be 4.39 billion USD lower than the BAU scenario in 2050. Though the capital investments of the RE power plants are higher than that of the conventional plants, the increasing fossil fuel prices would make the conventional plants more and more undesirable in the future. As a result of increasing the use of RE, the electricity production costs of the RE power plants such as biomass, MSW, solar, biogas, and wind will go up by about 4.57 billion USD, 0.7 billion USD, 3.76 billion USD, 1.27 billion USD, and 1.58 billion USD, respectively, in 2050. Thailand would share a large portion of the electricity costs of the RE power plants in the selected GMS countries. The externality cost can be reduced because the lower use of conventional power plants would account for 2.46 billion USD, which is only 36% of the externality cost in the BAU scenario.

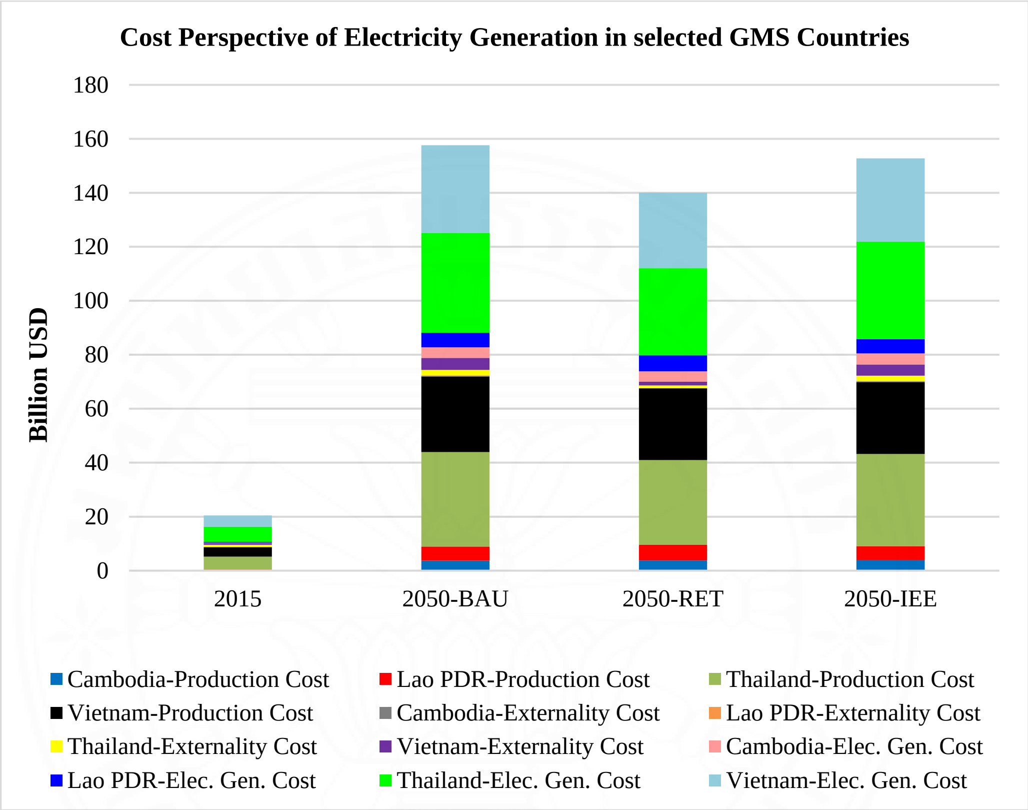

Figure 10.9 Cost perspective of electricity generation in the selected GMS countries.

On the other hand, the total electricity production cost and the externality cost in the IEE scenario would amount to only 2.07 billion USD in 2050, a slight reduction from the BAU scenario. Even though the IEE scenario considers the efficiency improvement in the end-use equipment which will lead to the reduction of energy demand in the future, the small amount of cost reduction from the BAU in the power sector in this scenario is due to the increase of electricity demand in the transport sector. Vietnam would have the biggest share of cost reduction among the total electricity production cost and the externality cost reductions in the four countries, followed by Thailand. In addition, Table 10.4 lists the details of the cost perspectives of electricity generation in selected GMS countries in 2015 and 2050 in all scenarios.

Table 10.4 Production cost and externality costs by type of energy sources in the selected GMS countries.

Production Cost (billion USD)				
Selected GMS Countries	2015	2050-BAU	2050-RET	2050-IEE
Coal and Lignite	2.37	31.33	17.43	30.18
Hydro	1.31	10.69	10.67	10.62
Biomass	0.30	4.02	8.59	3.93
MSW	0.03	1.18	1.88	1.15
Solar	0.07	1.33	5.09	1.33
Biogas	0.05	1.71	2.98	1.68
Nuclear	-	4.69	6.49	4.69
Wind	0.01	0.70	2.28	0.70
Fuel oil	0.22	0.00	0.00	0.00
Natural Gas	4.31	52.29	43.77	50.56
Imported Electricity	0.00	0.23	0.01	0.23
Diesel	0.04	0.31	0.28	0.31
Total	8.72	108.48	99.49	105.36
Externality Cost (billion USD)				
	2015	2050-BAU	2050-RET	2050-IEE
Selected GMS Countries	1.5	6.84	2.46	6.49

The Levelized Cost of Electricity (LCOE) of each GMS country during 2015-2045 are listed in Table 10.5. The lifetime and the capital costs of different power plants are found in Table 5.1 in Chapter 5 of this study. Vietnam would have the highest LCOE amongst the four countries in the BAU scenario due to the high amount of electricity produced from natural gas and coal. However, Thailand will have the highest LCOE in the RET and IEE scenario. This is due to the increasing installed capacity of renewable energy power plants which fundamentally have a high capital cost. Plus, Thailand would still strongly depend on natural gas power plants. The capital cost of the natural gas power plant is not as high as the renewables. However, due to the increasing price of natural gas in the future, the LCOE from the natural gas power plants would be high as well. Lao PDR has the lowest LCOE amongst the four countries because it relies on hydro power plants which have a relatively low capital cost. The LCOE of Lao PDR in the RET increases a little bit from the BAU due to the increasing installed capacity of renewable energy power plants. Figure 10.10 and 10.11 presents the LCOE in the selected GMS countries during 2015-2045 by scenario and country respectively. The LCOEs by type of power plant in each of the selected GMS countries can be found in Appendix A.

Table 10.5 The Levelized Cost of Electricity (LCOE) in the selected GMS countries during 2015-2045.

Country	BAU Scenario	RET Scenario	IEE Scenario
Cambodia	0.0438	0.0392	0.0420
Lao PDR	0.0229	0.0232	0.0228
Thailand	0.0449	0.0452	0.0449
Vietnam	0.0465	0.0414	0.0427

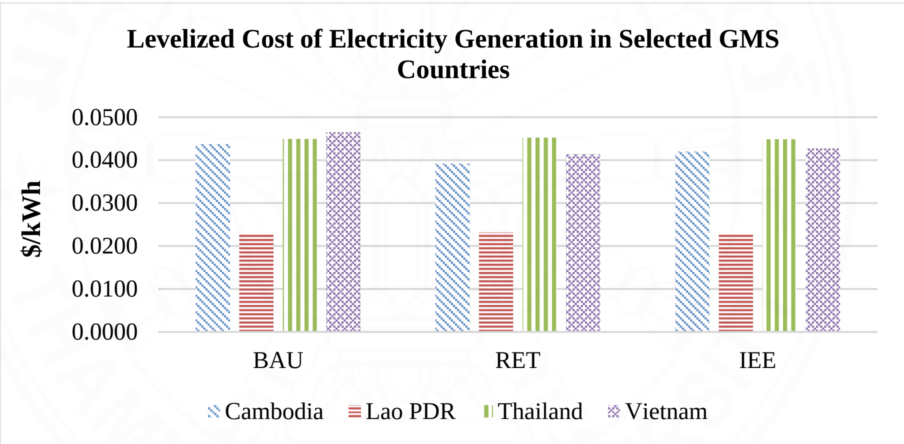

Figure 10.10 LCOE in the selected GMS countries during 2015-2045 by scenario.

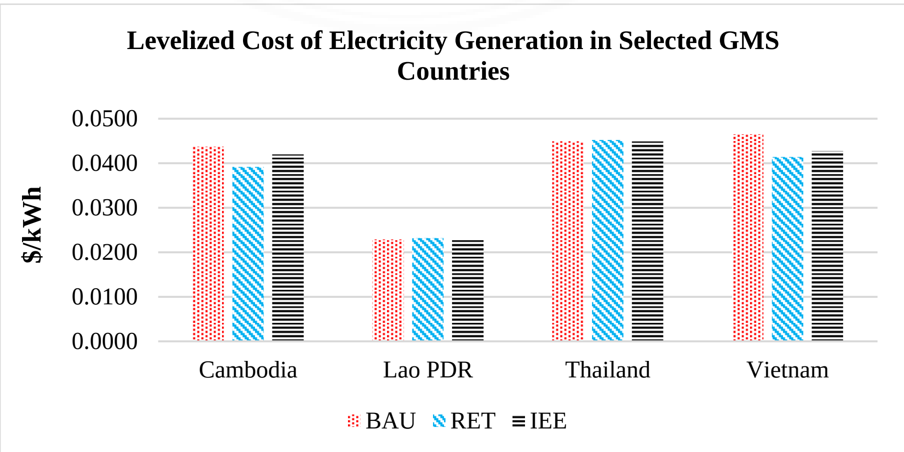

Figure 10.11 LCOE in the selected GMS countries during 2015-2045 by country.

10.7 Marginal Abatement Cost

10.7.1 Residential Sector

In the residential sector, the results of the Marginal Abatement Cost (MAC) suggest that the cumulative GHG emissions mitigation in the selected GMS countries that can be obtained during 2015-2050 from efficient technologies such as LED lamps, CFLs, LFLs, High-EER air conditioners, and COP-5 refrigerators would collectively amount to 1,112.11 Mt-CO_2eq. The emissions reductions that would be achieved would have different marginal abatement costs as can be seen in Figure 10.12.

During 2015-2050, the replacement of 25% of the traditional refrigerators in Lao PDR with the COP-5 refrigerators would lead to the lowest marginal abatement cost among the MAC perspectives in the four countries. However, its cumulative GHG abatement would be only 0.24 Mt-CO_2eq. In Lao PDR, the replacement of LFLs with LED tubes would lead to the largest cumulative GHG emissions reduction during 2015-2050 in the residential sector which would be 0.84 Mt-CO_2eq with the corresponding MAC of -807.3 $/t-$CO_2$eq. In Cambodia, the largest and the smallest cumulative GHG emissions mitigation would come from the replacement of EER-9 air conditioners with EER-12.8 air conditioners, and the replacement of incandescent lamps with CFLs, respectively. Their cumulative GHG abatements and corresponding MACs would be 12.37 Mt-CO_2eq and -471.2 $/t-$CO_2$eq and 0.3 Mt-$CO_2$eq, and -551.6 $/t-$CO_2$eq.

On the other hand, the largest and the smallest cumulative GHG abatements in Thailand are found when the replacement of 100% of the traditional refrigerators with COP-5 refrigerators and the replacement of CFLs with LED lamps are implemented. Their cumulative emissions savings and corresponding MACs would be 67.99 Mt-CO_2eq and -204 $/t-$CO_2$eq and 7.28 Mt-$CO_2$, and -324.2 $/t-$CO_2$eq, respectively. In Vietnam, the lowest and highest cumulative marginal abatement costs in the MAC study are found when replacing 90% and 30% of the traditional refrigerators with the COP-5 refrigerators, which would have the corresponding GHG abatements of 98.92 Mt-CO_2eq and 46.17 Mt-CO_2eq. The values for the cumulative MAC during 2015-2050 in the residential sector in the selected GMS countries are listed in Appendix B.

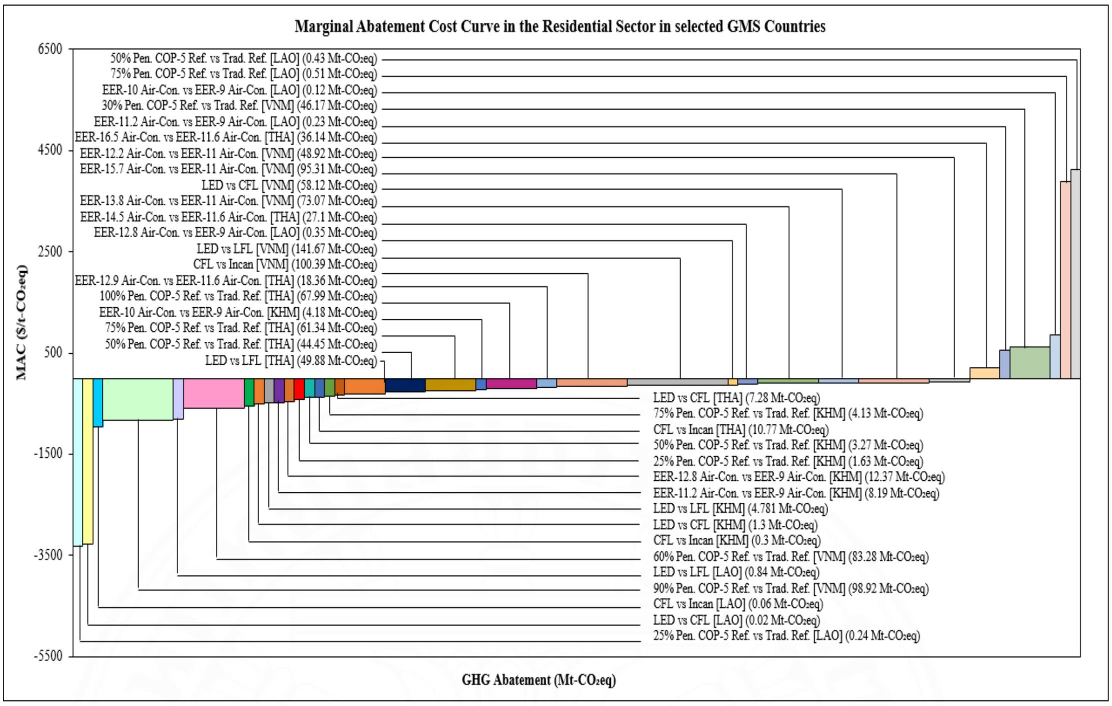

Figure 10.12 Cumulative MAC curve in the residential sector in the selected GMS countries during 2015-2050.

Note: KHM=Cambodia, LAO=Lao PDR, THA=Thailand, VNM=Vietnam.

10.7.2 Commercial Sector

The MAC analysis in the commercial sector within the selected GMS countries considers only the lighting systems. The total cumulative GHG emissions in the lighting systems of the commercial sector in the selected four countries during 2015-2050 would collectively amount to 31.07 Mt-CO_2eq. Figure 10.13 represents the cumulative MAC curve of the measures in the commercial sector in the selected GMS countries during 2015-2050. Appendix C lists the value of the cumulative MAC in the commercial sector in the selected GMS countries during 2015-2050. In all countries except for Thailand, the results indicate that the replacement of LFLs with LED tubes is found more desirable than the replacement of CFLs by LED lamps in terms of GHG emissions abatement. Vietnam would most benefit from GHG abatement in the replacement of LFLs with LED tubes as its GHG abatement would be 18 Mt-CO_2eq. In Thailand, the cumulative GHG emissions reduction during 2015-2050 caused by the replacement of CFLs with LED lamps would be 4.35 Mt-CO_2eq, whereas in Cambodia, Lao PDR, and

Vietnam, the values would be 0.43 Mt-CO_2eq, 0.009 Mt-CO_2eq, and 0.76 Mt-CO_2eq, respectively.

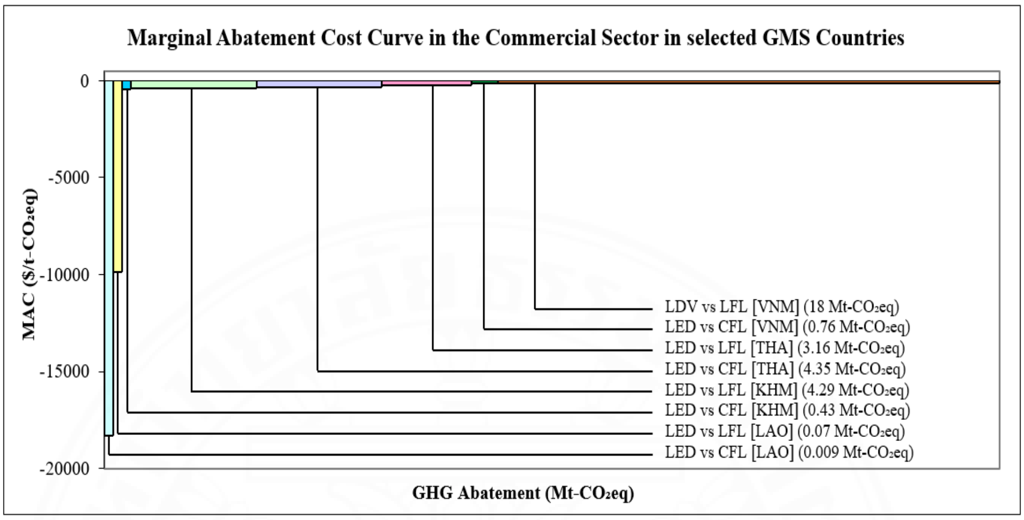

Figure 10.13 Cumulative MAC curve in the commercial sector in the selected GMS countries during 2015-2050.

10.7.3 Transport Sector

In the transport sector, the MAC study considers the benefits of biofuel-fired vehicles and electric vehicles such as electric LDVs, electric motorcycles, electric buses, E20 LDVs, E10 motorcycles, B20 buses, CNG trucks, and B20 trucks in the selected GMS countries. Figure 10.14 presents the cumulative MAC curve of the measures in the transport sector in the selected GMS countries during 2015-2050.

The results suggest that the cumulative GHG emissions mitigation in the selected GMS countries can be obtained during 2015-2050 from the efficient and environmental-friendly vehicles would collectively amount to 439.92 Mt-CO_2eq. The penetration of CNG trucks over diesel trucks in Vietnam and Thailand would have the lowest and second-lowest cumulative MACs among the other measures in the selected GMS countries during 2015-2050, which would account for -2,139 \$/t-CO_2eq and -2,089 \$/t-CO_2eq. However, the corresponding GHG abatement would also be low when compared to the savings of B20 trucks.

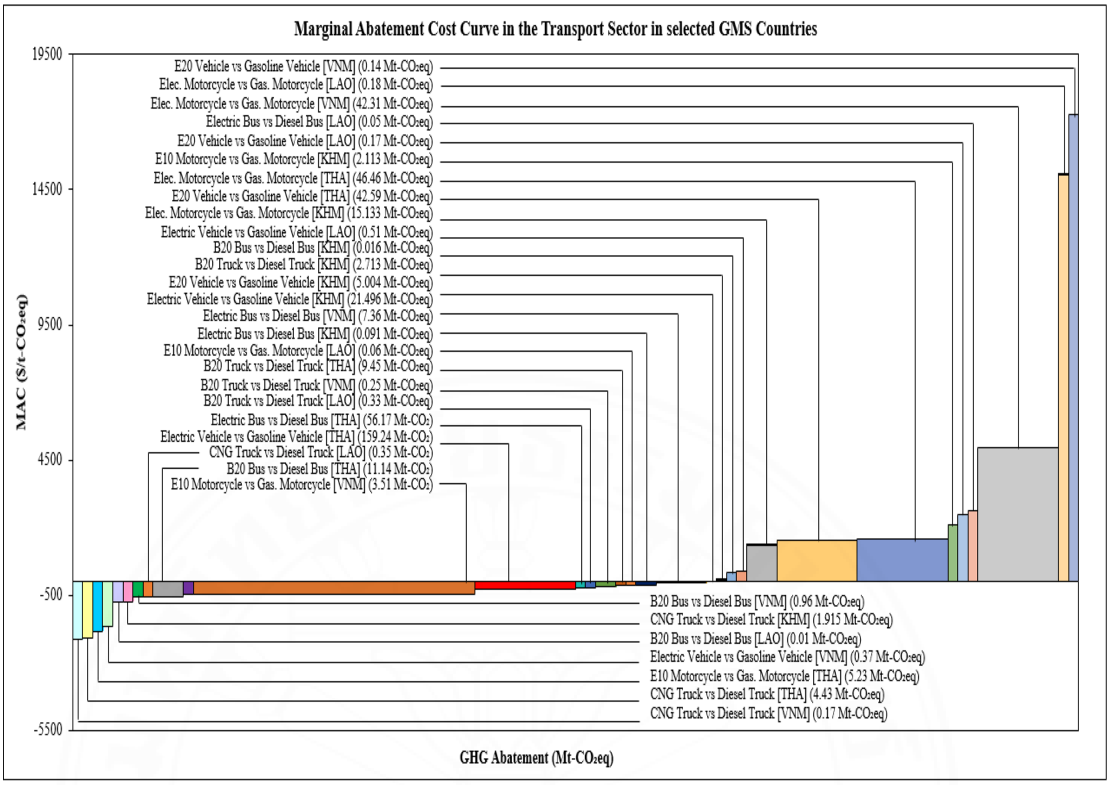

Figure 10.14 Cumulative MAC curve in the transport sector in the selected GMS countries during 2015-2050.

The penetration of electric motorcycles over gasoline motorcycles would result in high MACs in all of the four countries. Nonetheless, their corresponding GHG abatements would not be guaranteed to be high as well. For instance, the cumulative GHG emissions savings from the penetration in Lao PDR during 2015-2050 would be only 0.18 Mt-CO_2eq. It can be seen that the cumulative GHG emissions saving from the electric buses in Cambodia and Lao PDR would be low due to the low traffic demand in the public transportation. The values of the cumulative MAC during 2015-2050 of the measures included in the transport in the selected GMS countries are listed in Appendix D.

10.7.4 Power Sector

The MAC in the power sector in the year 2050 in the selected GMS countries is discussed in this section. Within the MAC study for Cambodia in 2050, a total capacity of coal and natural gas power plants of 7,007 MW are considered to be replaced by biomass, solar, hydro, and nuclear. For Lao PDR, only 500 MW of coal power plants are considered to be replaced by biomass, solar, hydro, wind, nuclear, and MSW. In Thailand, a total capacity of 17,400 MW of coal and natural gas power plants are considered to be replaced by solar, MSW, wind, hydro, biomass, and nuclear. For Vietnam, a total capacity of 33,700 MW of coal and natural gas power plants are considered to be replaced by hydro, biomass, solar, nuclear, and wind technology. The results of the MAC study in the power sector in the selected GMS countries are shown in Figure 10.15.

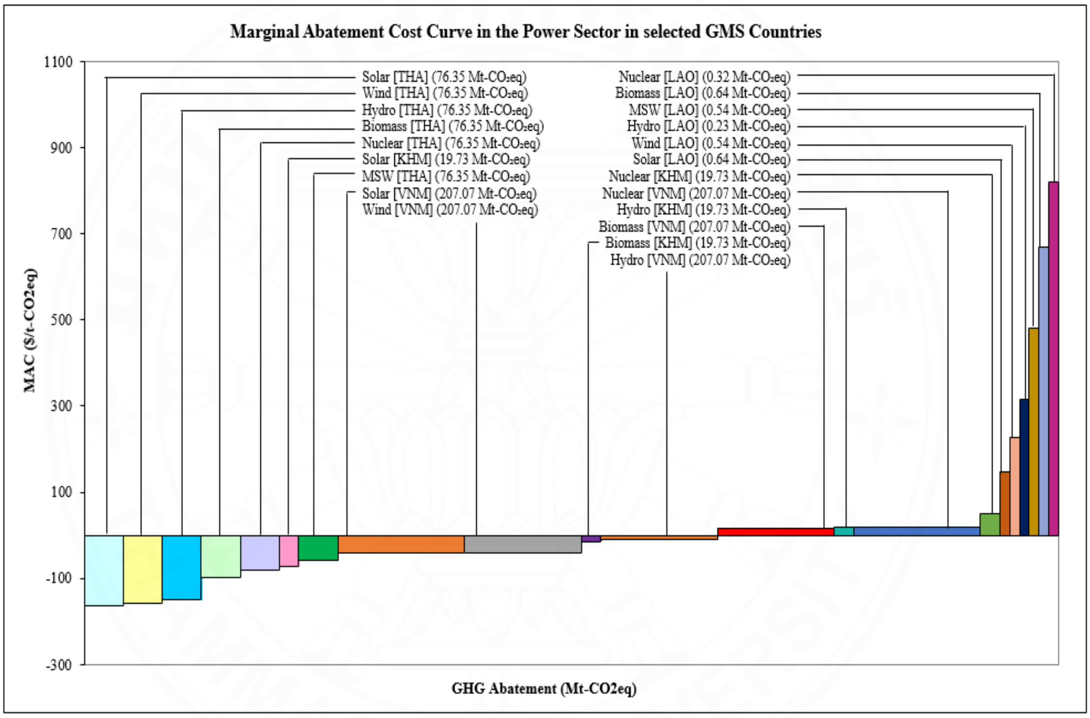

Figure 10.15 Cumulative MAC curve in the power sector in the selected GMS countries in 2050.

It can be seen that the replacement of coal and natural gas power plants by solar power plants in Cambodia is the most effective measure as it can potentially mitigate the emissions by approximately 19.73 Mt-CO_2eq while having the lowest MAC compared to other measures. The MAC of RE measures in Lao PDR is the highest among the selected GMS countries. Just like Cambodia, solar power is the most effective measure to replace coal power plants in Lao PDR in 2050 because it can reduce the emissions by around 0.64 Mt-CO_2eq. The RE measures to replace coal and natural gas power plants in Thailand are significantly implementable. Most of the measures in the MAC study in Thailand have lower MAC than the measures in the three other countries. It can be noticed that solar power is also the most effective option to substitute for coal and natural gas in Thailand as this measure would be able to reduce 76.35 Mt-CO_2eq of emissions in the year 2050. For Vietnam, the most effective option to replace coal and natural gas in 2050 is also the solar power plant as it can significantly reduce approximately 207.07 Mt-CO_2eq of emissions in 2050 while having the lowest MAC when compared to the other measures for Vietnam. For more details of the cumulative MAC values, go to Appendix E.

10.8 Emissions Gap

In the emissions gap analysis, the total GHG emissions (excluding LULUCF) in the selected GMS countries collectively amounted to 719.1 Mt-CO in 2015. In the baseline case, the total GHG emissions in these countries would go up to 1,572.4 Mt-CO_2eq. Vietnam would have the most GHG emissions in 2050 in the baseline case which would account for 810.5 Mt-CO_2eq, followed by Thailand accounting for 550.2 Mt-CO_2eq. In 2050, the selected GMS countries would not collectively achieve the 2℃ goal of the Paris Agreement nor the 1.5℃ target even when considering the full achievement of the pledged NDCs targets. To further observe the emissions gap, the pledged conditional NDCs targets in the selected countries are assumed to be doubled and tripled in 2050 in the NDC-C-DOU scenario and NDC-C-TRI scenario respectively. It is found that the emissions gaps between the NDC-C-DOU scenario and the NDC-C-TRI scenario to the 2-D2050 scenario in 2050 would be 290.5 Mt-CO_2eq and 160.7 Mt-CO_2eq, respectively. The emissions gaps to reach the 1.5℃ target would be even wider for the selected GMS countries to complete. The interpretation of the results would suggest that if the future NDCs of the selected GMS countries were to be increased, the conditional NDCs targets would have to be increased to more than triple the current NDCs targets to have a chance of reaching the 2℃ emissions pathway of the Paris Agreement in 2050. Figure 10.16 illustrates the emissions gap in various scenarios in the selected GMS countries during 2015-2050.

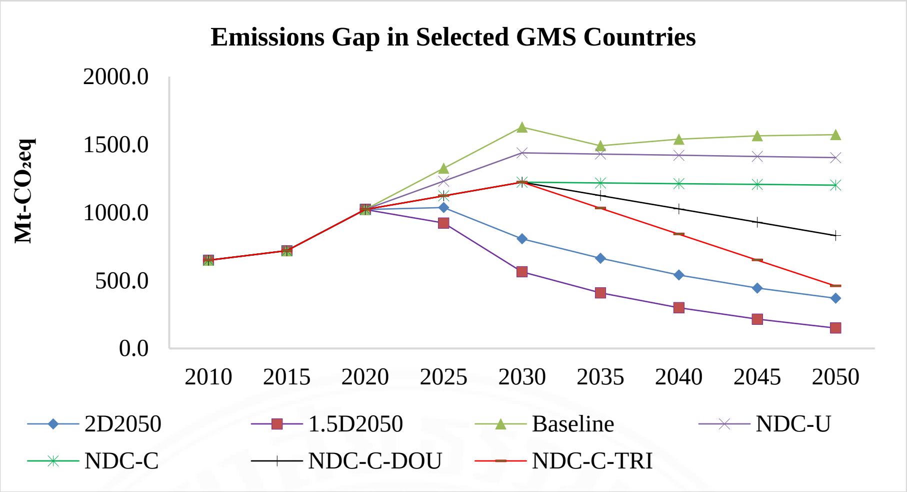

Figure 10.16 Emissions gap in the selected GMS countries in various scenarios.

10.9 Carbon Budgets

10.9.1 Carbon Budgets for Selected GMS Countries Based on the 2°C Goal of the Paris Agreement

The carbon budgets estimation for the selected GMS countries is done based on four effort-sharing approaches. The results of the carbon budgets analysis for the selected GMS countries suggest that the total cumulative carbon budgets in the GDR approach of the four selected countries will be bigger than the other three approaches during 2011-2050. Lao PDR would be given the smallest cumulative carbon budget when compared to Cambodia, Thailand, and Vietnam in the IEPC approach. This is due to the fact that Lao PDR has the smallest population among the four countries and Lao PDR was the lowest CO_2 emitter in the past among the four countries.

In 2050 in the GDR approach, the carbon budgets relative to 2010 carbon emissions for Cambodia, Lao PDR, Thailand, and Vietnam would be approximately 92.1%, 308.9%, 69.3%, and 40.4%, respectively, as can be seen from Figure 10.17. Lao PDR will be allowed to emit much more CO_2 emissions in the year 2050 than the emissions in the year 2010 because Lao PDR has the smallest RCI values when compared to the other three countries.

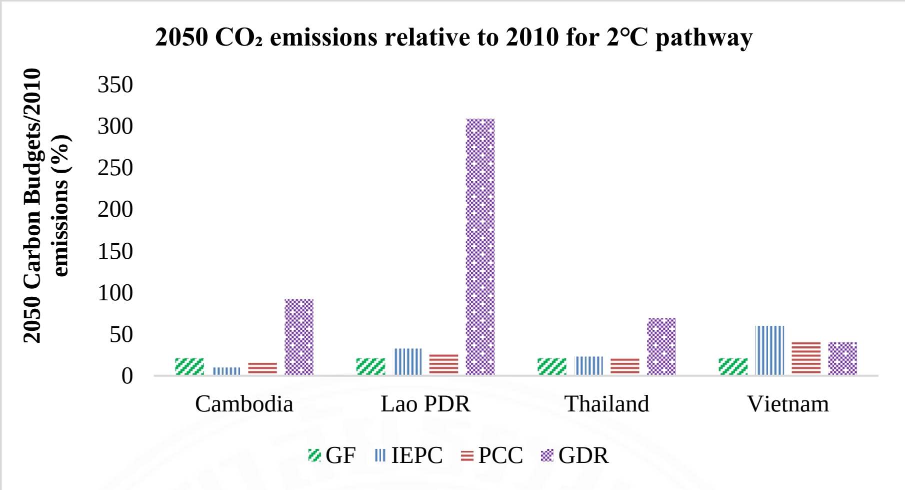

Figure 10.17 Carbon budgets (including LULUCF) of effort-sharing approaches in 2050 relative to 2010 emissions.

Note: The carbon budgets are expressed as a percentage of the carbon dioxide emissions in 2010.

Figure 10.18 presents the cumulative 2011-2050 carbon budgets (including LULUCF) relative to the 2010 carbon emissions for the selected GMS countries based on the 2°C emissions pathway.

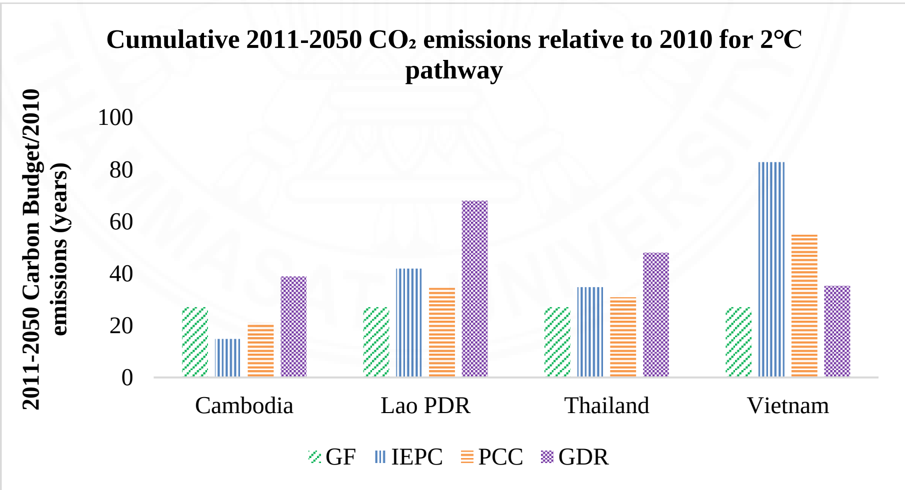

Figure 10.18 Cumulative carbon budgets (including LULUCF) relative to 2010 based on the 2°C target.

Notes: Cumulative carbon budgets (2011-2050/2010 carbon emissions) are based on the 2°C goal and are expressed in emission years (i.e. the cumulative carbon budgets during 2011-2050 is equal to the amount of 2010 emissions emitted constantly throughout the years that are expressed in the graph).

The cumulative carbon budgets during 2011-2050 based on the 2°C goal of the Paris Agreement for Cambodia, Lao PDR, Thailand, and Vietnam in the GDR approach would be 5.28 Gt-CO_2eq, 1.33 Gt-CO_2eq, 10.79 Gt-CO_2eq, and 4.49 Gt-CO_2eq, respectively. Vietnam would be allowed for the most cumulative carbon budget during 2011-2050 in the IEPC approach because of its huge population. However, in the GDR approach, Thailand would have the biggest cumulative carbon budget during the same period because Thailand emitted the most CO_2 emissions in the past.

10.9.2 Carbon Budgets for Selected GMS Countries Based on the 1.5°C Target

Based on the 1.5°C target, the total cumulative carbon budgets (including LULUCF) during 2011-2050 of the four countries in the GF, IEPC, PCC, and GDR approaches would be 11.68 Gt-CO_2eq, 18.21 Gt-CO_2eq, 14.94 Gt-CO_2eq, and 19.8 Gt-CO_2eq, respectively. In the GF approach, Thailand would have the biggest cumulative carbon budget during 2011-2050 based on the 1.5°C emissions pathway followed by Cambodia, Vietnam, and Lao PDR. In the IEPC, Vietnam would have the largest cumulative carbon budget and would be followed by Thailand, Cambodia, and Lao PDR. Even though the carbon budgets in the four effort-sharing approaches based on the 1.5°C emissions pathway would shrink from those based on the 2°C emissions pathway, the trend of carbon budgets based on the 1.5°C pathway still would be the same as the trend based on the 2°C pathway. Figure 10.19 illustrates the cumulative carbon budgets during 2011-2050 for the selected GMS countries based on the 1.5°C target in various approaches.

Similar to the cumulative carbon budgets based on the 2°C emissions pathway relative to the 2010 CO_2 emissions, the IEPC approach would allow Vietnam to have the largest cumulative 2011-2050 carbon budgets based on the 1.5°C emissions pathway relative to the 2010 CO_2 emissions (see Figure 10.20). It can be noted that the GDR approach would allow for the most cumulative carbon budgets for Cambodia, Lao PDR, and Thailand when compared to the effort-sharing approaches. In contrast, only Vietnam would have the smallest cumulative carbon budget compared to the three other approaches during 2011-2050.

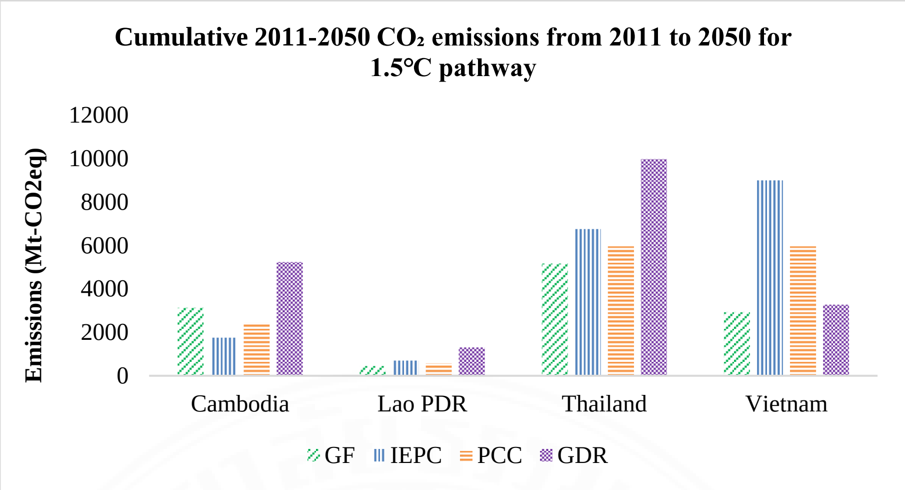

Figure 10.19 Cumulative carbon budgets (including LULUCF) of effort-sharing approaches based on the 1.5°C pathway.

Notes: Cumulative carbon budgets (2011-2050 carbon emissions) are based on the 1.5°C target and are expressed in Mt-CO_2eq.

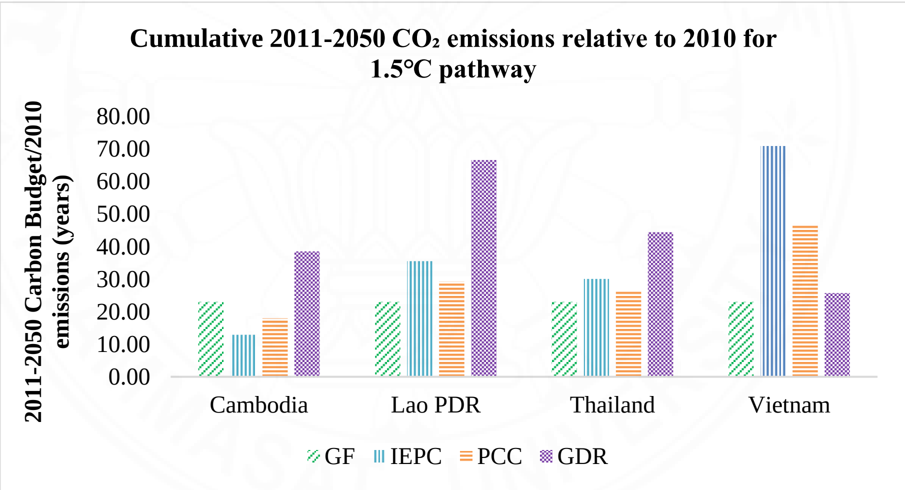

Figure 10.20 Cumulative carbon budgets (including LULUCF) relative to 2010 based on the 1.5°C target.

Notes: Cumulative carbon budgets (2011-2050/2010 carbon emissions) are based on the 1.5°C target and are expressed in emission years (i.e. the cumulative carbon budgets during 2011-2050 is equal to the amount of 2010 emissions emitted constantly throughout the years that are expressed in the graph).

For comparison purposes, the cumulative carbon budgets relative to 2010 emissions based on the 2°C and 1.5°C emissions pathway are shown in Figure 10.21.

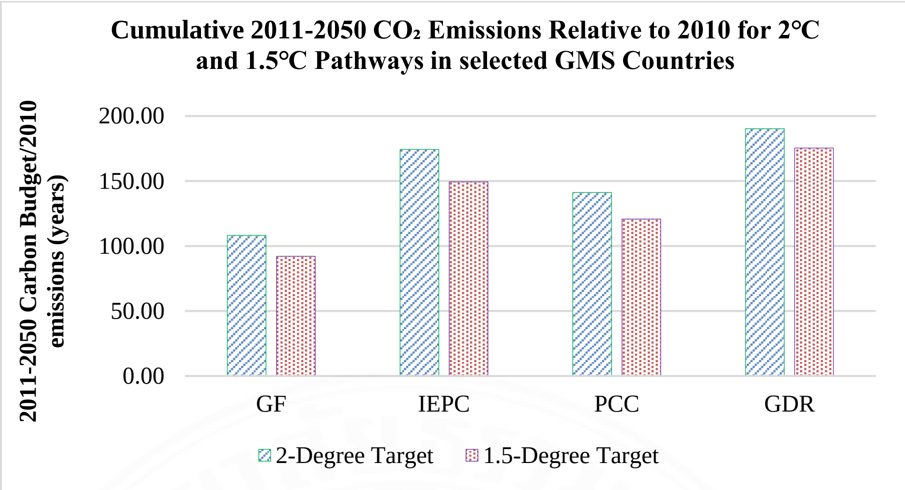

Figure 10.21 Cumulative 2011-2050 carbon budgets relative to 2010 emissions based on 2°C and 1.5°C pathways.

10.10 Carbon Budgets Pathways

In addition to the carbon budgets estimation, based on the GF, IEPC, PCC, and GDR approaches, the 2-degree carbon budgets pathway during 2010-2100 of the selected GMS countries is picked to be demonstrated in this study as well. According to the results of the emissions pathway based on the GF, IEPC, PCC, and GDR approach, the CO_2 emissions in the selected GMS countries as a whole are expected to be net-zero by 2064 in the GF, IEPC, and PCC approaches and 2058 in GDR approaches. However, after reaching net-zero emissions, the CO_2 emissions in all approaches except the GDR approach will go up a little and stay near zero by 2100. This is due to the global trend of the CO_2 emissions in the 2-degree pathway. In the GDR approach, the CO_2 emissions in the selected GMS countries will keep decreasing even after reaching the net-zero in 2058. The reasons for the continuous decrease of CO_2 emissions in these selected countries in the GDR are that the RCI values, which is the index corresponding to the GDP per capita and emissions mitigation capability index, after the year 2030 are assumed to stay constant and the assumption of a linear convergence to PCC outcomes after 2030. Figure 10.22 represents the 2-degree carbon budgets pathway of the selected GMS countries during 2010-2100 based on the GF, IEPC, PCC, and GDR approaches.

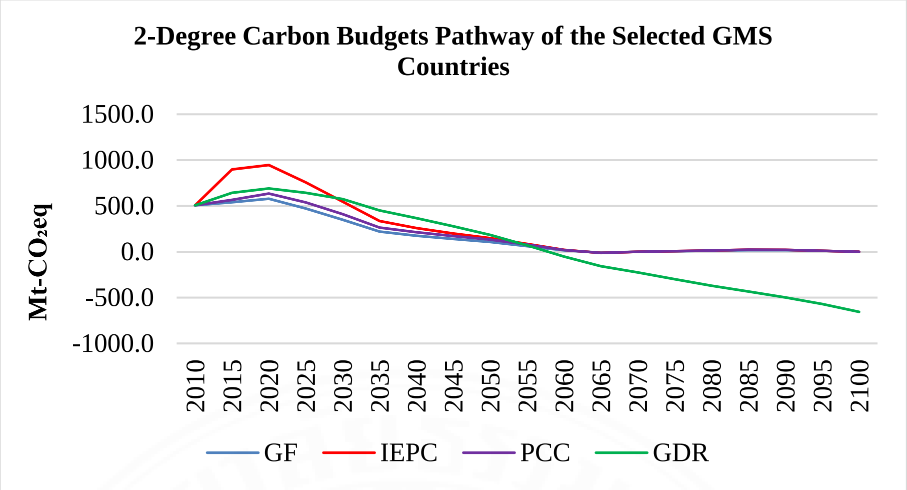

Figure 10.22 2-degree carbon budgets pathway of the selected GMS countries based on the four approaches during 2010-2100.

The 1.5-degree carbon budgets pathways based on the GD, IEPC, PCC, and GDR approaches of the selected GMS countries show a faster trend of reaching net-zero than the 2-degree carbon budgets pathways. Figure 10.23 shows the trend of the 1.5-degree carbon budgets pathway of the selected GMS countries during 2010-2100 based on the GF, IEPC, PCC, and GDR approaches. Due to the trend in the global emissions, the net-zero emissions year of the selected GMS countries based on the 1.5-degree target would be in the year 2045 in the GF, IEPC, and PCC approaches. However, the carbon budgets pathway of the selected GMS countries in the GDR approach will reach net-zero in 2051 which is a little bit slower than the other three approaches. The RCI values of Thailand are the biggest among the four countries and are followed by Vietnam, Cambodia, and Lao PDR. Besides, the historical emissions in Thailand are also the biggest among the four countries. The historical emissions in Vietnam are nearly two times smaller than in Thailand. In terms of the capability of mitigating future emissions, Thailand would meet the emission targets followed by Vietnam, Cambodia, and Lao PDR. These three factors are the causes of the trend of the 1.5-degree carbon budgets pathway of the selected GMS countries in the GDR approach. In terms of fairness, the selected GMS countries cumulatively have an insignificant population and current share of the emissions compared to the world. Thus, the approach that allows for the biggest cumulative carbon budgets and a slower rate of reaching net-zero emissions would be considered to be the appropriate approach to adopt in the selected GMS countries. This would result in fewer effects on economic development in each of the selected countries.

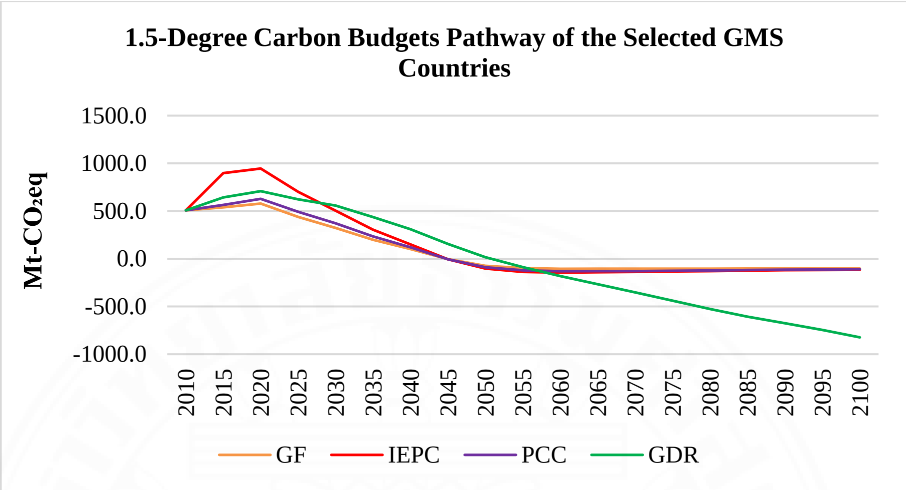

Figure 10.23 1.5-degree carbon budgets pathway of the selected GMS countries based on the four approaches during 2010-2100.

CHAPTER 11
CONCLUSION AND POLICY RECOMMENDATIONS

Two main analyses namely, the electricity planning analysis and the estimation of the emissions gap in the selected Greater Mekong Subregion (GMS) countries are covered in this study. In the electricity planning analysis, this study assesses the impacts of renewable energy (RE), energy efficiency (EE) improvement measures, efficient technologies, and carbon taxation on the electricity demand and generation and the Greenhouse gas (GHG) emissions mitigation in the power sector of the selected GMS countries. In addition, the assessments of energy demand and GHG emissions mitigation potential in the transport sector of the four countries are included as well. In the estimation of the emissions gap, excluding Land-Use Change and Forestry (LULUCF) emissions, for the selected GMS countries, this study seeks to evaluate the emissions gap between the pledged Nationally Determined Contributions (NDCs) targets of the selected GMS countries to the 2-degree and 1.5-degree emissions pathways. Following the emissions gap assessment, the carbon budgets (CO_2 emissions only) estimation are also considered in the study to further investigate the remaining CO_2 emissions allowance until 2050.

A total of three scenarios namely, Business-as-Usual (BAU), Renewable Energy Technologies (RET), and Improved Energy Efficiency (IEE) in the electricity planning analysis are developed in this study. The Low Emissions Analysis Platform (LEAP) model is used to determine the electricity generation, the cost of electricity production, and the GHG emissions in the selected GMS countries. On the other hand, in the emissions gap estimation, the study considers seven scenarios: Baseline, unconditional NDCs (NDC-U), conditional NDCs (NDC-C), doubled targets of conditional NDCs by 2050 (NDC-C-DOU), tripled targets of conditional NDCs by 2050 (NDC-C-TRI), 2-degree emissions pathway (2-D2050), and 1.5-degree emissions pathway (1.5-D2050). In addition, the carbon budgets for the selected GMS countries are evaluated through the use of four effort-sharing approaches namely, Grandfathering (GF), Immediate Per Capita Convergence (IEPC), Per Capita Convergence (PCC), and Greenhouse Development Rights (GDR).

The findings of the study show that the total electricity demand in the selected GMS countries in the IEE scenario could be reduced from the BAU scenario by 4.25% in 2050. The outcomes also suggest that the electricity generated from RE in the RET and IEE scenarios in 2050 would have the shares of 62% and 41.9%, respectively, of the total electricity generation in the four countries. The electric vehicles in the transport sector will cause the electricity demand in the IEE scenario to increase by about 107 times from the BAU scenario in 2050; however, the total energy demand in the transport sector in the selected GMS countries would be reduced by 65.9% in 2050 when compared to the BAU scenario. The GHG emissions mitigation that could be achieved in the power sectors of the selected GMS countries in the RET and IEE scenarios would be 332.98 Mt-CO_2eq and 30.95 Mt-CO_2eq respectively in 2050 when compared to the BAU scenario. The CCS technologies would contribute 67.8% to the total GHG emissions mitigation in the power sector in the RET scenario. In terms of the costs, cost reductions of about 13.1% and 3% are expected in the total electricity generation costs in the RET and IEE scenarios in 2050. Besides, the findings of the MAC study suggest that the solar power plants would be the ideal technology to partially phase out the coal and natural gas power plants in the selected GMS countries in 2050. In the residential sector, the replacements of conventional air conditioners with high-EER air conditioners prove to be the most desirable measure to adopt in the four countries in terms of GHG abatement whereas, in the transport sector, electric LDVs would stand out the most among other measures.

The results of the emissions gap estimation imply that the selected GMS countries, as a whole, will not be able to reach the 2-degree nor the 1.5-degree emissions pathways in both 2030 and 2050 even when the conditional NDCs targets are fully achieved. When considering that the current conditional NDCs targets of the four countries be tripled by 2050, the emissions gap to reach the 2-degree emissions pathway in 2050 would shrink to only 89.9 Mt-CO_2eq. Based on the emissions pathway of the 2-degree target, the total cumulative carbon budgets for the selected GMS countries during 2011-2050 in the GF, IEPC, PCC, and GDR approaches would be 13.71 Gt-CO_2eq, 21.17 Gt-CO_2eq, 17.44 Gt-CO_2eq, and 21.89 Gt-CO_2eq, respectively. In addition to the carbon budgets estimation based on the four effort-sharing approaches, the 2-degree carbon budgets pathway of the selected GMS countries can also be determined based on the approaches. The CO_2 emissions based on the 2°C target in the selected GMS countries are expected to be net-zero by the year 2064 in the GF, IEPC, and PCC approaches and 2058 in the GDR approach. The net-zero emissions years of the selected GMS countries based on the 1.5°C target would be even faster compared to the 2°C target which is 2045 in the GF, IEPC, and PCC approaches and 2051 in the GDR approach.

The impacts of the measures in the RET scenario indicate that the GHG emissions mitigation that can be obtained from the power sector alone already exceeds the total GHG emissions reduction targets in the energy sector of the selected GMS, and even more, is almost equal to the current conditional NDC targets of the four countries. It shows that the RET scenario has a huge potential to contribute to the achievement of the NDCs targets and to reduce the emissions gap in the selected GMS countries. The findings of the emissions gap (excluding LULUCF emissions) estimation in the selected GMS countries show that if the current NDCs targets of the selected GMS countries were to be increased from 2030 onward, the new and more ambitious targets would need to be three-fold higher than the 2030 targets of the NDCs in order to have a chance of reaching the 2°C target in 2050. Moreover, the outcomes of the carbon budgets calculation prove that the annual CO_2 emissions allowance for the selected GMS countries would collectively be only 342.79 Mt-CO_2eq, 529.17 Mt-CO_2eq, 435.98 Mt-CO_2eq, and 547.29 Mt-CO_2eq under the GF, IEPC, PCC, and GDR approaches, respectively. The carbon budgets pathways based on the 2°C and 1.5°C targets imply that the selected GMS countries will not have much time left to reduce their CO_2 emissions to zero. The latest years to do so are 2064 and 2051 based on the 2°C and 1.5°C targets, respectively. The four countries have to start restraining their emissions reduction targets aggressively from now on to achieve the goal of the Paris Agreement.

There are many barriers to the success of the GHG emissions mitigation in the selected GMS countries. For instance, the unstable prices of fossil fuels would leave uncertainties in the decision-making of the policymakers when it comes to phasing out fossil fuel power plants. The price of biomass will likely increase in the future due to limited resources, thus creating a drawback. The deployments of renewable energy power plants such as solar farms and wind farms would affect the land-use which would cause social problems. Therefore, this study would like to give suggestions and recommendations to the policymakers of the individual country as follows:

A. Cambodia and Lao PDR

- Include the demand-side measures into the electricity planning: promote the use of efficient end-use equipment such as LED lamps, high-EER air conditioners, and high-COP refrigerators, etc.
- Increase energy-saving awareness: cut down the limit of knowledge on energy-saving behaviors and technologies of the people.
- Create National Energy Efficiency Rating Label: the national energy efficiency rating label would boost the adoption of efficient end-use equipment.
- Adopt Time-of-Use (TOU) tariff: the TOU tariff rates would be able to restrain the electricity demand in the country.
- Revise master plans, accelerate and increase the deployment of renewable energy power plants: solar farms, hydro, and wind farms are found to be desirable in Cambodia and Lao PDR.
- Set carbon tax: carbon taxation of 9 \$/t-CO_2eq would be a good starting point and suitable in the short-term but a much higher carbon tax would be more preferable in the long-run.
- Provide subsidies to RE: the Feed-in Tariff or Adder program should be considered to attract more investment in Renewable Energy.
- Promote the CCS technologies: the CCS technologies implemented in the coal and natural gas power plants show the huge potential of CO_2 emissions mitigation.
- Develop the transmission and distribution technologies: the power transmission and distribution system have to be advanced enough to be able to implement advanced renewable energy technologies in the future.
- Promote biofuel-fired and electric vehicles: the use of biofuel-fired vehicles (B5 to B20 vehicles for the starting point) will reduce local air pollution, and electric vehicles, especially electric LDVs and motorcycles, show remarkable impacts on GHG mitigation in the transport sector.

- Preparedness of charging stations of electric vehicles: the charging stations for the electric vehicles must be powered by renewable energy power plants, otherwise they will prove inefficient to promote electric vehicles.
- Subsidies on electric and biofuel-fired vehicles: provide imported-tax subsidies on electric vehicles and vehicle-charging subsidies to the owners of electric vehicles. The price of biodiesel should be subsidized to lower than the diesel price and an acceptable rate.
- Promote public transport mode: the shift from private transport mode to the public transport mode such as buses, vans, and trains would cut down a desirable amount of energy demand and emissions in the transport sector.

B. Thailand

- Increase energy-saving awareness: cut down the limit of knowledge on energy-saving behaviors and technologies of the people.
- Accelerate the promotion of No. 5 labeled equipment: Thailand's No. 5 Label is getting acknowledged worldwide, thus the high penetration of No. 5 labeled equipment in the economy-wide sector would be able to reduce the national energy demand.
- Revise master plans, accelerate and increase the deployment of renewable energy power plants: solar farms, hydro, and wind farms are found to be desirable in Thailand.
- Set carbon tax: carbon taxation of 9 \$/t-CO_2eq would be a good starting point and suitable in the short-term but a much higher carbon tax would be more preferable in the long-run.
- Promote the CCS technologies: the CCS technologies implemented in the coal and natural gas power plants show the huge potential of CO_2 emissions mitigation.
- Develop the transmission and distribution technologies: the power transmission and distribution system have to be advanced enough to be able to implement advanced renewable energy technologies in the future.
- Promote biofuel-fired and electric vehicles: the use of biofuel-fired vehicles (B10 to B100 vehicles) will reduce local air pollutions and electric vehicles,

especially electric LDVs and motorcycles, show remarkable impacts on GHG mitigation in the transport sector.

- Preparedness of charging stations of electric vehicles: the charging stations for the electric vehicles must be powered by renewable energy power plants, otherwise they will prove inefficient to promote electric vehicles.
- Ban the use of conventional internal combustion engine (ICE) vehicles: the ban on pure oil-fired ICE vehicles would be the good first step of promoting biofuel, hybrid and electric vehicles. The next step in the long-run would be to ban the use of pure gasoline-fired and diesel-fired ICE vehicles.
- Subsidies on electric vehicles: provide imported tax subsidies on electric vehicles and vehicle-charging subsidies to the owners of electric vehicles. The price of biodiesel should be subsidized to lower than the diesel price and an acceptable rate.
- Promote public transport mode: the shift from private transport mode to the public transport mode such as buses, vans, and trains would cut down a desirable amount of energy demand and emissions in the transport sector.

C. Vietnam

- Include the demand-side measures into the electricity planning: promote the use of efficient end-use equipment such as LED lamps, high-EER air conditioners, and high-COP refrigerators, etc.
- Increase energy-saving awareness: cut down the limit of knowledge on energy-saving behaviors and technologies of the people.
- Create National Energy Efficiency Rating Label: the national energy efficiency rating label would boost the adoption of efficient end-use equipment.
- Revise master plans, accelerate and increase the deployment of renewable energy power plants: solar farms, hydro, and wind farms are found to be desirable in Vietnam.
- Set carbon tax: carbon taxation of 9 \$/t-CO_2eq would be a good starting point and suitable in the short-term but a much higher carbon tax would be more preferable in the long-run.

- Provide subsidies to RE: the Feed-in Tariff or Adder program should be considered.
- Promote the CCS technologies: the CCS technologies implemented in the coal and natural gas power plants show the huge potential of CO_2 emissions mitigation.
- Develop the transmission and distribution technologies: the power transmission and distribution system have to be advanced enough to be able to implement advanced renewable energy technologies in the future.
- Promote biofuel-fired and electric vehicles: the use of biofuel-fired vehicles (B5 to B100) will reduce local air pollutions and electric vehicles, especially electric motorcycles and LDVs, show remarkable impacts on GHG mitigation in the transport sector.
- Preparedness of charging stations of electric vehicles: the charging stations for the electric vehicles must be powered by renewable energy power plants, otherwise they will prove inefficient to promote electric vehicles.
- Ban the use of conventional internal combustion engine (ICE) vehicles: the ban on pure oil-fired ICE vehicles would be the good first step of promoting biofuel, hybrid and electric vehicles. The next step in the long-run would be to ban the use of pure gasoline-fired and diesel-fired ICE vehicles.
- Subsidies on electric vehicles: provide imported tax subsidies on electric vehicles and vehicle-charging subsidies to the owners of electric vehicles. The price of biodiesel should be subsidized to lower than the diesel price and an acceptable rate.
- Promote public transport mode: the shift from private transport mode to the public transport mode such as buses, vans, and trains would cut down a desirable amount of energy demand and emissions in the transport sector.

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APPENDICES

APPENDIX A
LEVELIZED COST OF ELECTRICITY GENERATION

- Cambodia

Unit: $/kWh

Power Plant Type	BAU scenario	RET scenario	IEE scenario
Biomass	0.072	0.068	0.069
Coal	0.047	0.040	0.046
Diesel	0.210	0.175	0.210
Hydro	0.035	0.029	0.032
Natural Gas	0.092	0.090	0.091
Nuclear	-	0.046	-
Solar	0.032	0.029	0.030
Total	0.044	0.039	0.042

- Lao PDR

Unit: $/kWh

Power Plant Type	BAU	RET	IEE
Coal Bituminous	0.035	0.034	0.035
Hydro	0.022	0.022	0.022
Biomass	0.049	0.055	0.049
MSW	-	0.044	-
Solar	0.018	0.018	0.018
Biogas	-	0.064	-
Nuclear	-	0.033	-
Wind	0.025	0.023	0.025
Total	0.023	0.023	0.023

- Thailand

Unit: $/kWh

Power Plant Type	BAU	RET	IEE
Biogas	0.066	0.065	0.066
Biomass	0.046	0.047	0.046
Coal and Lignite	0.038	0.038	0.038
Diesel	0.361	0.341	0.517
Fuel oil	0.196	0.196	0.197
Hydro	0.019	0.019	0.019
MSW	0.076	0.076	0.077
Natural Gas	0.068	0.068	0.067
Nuclear	0.027	0.027	0.028
Solar	0.015	0.015	0.015
Wind	0.019	0.019	0.019
Total	0.045	0.045	0.045

- Vietnam

Unit: $/kWh

Power Plant Type	BAU	RET	IEE
Biomass	0.078	0.073	0.079
Coal	0.048	0.045	0.054
Fuel oil	0.103	0.103	0.103
Hydro	0.020	0.021	0.020
Natural Gas	0.072	0.071	0.067
Nuclear	0.087	0.053	0.090
Solar	0.049	0.031	0.050
Wind	0.047	0.036	0.048
Total	0.047	0.041	0.043

APPENDIX B

MARGINAL ABATEMENT COST IN RESIDENTIAL SECTOR

	GHG Abatement ($Mt\text{-}CO_2eq$)	MAC ($\$/t\text{-}CO_2eq$)
25% Pen. COP-5 Ref. vs Trad. Ref. [LAO]	0.24	-3325.2
LED vs CFL [LAO]	0.02	-3273.02
CFL vs Incan [LAO]	0.06	-959.54
90% Pen. COP-5 Ref. vs Trad. Ref. [VNM]	98.92	-819.93
LED vs LFL [LAO]	0.84	-807.33
60% Pen. COP-5 Ref. vs Trad. Ref. [VNM]	83.28	-600.47
CFL vs Incan [KHM]	0.30	-551.58
LED vs CFL [KHM]	1.30	-514.64
LED vs LFL [KHM]	4.78	-488.35
EER-11.2 Air-Con. vs EER-9 Air-Con. [KHM]	8.19	-480.42
EER-12.8 Air-Con. vs EER-9 Air-Con. [KHM]	12.37	-471.16
25% Pen. COP-5 Ref. vs Trad. Ref. [KHM]	1.63	-419.3
50% Pen. COP-5 Ref. vs Trad. Ref. [KHM]	3.27	-382.92
CFL vs Incan [THA]	10.77	-371.81
75% Pen. COP-5 Ref. vs Trad. Ref. [KHM]	4.13	-363.04
LED vs CFL [THA]	7.28	-324.24
LED vs LFL [THA]	49.88	-314.16
50% Pen. COP-5 Ref. vs Trad. Ref. [THA]	44.45	-262.69
75% Pen. COP-5 Ref. vs Trad. Ref. [THA]	61.34	-249.55
EER-10 Air-Con. vs EER-9 Air-Con. [KHM]	4.18	-226.62
100% Pen. COP-5 Ref. vs Trad. Ref. [THA]	67.99	-203.89
EER-12.9 Air-Con. vs EER-11.6 Air-Con. [THA]	18.36	-174.07
CFL vs Incan [VNM]	100.39	-165.97
LED vs LFL [VNM]	141.67	-139.25
EER-12.8 Air-Con. vs EER-9 Air-Con. [LAO]	0.35	-138.33
EER-14.5 Air-Con. vs EER-11.6 Air-Con. [THA]	27.10	-112.56
EER-13.8 Air-Con. vs EER-11 Air-Con. [VNM]	73.07	-91.85
LED vs CFL [VNM]	58.12	-88.3
EER-15.7 Air-Con. vs EER-11 Air-Con. [VNM]	95.31	-88.11
EER-12.2 Air-Con. vs EER-11 Air-Con. [VNM]	48.92	-81.7
EER-16.5 Air-Con. vs EER-11.6 Air-Con. [THA]	36.14	204.68
EER-11.2 Air-Con. vs EER-9 Air-Con. [LAO]	0.23	547.82
30% Pen. COP-5 Ref. vs Trad. Ref. [VNM]	46.17	612.72
EER-10 Air-Con. vs EER-9 Air-Con. [LAO]	0.12	860.31
75% Pen. COP-5 Ref. vs Trad. Ref. [LAO]	0.51	3898.03
50% Pen. COP-5 Ref. vs Trad. Ref. [LAO]	0.43	4130.6

APPENDIX C

MARGINAL ABATEMENT COST IN COMMERCIAL SECTOR

	GHG Abatement ($Mt-CO_2eq$)	MAC ($\$/t-CO_2eq$)
LED vs CFL [LAO]	0.009	-18308.8
LED vs LFL [LAO]	0.07	-9865.16
LED vs CFL [KHM]	0.43	-469.73
LED vs LFL [KHM]	4.29	-428.09
LED vs CFL [THA]	4.35	-376.4
LED vs LFL [THA]	3.16	-255.97
LED vs CFL [VNM]	0.76	-164.58
LED vs LFL [VNM]	18	-144.8

APPENDIX D

MARGINAL ABATEMENT COST IN TRANSPORT SECTOR

	GHG Abatement ($Mt-CO_2eq$)	MAC ($\$/t-CO_2eq$)
CNG Truck vs Diesel Truck [VNM]	0.17	-2138.8
CNG Truck vs Diesel Truck [THA]	4.43	-2089.23
E10 Motorcycle vs Gas. Motorcycle [THA]	5.23	-1825.75
Electric Vehicle vs Gasoline Vehicle [VNM]	0.37	-1634.1
B20 Bus vs Diesel Bus [LAO]	0.01	-740.8
CNG Truck vs Diesel Truck [KHM]	1.915	-731.66
B20 Bus vs Diesel Bus [VNM]	0.96	-565.7
CNG Truck vs Diesel Truck [LAO]	0.35	-546.74
B20 Bus vs Diesel Bus [THA]	11.14	-529.87
E10 Motorcycle vs Gas. Motorcycle [VNM]	3.51	-457.76
Electric Vehicle vs Gasoline Vehicle [THA]	159.24	-450.86
Electric Bus vs Diesel Bus [THA]	56.17	-271.91
B20 Truck vs Diesel Truck [LAO]	0.33	-241.8
B20 Truck vs Diesel Truck [VNM]	0.25	-209.21
B20 Truck vs Diesel Truck [THA]	9.45	-172.34
E10 Motorcycle vs Gas. Motorcycle [LAO]	0.06	-144.97
Electric Bus vs Diesel Bus [KHM]	0.091	-144.63
Electric Bus vs Diesel Bus [VNM]	7.36	-107.95
Electric Vehicle vs Gasoline Vehicle [KHM]	21.496	-16.4
E20 Vehicle vs Gasoline Vehicle [KHM]	5.004	5
B20 Truck vs Diesel Truck [KHM]	2.713	91.01
B20 Bus vs Diesel Bus [KHM]	0.016	331.17
Electric Vehicle vs Gasoline Vehicle [LAO]	0.51	411.05
Elec. Motorcycle vs Gas. Motorcycle [KHM]	15.133	1374
E20 Vehicle vs Gasoline Vehicle [THA]	42.59	1548.02
Elec. Motorcycle vs Gas. Motorcycle [THA]	46.46	1609.66
E10 Motorcycle vs Gas. Motorcycle [KHM]	2.113	2122.12
E20 Vehicle vs Gasoline Vehicle [LAO]	0.17	2500.2
Electric Bus vs Diesel Bus [LAO]	0.05	2634.12
Elec. Motorcycle vs Gas. Motorcycle [VNM]	42.31	4975.7
Elec. Motorcycle vs Gas. Motorcycle [LAO]	0.18	15070.72
E20 Vehicle vs Gasoline Vehicle [VNM]	0.14	17267

APPENDIX E

MARGINAL ABATEMENT COST IN POWER SECTOR

	GHG Abatement ($Mt-CO_2eq$)	MAC ($\$/t-CO_2eq$)
Solar-Thailand	76.35	-163.33
Wind-Thailand	76.35	-157.89
Hydro-Thailand	76.35	-150.71
Biomass-Thailand	76.35	-97.31
Nuclear-Thailand	76.35	-82.16
Solar-Cambodia	19.73	-73.97
MSW-Thailand	76.35	-59.35
Solar-Vietnam	207.07	-41.28
Wind-Vietnam	207.07	-41.24
Biomass-Cambodia	19.73	-15.16
Hydro-Vietnam	207.07	-11.11
Biomass-Vietnam	207.07	16.11
Hydro-Cambodia	19.73	17.7
Nuclear-Vietnam	207.07	18.94
Nuclear-Cambodia	19.73	49.83
Solar-Lao PDR	0.64	148.34
Wind-Lao PDR	0.54	227.55
Hydro-Lao PDR	0.23	314.55
MSW-Lao PDR	0.54	482.19
Biomass-Lao PDR	0.64	671.07
Nuclear-Lao PDR	0.32	821.5

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