ASEAN Green Future Project Phase 2.2 Report

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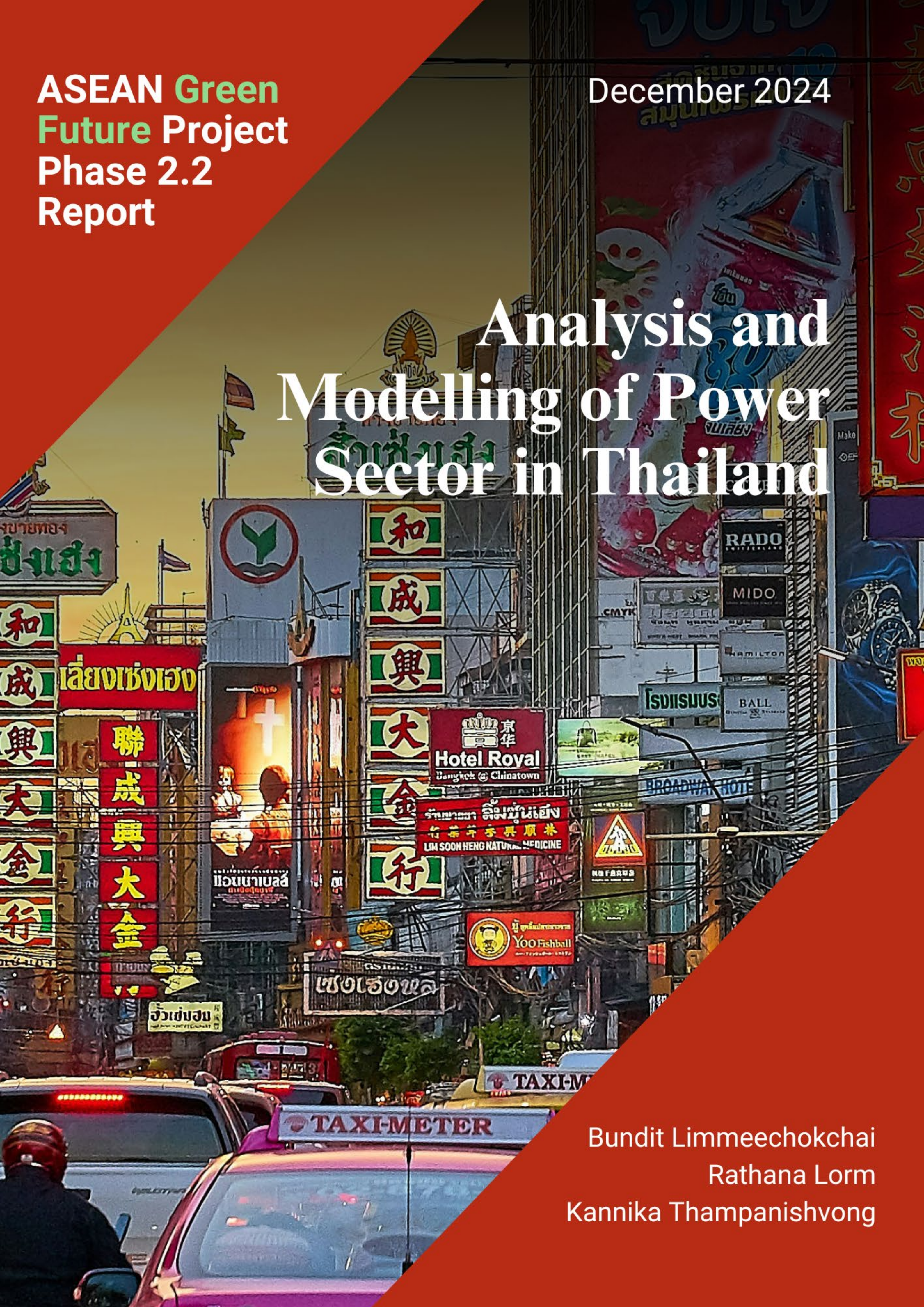

Analysis and Modelling of Power Sector in Thailand

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About ASEAN Green Future

ASEAN Green Future is a multi-year regional research project that involves the UN Sustainable Development Solutions Network (SDSN), Climateworks Centre and nine country teams from leading universities and think tanks across Southeast Asia (Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand and Vietnam). The researchers undertake quantitative and qualitative climate policy analysis and develop net zero pathways to inform policy recommendations and support the strategic foresight of policy makers.

The Phase 1 country reports present priorities and actions to date, and key technology and policy opportunities to further advance domestic climate action. The Phase 1 regional report positions Southeast Asia's low carbon transition pathways within a global context using the country reports and other studies. This series of reports, produced through a synthesis of existing research and knowledge, builds the case for advancing the region's climate agenda. Phase 2 of the ASEAN Green Future project uses modelling to quantitatively assess the different decarbonisation pathways for Southeast Asia. The analysis of the Phase 2.2 report presents the increasing ambition of countries to achieve the near zero emission pathways.

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Disclaimer

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[1] Heaps, C.G., 2022. LEAP: The Low Emissions Analysis Platform. [Software version: 2020.1.107] Stockholm Environment Institute. Somerville, MA, USA. https://leap.sei.org

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION TO THAILAND

Thailand is in the center of the Southeast Asian mainland, bordered by Cambodia, Lao PDR, Malaysia, and Myanmar. The total population in the country increased at an average growth rate of 0.69% (United Nations, 2022), rising from 62.77 million in 2000 to 71.03 million in 2018. As of 2018, 49.94% of the total population resided in urban areas (United Nations, 2018). Thailand is the second-largest economy among the ASEAN countries, and the gross domestic product (GDP) has increased by 3.63% average annual growth rate between 2000 and 2018 (World Bank, 2023). In 2018, the total GDP in Thailand accounted for 1,172.34 billion U.S. dollars in Purchasing Power Parity ($PPP), while the per capita income stood at 16.50 thousand $PPP (World Bank, 2023).

The energy sector, especially electricity, plays a key role in boosting the country's economy and urbanization. Therefore, the growth of electricity demand is influenced by multiple factors such as GDP and population size (Kandananond, 2011). The increase in energy prices and the unsustainable of fossil fuel resources over the years have emerged as significant challenges for every nation. On the other hand, dependency on fossil fuels leads to the production of a massive amount of greenhouse gas (GHG) emissions, posing a significant threat to global warming and severely affect the environment of all nations, particularly those most vulnerable to climate change, like Thailand and other ASEAN nations. Therefore, projecting future electricity demand and generation is necessary to maintain the balance between demand and supply growth, minimize environmental impacts, and ensure energy security aligns with sustainable development goals.

2. HISTORICAL ENERGY CONSUMPTION, ELECTRICITY DEMAND, POWER GENERATION, AND GHG EMISSIONS

2.1 Historical Trends of Energy Consumption

Energy plays a vital role in developing a country. Between 2000 and 2018, the total final energy consumption (TFEC) increased from 47,789 thousand tonnes of oil equivalent (ktoe) to 83,955 ktoe, with an average annual growth rate of 3.20% (DEDE, 2020b). In 2018, the transport sector alone consumed 39.41% of the TFEC, followed by the industrial sector (36.26%), residential sector (13.10%), commercial sector (7.8%), and agricultural sector (3.43%) (see Figure 2.1).

According to the report on the energy balance of Thailand 2020 (DEDE, 2020b), the TFEC comes from fossil fuels (oil or petroleum products, natural gas, and coal), followed by electricity and biomass. As shown in Figure 2.2, in 2018, the final energy consumption from oil products was approximately 41.38 Mtoe, followed by electricity (16.81 Mtoe), biomass (13.13 Mtoe), coal products (6.87 Mtoe), and natural gas (5.77 Mtoe), respectively.

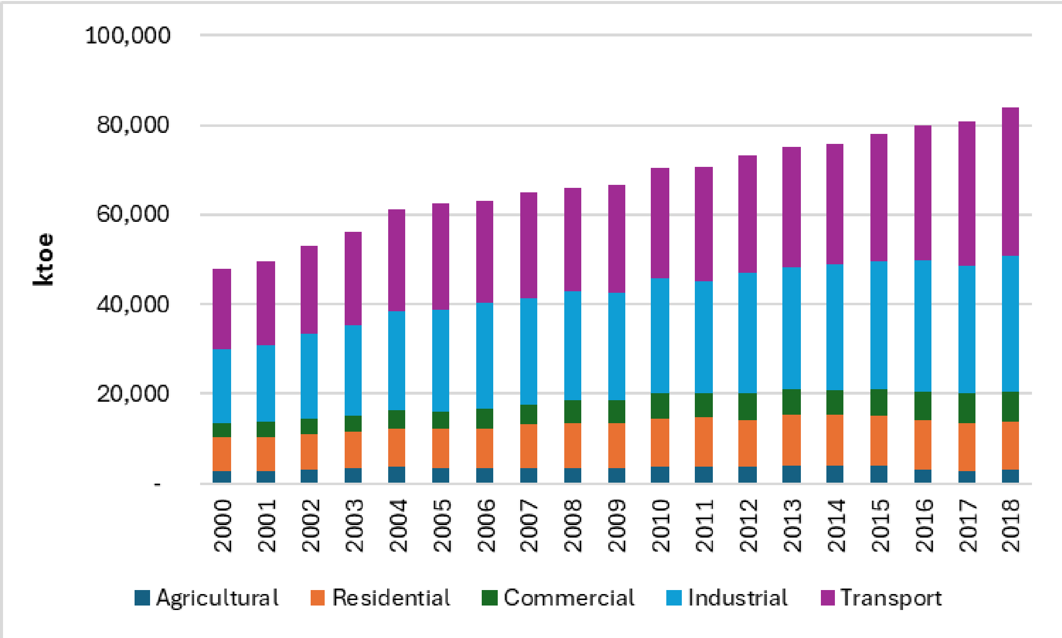

Figure 2.1: Historical energy consumption by sector (DEDE, 2020b)

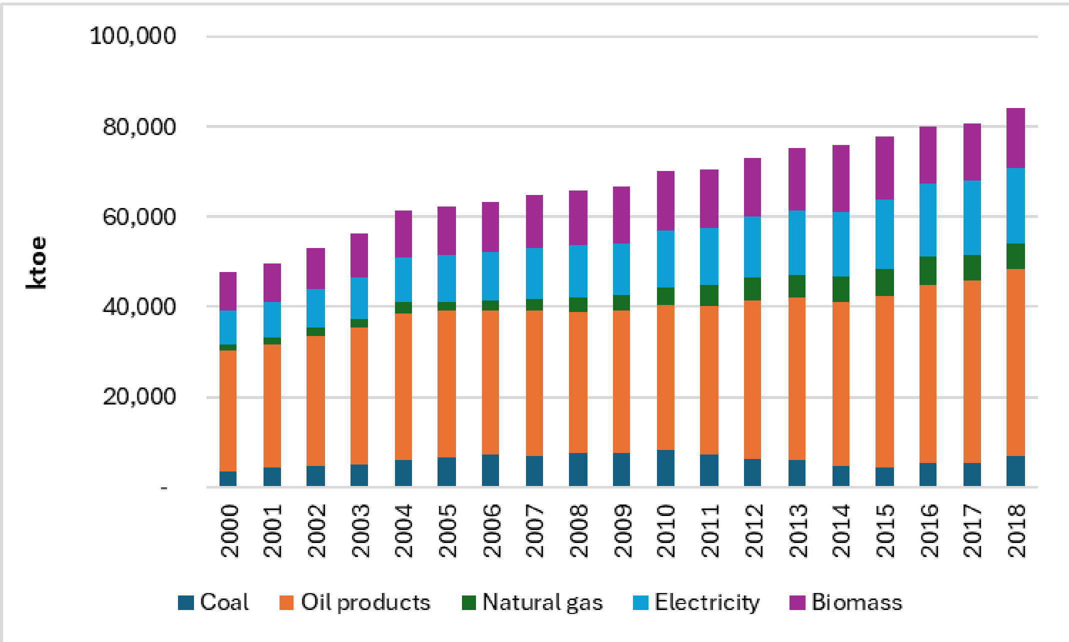

Figure 2.2: Historical energy consumption by fuel type (DEDE, 2020b)

2.2 Historical Trends of Electricity Demand

The total electricity demand in Thailand has tremendously increased between 2000 and 2018, with an average growth rate of 4.63% per annum, from 87.20 TWh to 195.44 TWh (EPPO, 2023a). In 2018, the share of electricity consumption by sector showed that the industrial sector consumed around 41.39% of the country's total electricity consumption. The building sector, including the residential and commercial sectors, utilized 23.01% and 35.31%, respectively, of the total electricity demand. On the other hand, electricity consumption in the transport sector was too small compared to other sectors, which accounted for 0.11% due to the limited use of electric vehicles (EPPO, 2023a). Other sectors, such as public lighting, agriculture, and public buildings, contribute to the rest of electricity consumption. Figure 2.3 illustrates the trend of sectoral electricity demand from 2000 to 2018.

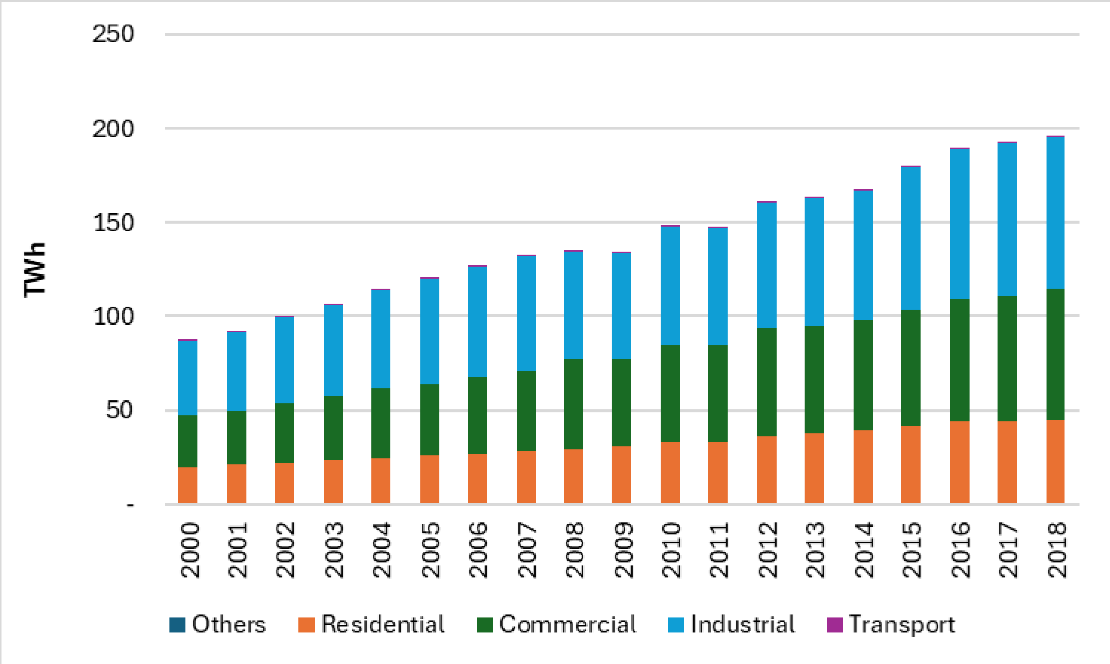

Figure 2.3: Historical electricity demand by sector (EPPO, 2023a)

2.3 Power Generation and Installed Capacity

The electricity generation in Thailand has grown tremendously from 80.44 TWh in 2000 to 204.43 TWh in 2018, according to the electricity statistics for 2023 of the Energy Policy and Planning Office (EPPO), Ministry of Energy (EPPO, 2023a). Electricity generation in Thailand relies on natural gas, coal, and hydropower. In 2018, natural gas accounted for 56.87% of the total electricity generation mix, followed by coal at 17.51%, hydropower at 3.72%, other renewable energy at 8.77%, imported electricity from Lao PDR and Malaysia at 13.04%, and other oil products at 0.09% (see Figure 2.4).

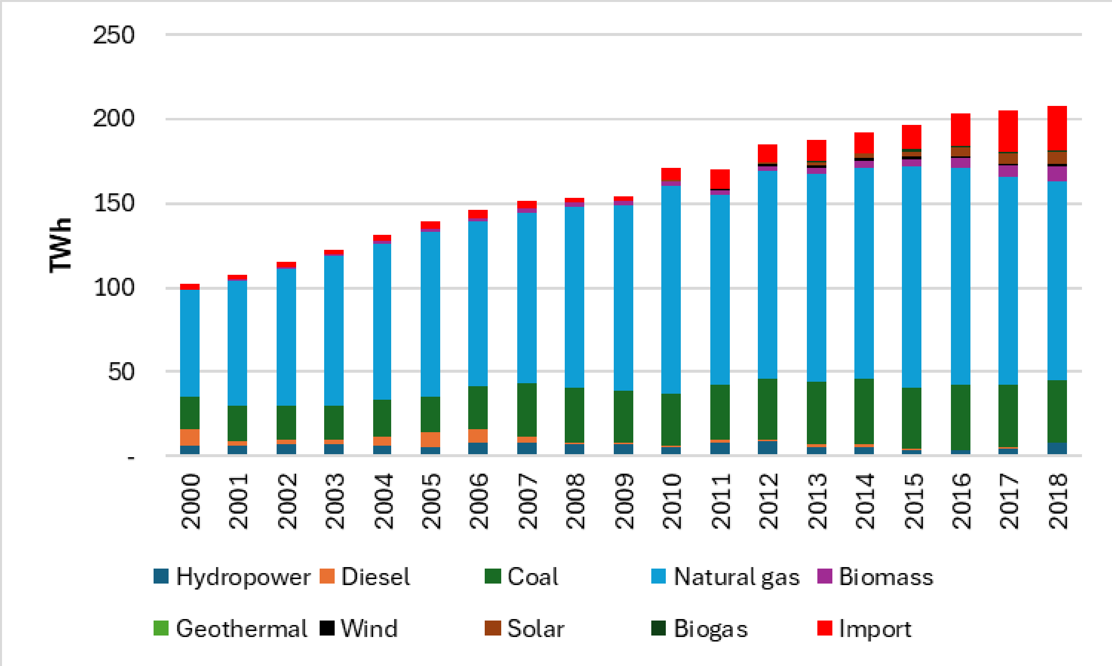

Figure 2.4: Historical power generation by fuel type (EPPO, 2023a)

The total installed capacity of power plants in Thailand shows a remarkable increase due to the growth of electricity demand in the country. The total capacity of power generation increased by approximately 201% between 1995 (14,441 MW) and 2018 (43,374 MW) (EPPO, 2023a). In 2018, the installed capacity of natural gas power plants was 24,837 MW, followed by coal power plants with 4,637 MW. However, the total capacity of RE was 8,586 MW, consisting of hydropower (3,282 MW), solar (2,967 MW), biomass (2,257 MW), wind (1,081 MW), and biogas (80 MW). The remaining 3,878 MW and 355 MW of installed capacity originated from neighboring countries and diesel/oil power plants, respectively (see Figure 2.5).

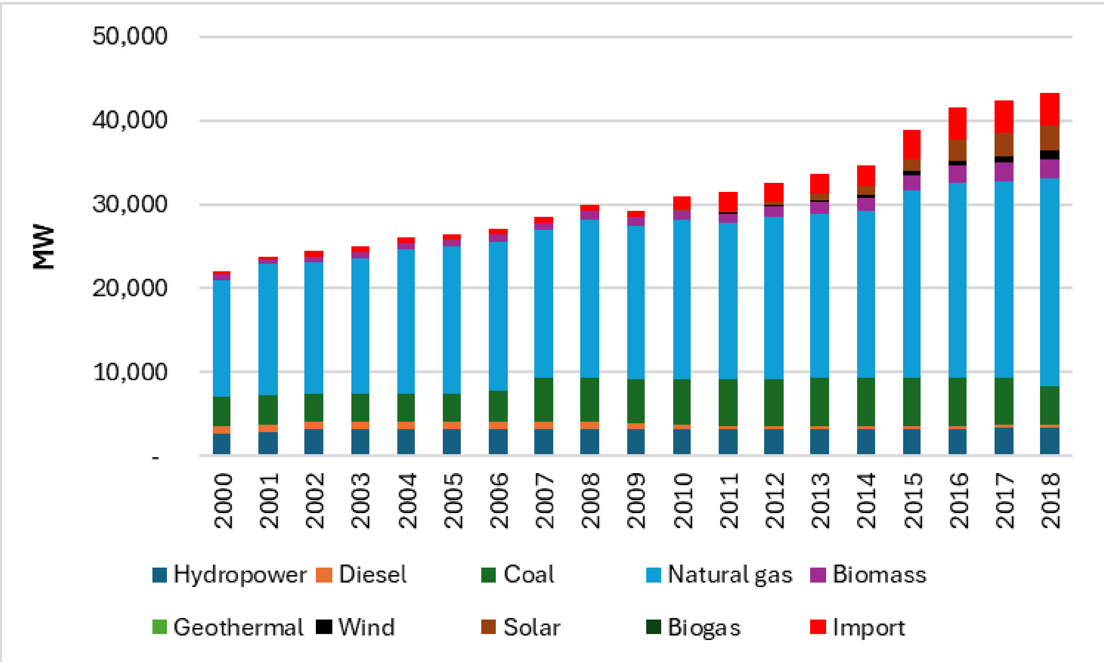

Figure 2.5: Historical installed capacity by fuel type (1995-2018)

2.4 Historical GHG Emissions from the Energy Sector and Power Generation

The Fourth Biennial Update Report of Thailand indicates the trend of GHG emissions in the energy sector has increased from 165 $MtCO_2eq$ in 2000 to 257 $MtCO_2eq$ in 2018 (MoNRE, 2023). Of the amount of emissions in 2018, the transport and power sectors contributed the highest emissions, emitting 95 $MtCO_2eq$ and 100 $MtCO_2eq$, respectively. The industrial sector, the third highest emissions contributor, emitted 46 $MtCO_2eq$ in the country, followed by the others (8 $MtCO_2eq$), the residential sector (6 $MtCO_2eq$), and the commercial sector (2 $MtCO_2eq$) (see Figure 2.6).

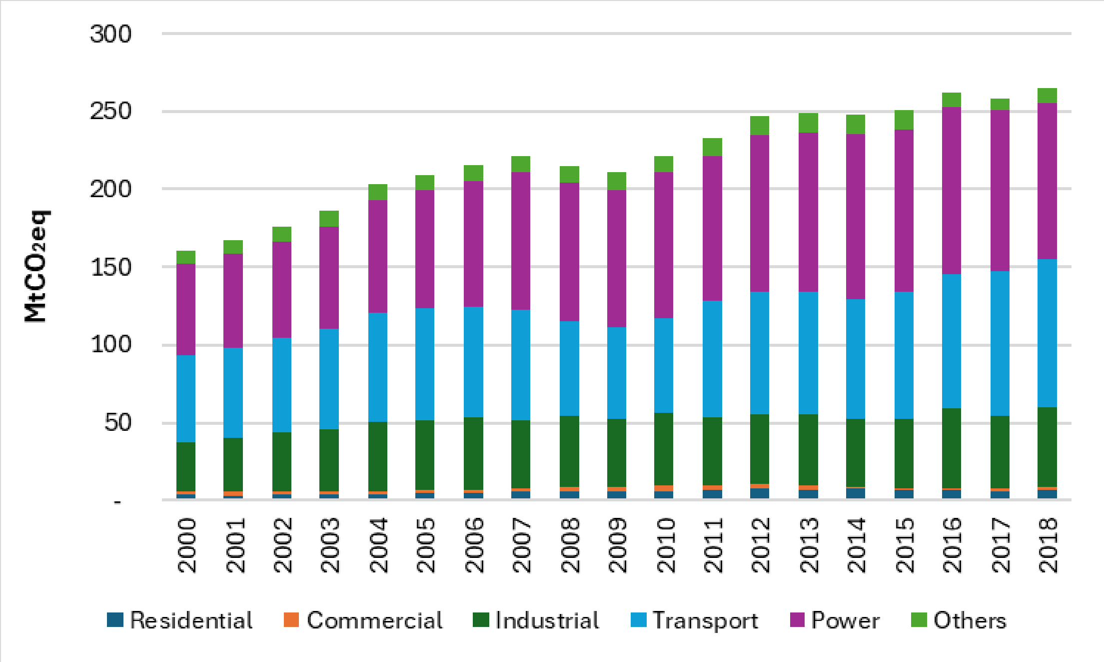

Figure 2.6: Historical GHG emissions from the energy sector (MoNRE, 2023)

In the power sector, the main sources of emissions are coal, natural gas, and diesel power plants. Figure 2.7 demonstrates that the power sector in Thailand has produced a heavy amount of GHG emissions, from 62 MtCO2eq in 2000 to 100 MtCO2eq in 2018 (EPPO, 2023b). In 2018, coal and natural gas power plants accounted for 50% and 49% of the total emissions, respectively, while the remaining 1% was emitted by diesel power plants.

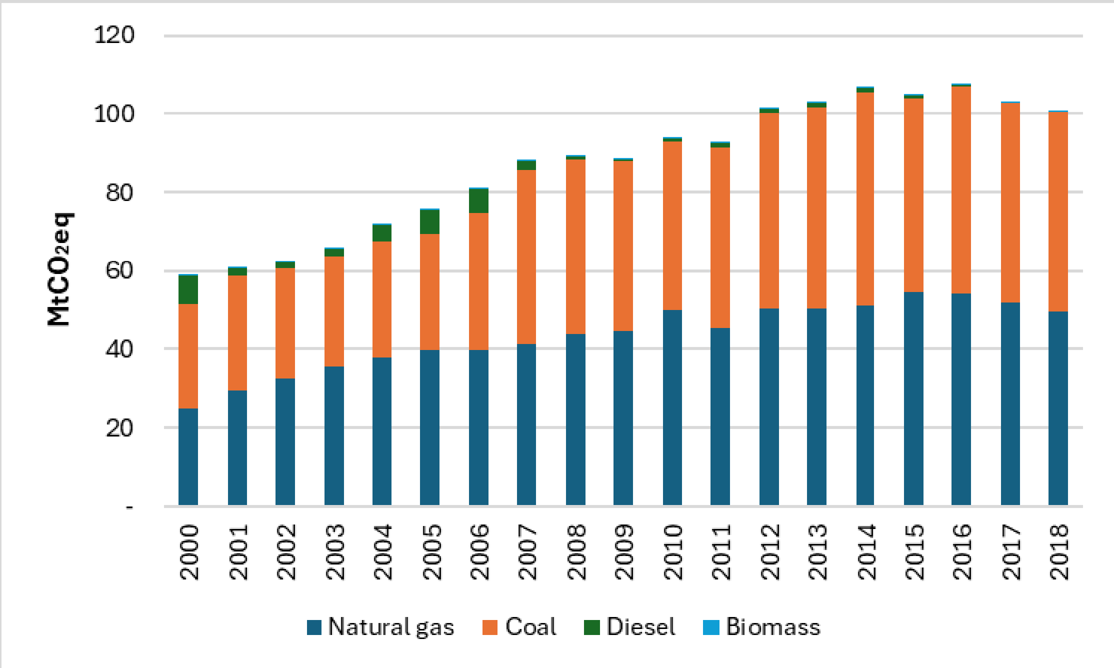

Figure 2.7: Historical GHG emissions from electricity generation (EPPO, 2023b)

3. METHODOLOGY

3.1 Low Emissions Analysis Platform (LEAP) and the Next Energy Modelling System for Optimization Model (NEMO)

The Stockholm Environment Institute (SEI) developed the Low Emissions Analysis Platform (LEAP) software to evaluate energy policy and climate change management (Heaps, 2022). LEAP is structured as a hierarchical tree, allowing the input of historical data and assumptions for the future, to analyze the Demand, Transformation, Resource, and Environmental dimensions. The LEAP model can be classified as a flexible tool for tracking energy consumption and supply of all economic sectors and GHG emissions from both energy and non-energy sectors. It is suitable for designing energy policies.

SEI has lately implemented an integrated model for LEAP, namely the Next Energy Modeling System for Optimization (NEMO) (SEI, 2023). NEMO is a powerful tool developed in the Julia programming language that supports and allows users to add emission constraints together with renewable energy target settings to meet their maximum potential. Furthermore, this tool comprises multiple popular optimization calculation solvers, including Cbc, CPLEX, GLPK, Gurobi, HiGHS, Mosek, and Xpress.

3.2 Scope of the Study

The scopes of this study are illustrated as follows:

- The study focuses on the power sector, including both the supply side (electricity generation) and the demand side (electricity consumption in the residential, commercial, industrial, and transportation sectors).
- Thailand's historical data ranges from 2000 to 2018 due to the data limitation, and the first scenario year begins in 2019 towards the end year of 2060.
- The data is gathered from reliable sources such as official reports and documents from the government as well as online databases from official organizations (World Bank, World Health Organization, Global Data Lab, etc.).

3.3 Key Drivers for the Energy Demand Projections

There are some main drivers for the energy demand projections, including GDP, population, household electrification, appliance ownership, energy intensity, and sectoral value-added.

- **Gross Domestic Product (GDP):** In this study, the projection of Thailand’s GDP is gathered from the Share Socioeconomic Pathway scenarios, projected by the International Institute for Applied Systems Analysis (IIASA). The GDP projection in the 2nd Shared Socioeconomic Pathway scenario (SSP2) indicates the best fit to the current situation of Thailand’s economy; therefore, the SSP2 is selected to be the key driver for the energy demand projections (IIASA, 2023). The total GDP of Thailand is estimated to increase by 3.00% per year between 2018 and 2060 (IIASA, 2023). The total GDP in Thailand would be 4,096.8 billion $PPP in 2060 (see Figure 3.1).

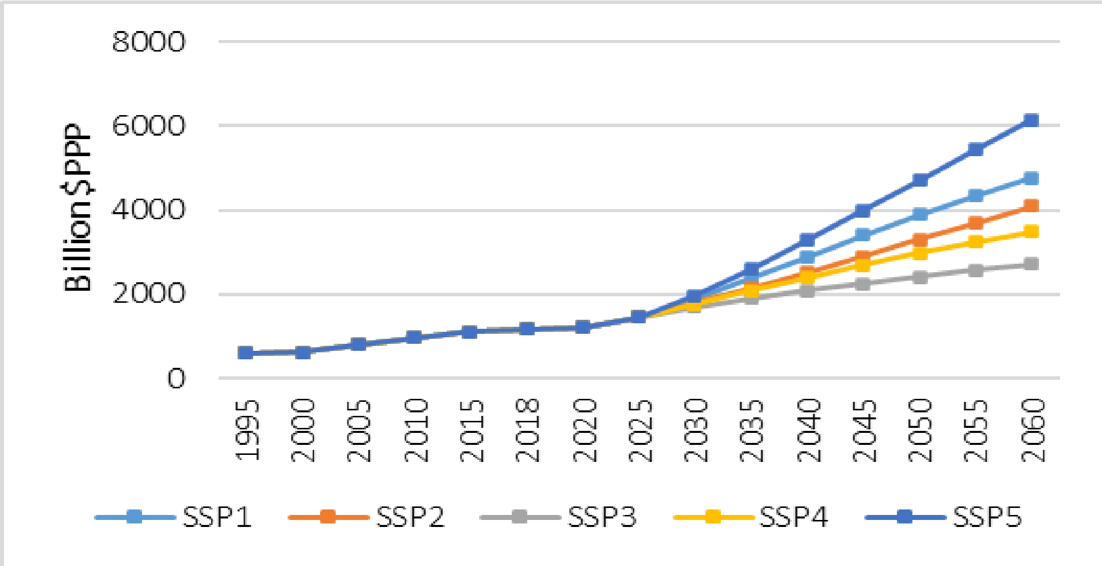

Figure 3.1: GDP projections

- **Population:** The medium scenario of world population prospects 2022, forecasted by the United Nations, illustrates that the average annual growth rate of population in Thailand between 2018 and 2060 will be -0.26% (United Nations, 2022). The total population of Thailand is estimated to be around 63.61 million people by 2060 (see Figure 3.2).

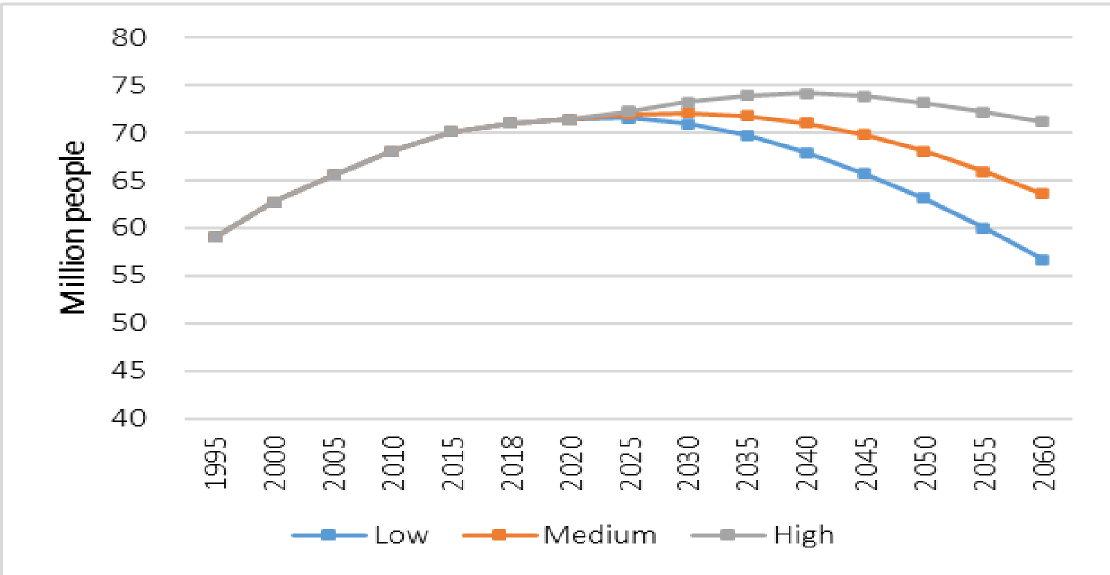

Figure 3.2: Population projections

- **Household numbers and Urbanization Growth:** Number of households is forecasted proportionally to the number of populations in the country divided by the number of people per household. The assumption of people per household is derived from the historical trend from the National Statistics Office report (NSO, 2023a). Besides this, the urbanization growth is gathered from the World Urbanization Prospects 2018 forecasted by the United Nations (United Nations, 2018). Therefore, the total number of households in Thailand in 2060 would be 23.13 million, an increase of one million from 2018, while urbanization in the country would increase from 49.94% in 2018 to approximately 74.35% in 2060 (see Figure 3.3).

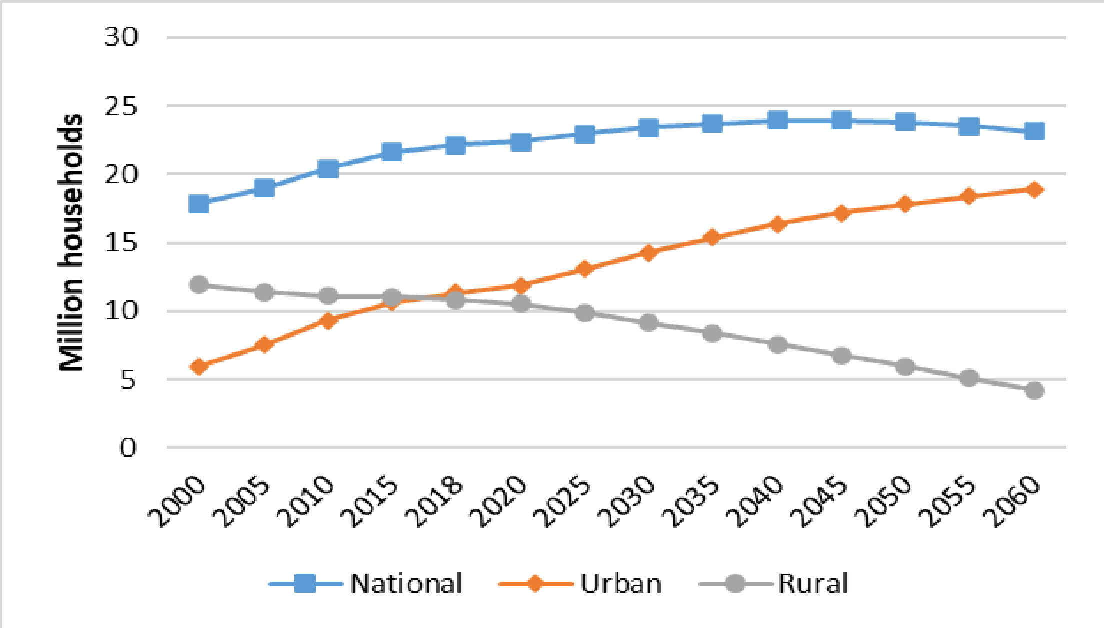

Figure 3.3: Household numbers and urbanization projections

- **Household electrification:** From the data in the world development indicator of the World Bank (World Bank, 2023) and the Thailand Annual Statistics Report (NSO, 2023b), the residential sector of Thailand achieved 100% electrification in 2020.

- **Appliance ownership:** The ownership of appliances in the residential sector can be found in the Household Socio-Economic Survey (NSO, 2023a).

- **Energy intensity:** Refers to the energy consumption per unit of activity such as economic output (GDP), households, and vehicles. In the commercial sector, industrial sector, and other sectors, historical energy intensity is used to forecast the future of energy demand in the respective sectors.

- **Sectoral value-added:** Refers to the GDP contribution to the country from different economic sectors, such as the commercial, industrial, and agricultural sectors. The sectoral value-added can be found in the World Development Indicators (World Bank, 2023) and in the Thailand Annual Statistics Report (NSO, 2023b). The projection of the share of sectoral value added to GDP is made based on the historical trend taken from these sources. As shown in Figure 3.4, the share of GDP from the commercial sector is steadily increasing from 55.71% to 66.49% between 2018 and 2060, whereas the share of the industrial sector in the GPD contribution drops from 35.27% to 30.10%. The remaining share of sectoral value added to the country's GDP comes from the agricultural sector.

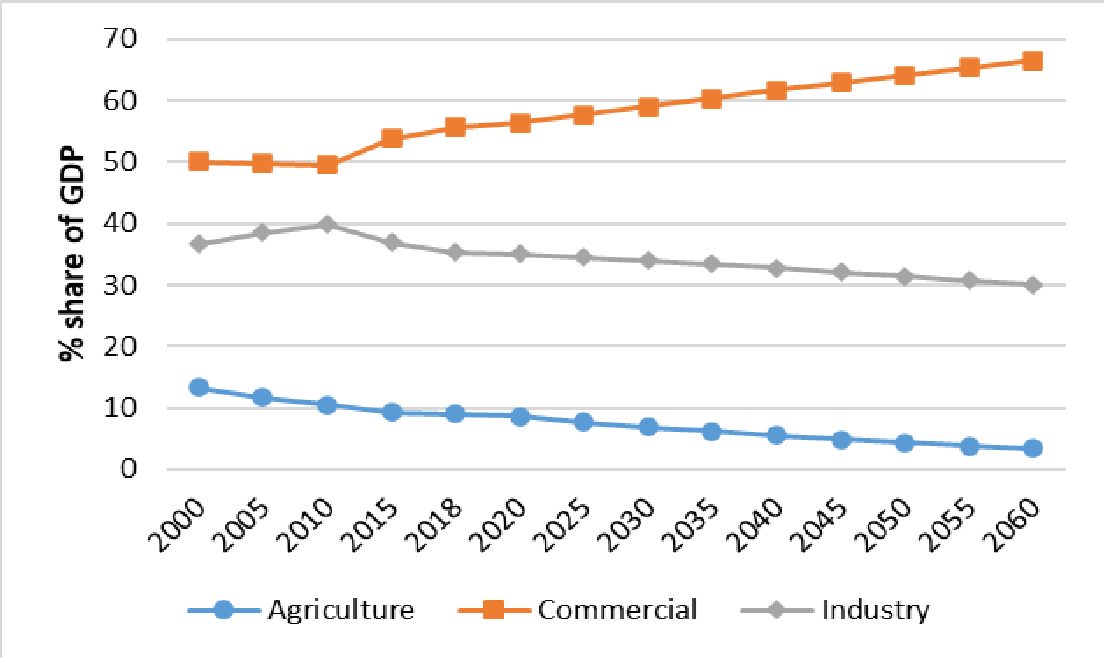

Figure 3.4: Projections of the share of sectoral value-added to the GDP

- **Number of vehicles:** The projection of number of vehicles in Thailand is estimated by multiplying the vehicle ownership per capita by the number of populations, where the vehicle per capita is calculated by using the linear regression model between the historical number of vehicle per capita as a dependent variable and income per capita as an independent variable. Furthermore, the share of types of vehicles in the future is also projected based on historical trends. The historical number of vehicles and share of vehicles are extracted from the statistics report of the Transport Statistics Group 2023 of the Department of Land Transport (DLT, 2023). By 2060, the total number of vehicles is estimated to be around 50 million, which is a 26% increase compared to 2018. The estimations suggest that cars, motorcycles, buses, and trucks will account for approximately 41.71%, 53.35%, 0.41%, and 4.51% of the total number of vehicles in 2060, respectively.

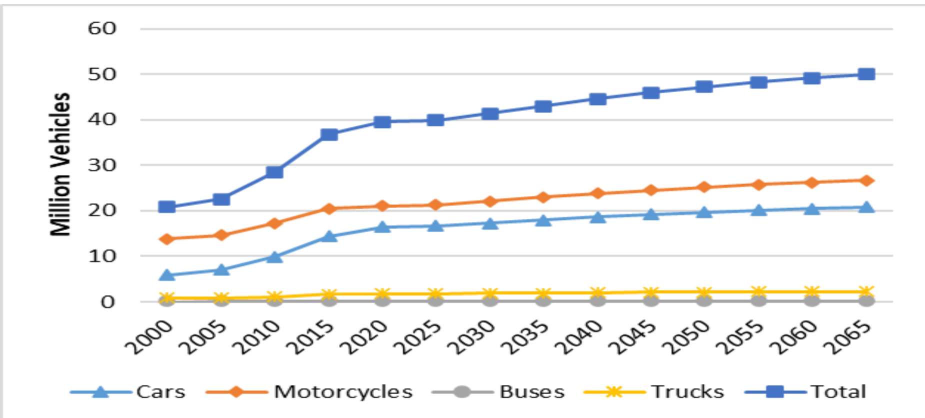

Figure 3.5: Projections of number of vehicles

4. EXISTING POLICY (EXT) SCENARIO

4.1 Description of the Existing Policy Scenario

The Existing Policy (EXT) scenario development in this study is influenced by the current energy policy and development plan from the Thai government, such as the Energy Efficiency Plan 2018–2037 (EEP2018), the Alternative Energy Development Plan 2018–2037 (AEDP2018), and the Power Development Plan 2018–2037 (PDP2018) (DEDE, 2020c; DEDE, 2020a; EPPO, 2020). Since the target year in the existing policies is set to be 2037, in this EXT scenario, the target of energy efficiency (EE) improvement measures as well as the target of renewable energy (RE) promotion are assumed to be the same as the target in 2037 of the government plans.

a) Residential Sector

Forecasting energy demand in the residential sector involves multiplying the energy intensity of each appliance with the activity data (number of households). In the residential sector, under the Existing Policy scenario, the Energy Efficiency Plan 2018–2037 (EEP2018) (DEDE, 2020c) is integrated into the demand projection. There are three main measures to be implemented, comprising light-emitting diode (LED) lighting, energy labeling, and energy efficiency resource standards (EERS). The total energy savings from the implementation of the EEP2018 in 2037 will be 3,300 ktoe. The assumptions of energy efficiency measures in the residential sector are illustrated below:

- **Deployment of LED lighting:** The LED lamps will replace conventional lamps. It is assumed that in 2018, no households have LED lamps. In 2037, it is expected that 70% of households will switch from conventional lamps to LED light bulbs.

- **Implementation of energy labelling:** It is expected that the share of efficient air-conditioning and refrigerators will increase from zero percent in 2018 to 30% in 2037.

- **Implementation of energy efficiency resource standards (EERS):** It is expected that the conventional appliances in other services will be fully replaced by the efficient ones in 2037.

b) Commercial Sector

In the commercial sector, the projection of energy demand is estimated by using the growth of GDP and share value-added from this sector. Additionally, in this scenario, there will be an integration of the government's energy development plan, namely the Alternative Energy Development Plan 2018–2037 (AEDP2018) (DEDE, 2020a). The key measure in the commercial sector is the utilization of solar in cooling and heating systems. There are five measures in the EEP2018 (DEDE, 2020c), including LED lighting, energy labeling, EERS, designated buildings, and building energy codes. The implementation of renewable energy and energy efficiency enhancement are assumed as follows:

- **Implementation of renewable energy:** The application of solar in cooling and heating services is expected to increase from 0.15% in 2018 to 2% in 2037 (DEDE, 2020a).
- **Implementation of energy efficiency improvements:** It is expected that the total energy savings in the commercial sector will be 6,418 ktoe by 2037 (DEDE, 2020c).

c) Industrial Sector

The implication of GDP share from the industrial sector is utilized to estimate future energy consumption in this sector. Furthermore, under this scenario, there would be integration with the AEDP2018 and EEP2018 plans from the government. The AEDP2018 plan aims to increase the share of renewable energy to replace the utilization of coal and oil products in the industrial sector (DEDE, 2020a). The EEP2018 plan consists of four measures, including LED deployment, energy labelling, EERS, and designated factories (DEDE, 2020c). The following points show the assumptions of the EXT scenario in the industrial sector:

- **Implementation of renewable energy:** The share of biomass and solar in the industrial sector will increase from 26% in 2018 to 30% in 2037.
- **Implementation of energy efficiency improvements:** Energy efficiency improvements will decrease the amount of total energy consumption by 21,137 ktoe in 2037 in this sector.

d) Transport Sector

Energy demand in the transport sector is forecasted based on the number of vehicles and average travel distance of vehicle fleet (kilometer per vehicle per year). The projections of the number of vehicles are estimated as indicated in Figure 3.5. The distance driven by each type of vehicle is based on assumptions, such as assuming that in 2018, cars, motorcycles, buses, and trucks covered approximately 12,000 kilometers per vehicle per year (km/veh/yr), 5,000 km/veh/yr, 18,000 km/veh/yr, and 12,000 km/veh/yr, respectively. It is assumed that the travel distance of each type of vehicle will increase proportionately with the rise in income. Therefore, by 2060, the average distance driven by cars, motorcycles, buses, and trucks is expected to increase to 20,000 km/veh/yr, 10,000 km/veh/yr, 26,000 km/veh/yr, and 20,000 km/veh/yr, respectively.

In the projection of energy demand in this sector, the EEP2018 plan would be included. This strategy aims to decrease energy consumption in the transport sector through fuel economy and efficiency enhancement in the internal combustion engine (ICE) vehicles. With the increasing fuel economy efficiency of ICE vehicles, the total amount of energy savings in the transport sector will be 17,682 ktoe in 2037 (DEDE, 2020c).

Under the latest Long-Term Low Emissions Development Strategy (LT-LEDS), Thailand aims to achieve 30% of light-duty vehicle penetration into road passenger transport by 2030 (ONEP, 2022).

e) Power Sector

Based on the Renewable Energy Outlook of ASEAN 2020 (IRENA & ACE, 2022), Thailand has a significant potential for RE, including solar PV, onshore and offshore wind, biomass, and hydropower. The total potential capacity of the RE in Thailand is around 3,604 GW, consisting of Solar PV (3,509 GW), Onshore wind (32.4 GW), Offshore wind (29.4 GW), Biomass (18 GW), and Hydro (15 GW).

The Ministry of Energy of Thailand has formulated policies for electricity, namely the Power Development Plan 2018–2037 (PDP2018) (EPPO, 2020). The objective is to maintain the following aspects: (1) Energy Security, (2) Economy, and (3) Ecology.

The PDP2018 commits to increasing the share of RE installed capacity (including hydropower/import hydropower from Lao PDR) from 21% in 2018 to around 47% (37% domestically) in 2037. It is assumed that the share of RE installed capacity in 2060 corresponds to the target in 2037. The total installed capacity in 2060 is assumed to increase based on the trend from the PDP2018.

Table 4.1: Installed capacity in the Existing Policy scenario

Power plants	2018	2020	2025	2030	2037	2060
Import*	3,878	5,721	6,235	7,509	8,661	9,000
Natural gas	24,837	29,084	33,186	33,224	32,112	47,000
Coal	4,637	6,110	6,2080	6,307	6,505	7,000
Diesel	355	380	380	380	65	65
Hydro	3,282	4,073	4,105	4,105	4,105	4,105
Biomass	2,257	2,333	3,712	3,374	5,522	11,500
Solar	2,967	3,022	3,608	7,936	14,754	26,000
Wind	1,081	1,488	1,774	1,774	2,989	6,000
Biogas	80	666	1,165	1,165	1,565	2,600
Total	**43,374**	**52,577**	**60,374**	**65,775**	**76,279**	**113,270**

Unit: MW
Note: *the import of electricity from neighboring countries (Lao PDR, Myanmar, and Malaysia)

4.2 Results of the Existing Policy Scenario

a) Sectoral Electricity Demand

The results in the Existing Policy scenario for Thailand indicate that the total electricity consumption is projected to increase from 195 TWh in 2018 to approximately 562 TWh in 2060 (see Figure 4.1). The sectoral growth of electricity demand shows that the industrial sector would have the highest share of electricity, estimated to be 49% of total demand due to the increase in industry electrification. Besides this, the commercial sector has the second-largest consumption of electricity, which is estimated to account for 30% of the total 2060 electricity demand. The high demand in the commercial sector indicates that this sector uses electricity for all the building equipment. The transport sector jumps up to be the third-highest demand for electricity owing to the penetration of electric vehicles. Calculations estimate that this sector consumes 11% of the total electricity. Additionally, projections indicate that the residential sector will have the fourth largest electricity consumption, accounting for around 10% of the total. The electricity demand in this sector is comparatively low compared to others due to the drop in the total number of households and the decreasing population in the future. The remaining electricity demand will be absorbed by other sectors.

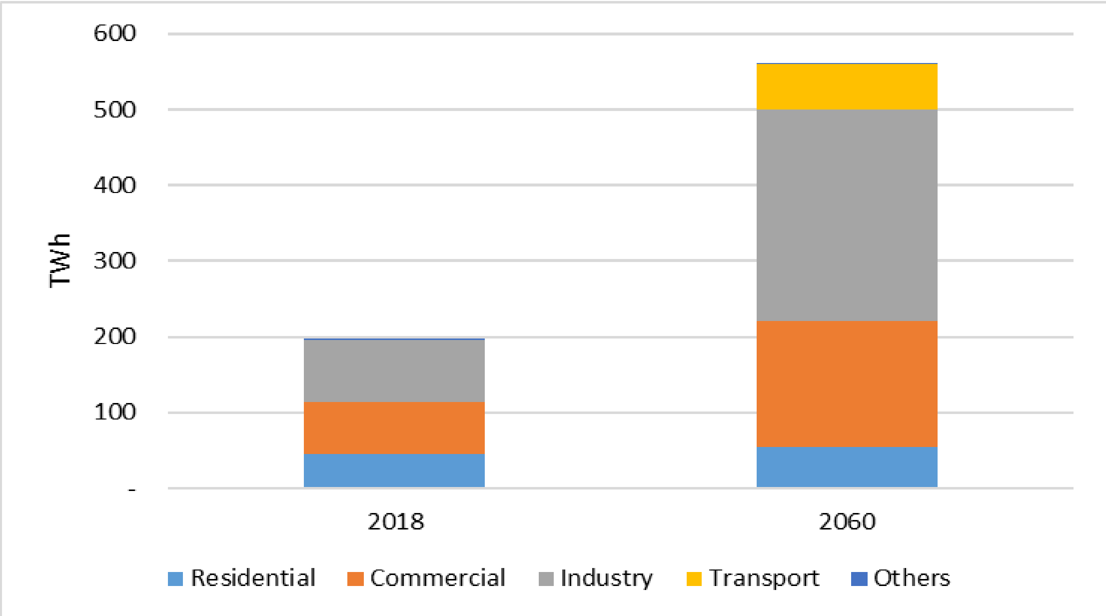

Figure 4.1: Electricity consumption by sector in the EXT scenario

b) Electricity Generation

Electricity generation will significantly expand from 204.43 TWh to 609.73 TWh between 2018 and 2060. During this study period, natural gas is expected to maintain the highest share of power production. In 2060, the share of natural gas in electricity production would be 51.69% of overall generation. With the deployment of the PDP2018 in Thailand, the share of domestic RE (including hydropower) would increase from 12.48% to 32.34% of total generation between 2018 and 2060. On the other hand, electricity generation from coal is gradually decreasing, from 17.51% in 2018 to around 7.23% in 2060. Imported electricity accounts for approximately 8.66% of the remaining electricity generation, while oil products contribute 0.07%.

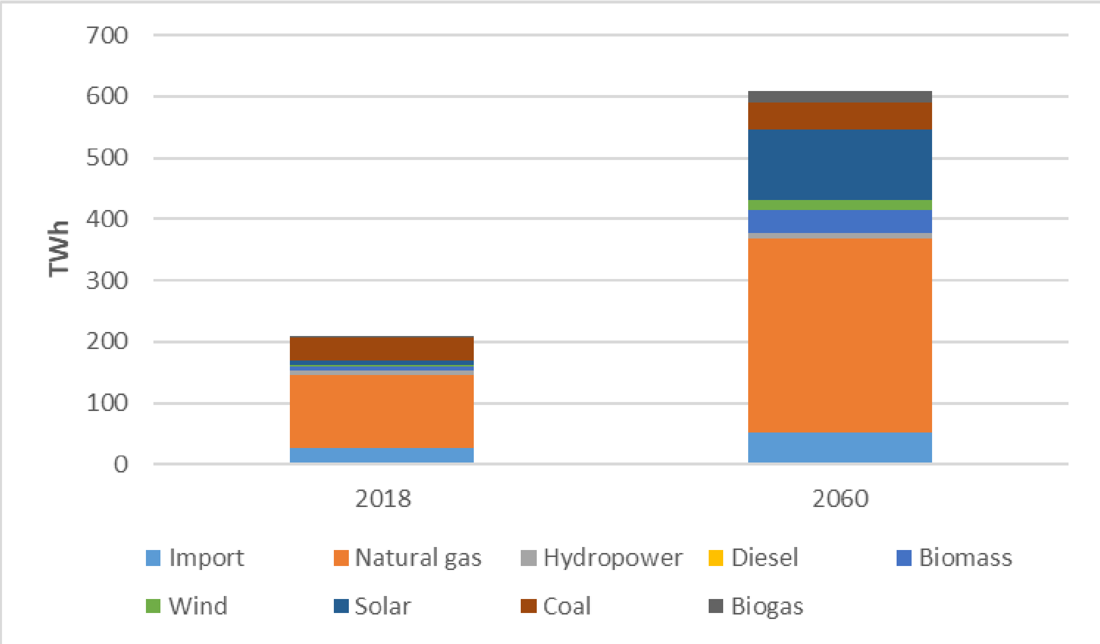

Figure 4.2: Electricity generation by fuel type in the EXT scenario

c) GHG Emissions from Electricity Generation

Under the Existing Policy scenario, GHG emissions would eminently increase due to the high dependency on fossil fuels to generate substantial amounts of electricity to meet the electricity requirements of each economic sector. The total amount of emissions from electricity production in Thailand was 100 MtCO2eq in 2018, and it is projected to increase by 77% to around 178.41 MtCO2eq by 2060. By 2060, the natural gas power plants are projected to become the main source of emissions, with 117.35 MtCO2eq (65.77% of total GHG emissions), as indicated in Figure 4.3. In addition, 33.69% of all GHG emissions would come from coal power generation. GHG emissions from bioenergy (biomass and biogas) are very low compared to the top two sources of emissions above. Bioenergy generation is estimated to emit around 0.40% of total emissions in 2060. The remaining emissions came from electricity generated by diesel and oil.

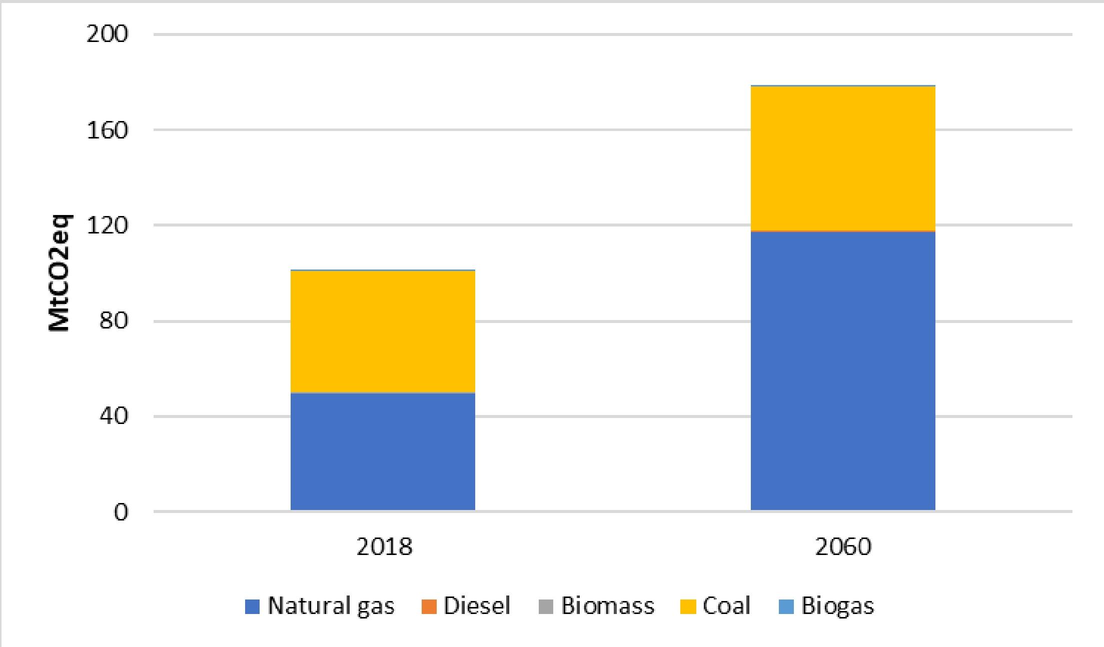

Figure 4.3: Total GHG emissions from electricity generation in the EXT scenario

5. MORE AMBITIOUS POLICY (MAP) SCENARIO

5.1 Description of the More Ambitious Policy Scenario

The More Ambitious Policy (MAP) scenario is the extended scenario from 2037 to 2060 of the Existing Policy scenario. In this scenario, the target of energy efficiency savings and the consumption of renewable energy in all sectors are assumed to increase from 2037 to 2060.

a) Residential Sector

In the residential sector, there are two assumptions, including energy efficiency and the promotion of electric cooking measures:

- **Energy efficiency improvement measures**
  - In 2060, every household in Thailand will fully utilize LED lamps for lighting.
  - In 2060, 60% of households in Thailand will switch to use efficient air-conditioners and efficient refrigerators.
- **Promotion of electric cooking**
  - In the residential sector, the percentage of households using electric cookers will linearly increase from 5% in 2018 to 25% in 2060.

The measures of the More Ambitious Policy Pathway in the residential sector are shown in Table 5.1.

Table 5.1: More Ambitious Policy pathway assumption in the residential sector

EE improvement measures	2018	2037	2050	2060
Lighting:				
- Penetration of LED lamps	0%	70%	85%	100%
Cooling:				
- Penetration of efficient AC - Penetration of efficient Refrigerator	0%	30%	45%	60%
Promotion of electric cooking				
Cooking services in households:				
- Biomass (Wood and Charcoal)	15%	10%	7%	5%
- LPG	80%	75%	73%	70%
- Electricity	5%	15%	20%	25%

Source: Authors' assumptions

b) Commercial Sector

There are two assumptions in the commercial sector: i) the enhancement of energy efficiency and ii) the promotion of renewable energy:

- **Energy efficiency improvement measure:** It is assumed that in 2060, the energy efficiency in the commercial sector will be double compared to the energy savings in 2037 under the Existing Policies Scenario, equivalent to 12,836 ktoe.
- **Renewable energy promotion:** The share of solar heating in 2060, is assumed to double compared to the share of solar heating in 2037 under the AEDP2018.

c) Industrial Sector

In this scenario, there are several assumptions in the industrial sector including energy efficiency improvement and renewable energy promotion:

- It is assumed that energy efficiency improvement in the industrial sector will increase 1% annually from 2018 to 2060.
- Regarding the RE promotion, in 2060, the share of RE (biomass and solar) in the final energy consumption in the industrial sector will increase by 5% higher than the RE target in 2037 under the AEDP2018. The promotion of RE in the industrial sector is illustrated in Table 5.2.

Table 5.2: RE promotion in the More Ambitious Policy pathway assumption in the industrial sector

	2018	2037	2050	2060
Fuel consumption in the industrial sector:				
- Oil products	16%	10%	8%	7%
- Electricity	23%	33%	34%	35%
- Biomass	26%	29%	31%	32%
- Solar	-	1%	2%	3%
- Natural Gas	13%	14%	15%	15%
- Coal products	22%	13%	10%	8%

Source: Authors' assumptions

d) Transport Sector

In the transport sector, the More Ambitious Policy scenario aims to increase the efficiency of internal combustion engine vehicles (ICE vehicles) and the efficiency of fuel economy, drastically utilize electric vehicles in the road transport, and increase the share of electric trains in passenger-kilometer and ton-kilometer. The measures of the More Ambitious Policy Pathway in the transport sector are shown in Table 5.3.

Table 5.3: More Ambitious Policy pathway assumption in the transport sector

	2018	2030	2050	2060
EE improvement measures				
Improving efficiency of fuel economy in ICE vehicles compared to fuel economy in 2018	0%	25%	30%	40%
EV promotion measures				
Road Transportation Mode:				
- The share of electric vehicles	0%	30%	45%	60%
Rail transportation:				
- Electric train for passenger-transport (pass-km)	31.91%	40%	45%	50%
- Electric train for freight-transport (ton-km)	0%	10%	20%	25%

Source: Authors' assumptions

e) Power Sector

Under the More Ambitious Policy scenario, two key assumptions are being made in the power sector. They are i) the reduction of transmission and distribution losses and ii) the increasing share of RE towards 2060 by extending from the existing plan (PDP2018). The share of domestic RE installed capacity in 2037 from the PDP2018 plan is 37% of the total capacity. Therefore, in 2060, in this scenario, the share of RE installed capacity will increase by around 28% compared to the existing policies. Hence, the share of domestic RE installed capacity is expected to be around 65% in 2060. The measures of the High Ambition Policies Pathway in the power sector are shown in Table 5.4.

Table 5.4: More Ambition Policies Pathway assumption in the power sector

	2018	2037	2060
EE improvement measures			
Transmission and distribution losses:			
- T&D losses reduction	6.42%	5%	5%
RE promotion measures			
Power generation installed capacity:			
- Import	3,878	8,661	11,000
- Coal-based power plant	4,637	6,505	2,000
- Natural gas-based power plant	24,837	32,112	31,000
- Diesel/Fuel oil-based power plant	355	65	65
- Hydropower	3,282	4,105	4,105
- Biomass-based power plant	2,257	5,522	14,900
- Biogas-based power plant	80	1,565	3,000
- Solar	2,967	14,754	45,000
- Wind	1081	2,989	15,000

Unit: MW
Source: Authors' assumptions

5.2 Results of the More Ambitious Policy Scenario

a) Sectoral Electricity Demand

The results in the MAP scenario show that, despite having more efficient technologies integrated into the energy system, total electricity consumption will slightly increase by 5.55% in 2060 compared to the EXT scenario. Electric vehicles in the road transport and electric trains in rail transport contribute to the increasing electricity demand. The results illustrate a 120% increase in electricity demand in the transport sector compared to the 2060 EXT scenario. In the MAP scenario, it clearly shows that the electricity demand in the commercial sector and industrial sector has decreased by 24.84% and 11.48%, respectively, compared to the amount of electricity demand in the EXT scenario due to the high integration of efficient technologies. On the other hand, the consumption of electricity in the residential sector has grown by 2.5 TWh owing to the increase in electric cooking (see Figure 5.1).

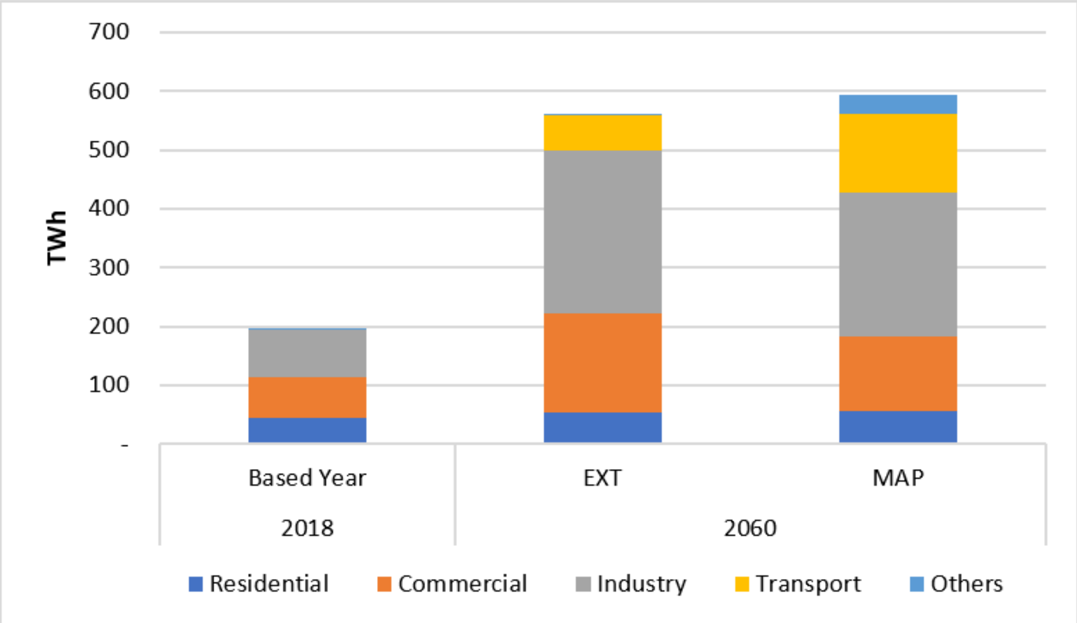

Figure 5.1: Electricity consumption by sector

b) Electricity Generation

Due to the larger increase in electricity consumption, estimated 2060 electricity generation in the MAP scenario, totaling 617.67 TWh, will be higher than the EXT scenario by 1.3%.

Looking into the share of fuel types in power generation, the total electricity generation from RE (including hydropower) would tremendously increase to around 52.24%, which is around 20% higher than the share of electricity generation from RE in the Existing Policy scenario. Besides this, the generation from coal power plants would drastically decrease to 2.04% of total generation. In addition, natural gas electricity generation is projected to decrease from 56.87% in 2018 to 35.19% in 2060. The share of electricity imports from neighboring countries would slightly increase to 10.45%, while the remaining generation would come from oil power plants (see Figure 5.2).

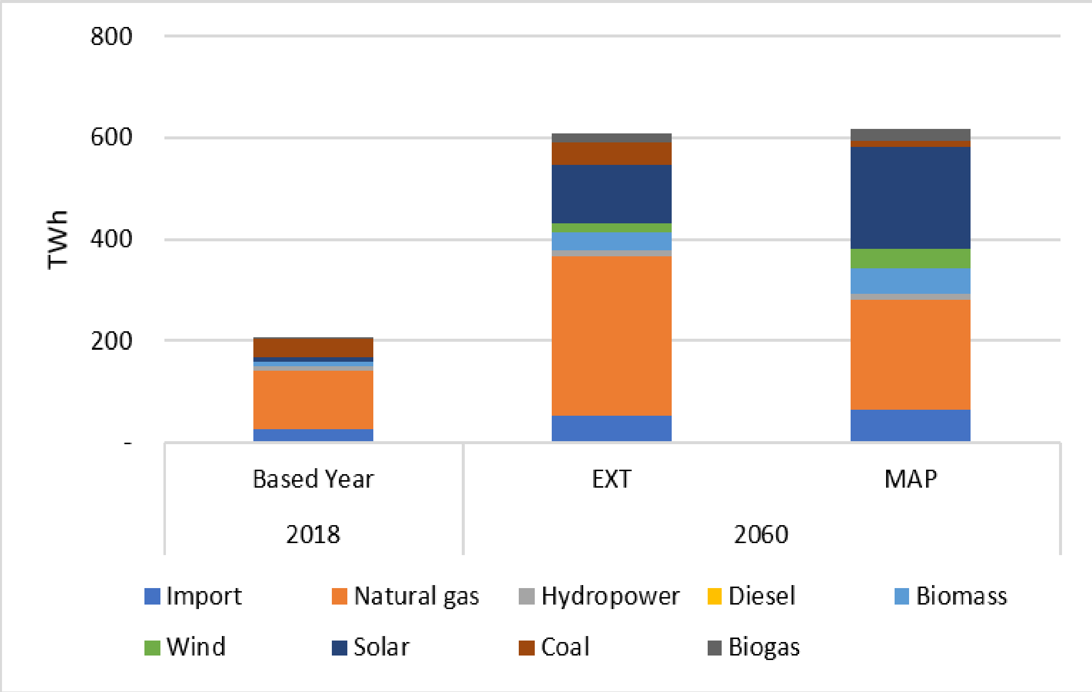

Figure 5.2: Electricity generation by fuel type

c) GHG Emissions from Electricity Generation

In the MAP scenario, GHG emissions from power generation would be massively reduced. Compared to the EXT scenario, the total GHG emissions in 2060 would drop by 44.14% or account for an emissions reduction of 78.75 MtCO2eq (see Figure 5.3). The approximate GHG emissions from electricity production in Thailand would be 99.66 MtCO2eq in 2060. The results of the great reduction in emissions are primarily attributed to the integration of more renewable energy such as solar, wind, biomass, and biogas into electricity generation, coupled with the massive reduction in power generation from coal and natural gas power plants. The amount of GHG emissions in 2060 from natural gas power generation notably decreased from 117.35 MtCO2eq in the EXT scenario to 81.34 MtCO2eq (30.69%) in the MAP scenario. Meanwhile, coal generation in 2060 is estimated to have a significant reduction in GHG emissions, and corresponding emissions dropped from 60.10 MtCO2eq in the EXT scenario to 17.15 MtCO2eq in the MAP scenario.

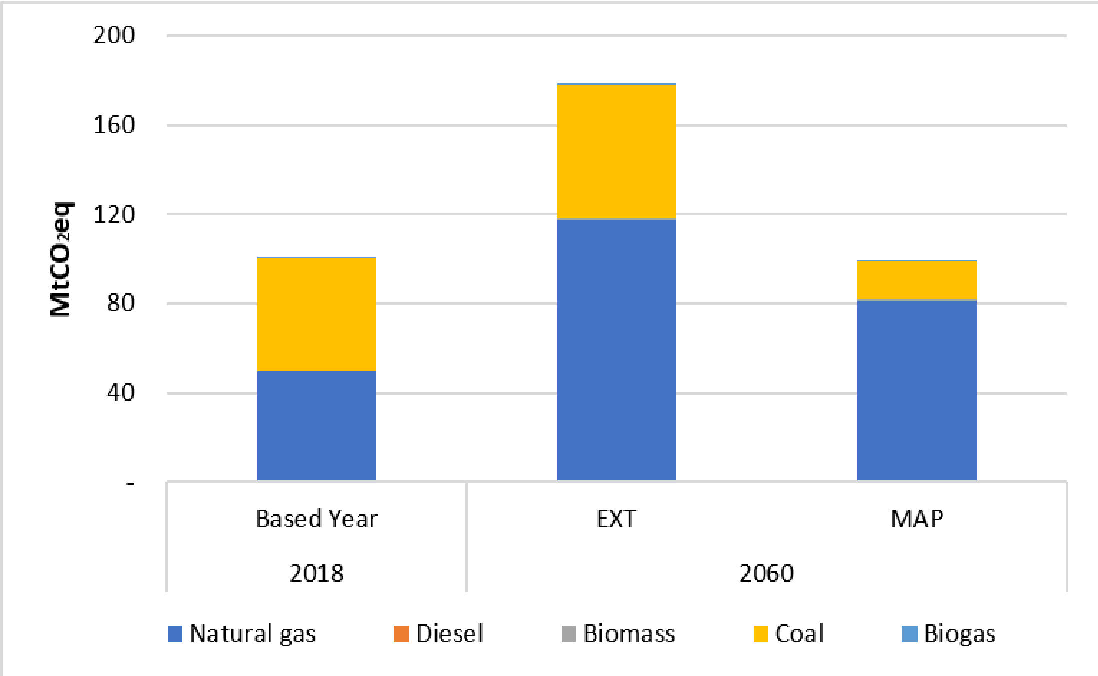

Figure 5.3: Total GHG emissions from electricity generation

6. NEAR ZERO EMISSION (NZE) SCENARIO

6.1 Description of the NZE Scenario

The goal of the Near Zero Emission (NZE) scenario is to identify the most effective strategy of action for achieving the lowest feasible level of greenhouse gas emissions in the power sector by 2060. In this case study, Thailand's power generation uses Next Energy Modeling for Optimization (NEMO) integrated with the Low Emission Analysis Platform (LEAP) as an optimization tool for least-cost planning and greenhouse gas mitigation analysis.

Besides the least-cost optimization in the power sector, there are some important implementations of low-carbon technologies in the other sectors such as residential, commercial, industrial, and transport sectors. These sub-sections outline the assumptions for NZE scenario implementation:

a) Residential Sector

In this sector, energy efficiency enhancement and electric cooking promotion are the two important keys to minimizing both energy consumption and GHG emissions.

- **Enhancement of energy efficiency:** The efficient technologies in lighting systems, air conditioning, refrigeration, and other household electric appliances are gradually increasing to fully replace the conventional ones by 2060.
- **Electric cookers:** By 2060, the share of efficient electric cooking devices is assumed to be increased to 80% in the residential sector.

b) Commercial Sector

The commercial sector is one of the sectors with a high share of electricity consumption. This sector has a crucial impact on electricity generation. The important implementations to achieve the lowest energy consumption and GHG emissions are the application of high-efficiency technologies and the utilization of solar energy in commercial buildings.

- **Energy efficiency enhancement:** With the gradual increase in the utilization of efficient appliances, the concept design of zero-energy buildings, and applications of building energy code standards, the energy intensity in this sector is assumed to decline by 2% annually.

- **Renewable energy promotion:** Solar energy is the best option for promoting sustainability in buildings. It is assumed that by 2060, solar energy used in the commercial sector is estimated to increase by 15%.

c) Industrial Sector

In Thailand, the industrial sector is one of the most important sectors to boost economic development. This sector not only consumes substantial amounts of energy but also produces massive amounts of GHG emissions into the atmosphere. The promotion of renewable energy, especially biomass and solar energy in industries, and the improvement of energy efficiency are the main domains for reducing great amounts of emissions. The assumptions of the NZE scenario in this sector are illustrated as follows:

- **Energy efficiency improvement:** Energy efficiency in the industry is assumed to increase by 1.5% per year between 2018 and 2060. This assumption is made based on the trend of technology efficiency enhancement.
- **Fuel Switching:**
  - Electricity consumption is assumed to increase by around 41% by 2060.
  - The application of biomass is assumed to reach 39% by 2060.
  - The consumption of coal will gradually decrease to zero by 2050.
  - Share of solar is increased to 5% by 2060.
  - Clean hydrogen will begin in 2030 and its share will reach 3% in 2060.
  - The share of natural gas consumption is assumed to increase to 12% by 2060.
  - Oil products are assumed to decrease to 1% by 2060.

d) Transport Sector

The transport sector is the backbone of the country's economic development. This sector has the highest energy consumption and the second largest GHG emissions. The implementation of decarbonization in this sector presents great challenges for Thailand to reach the goal of carbon neutrality and net zero GHG emissions. Electric vehicles in the road transport sector are playing a vital role in GHG mitigation, along with the increase in mass transportation modes such as electric trains and electric buses. Besides this, the increase in fuel economy efficiency could help reduce energy expenses while also reducing GHG emissions. The implementation of the NZE scenario in the transport sector is shown in Table 6.1.

Table 6.1: Assumptions of Near Zero Emission scenario for the transport sector

Mode	Measures in the Near-Zero Emissions scenario
Road transportation	● ***Fuel economy improvement:*** Fuel economy of the internal combustion engine vehicle is assumed to increase by 50% in 2050 compared to fuel economy in 2018. ● ***Electric vehicles and hydrogen vehicles promotion:*** - ***Passenger transport:*** The share of electric vehicles in the road passenger transport is assumed to be 85% of total vehicles fleet in 2060. On the other hand, hydrogen fuel cell vehicles are assumed to start running from 2030 and it will increase to 5% by 2060. - ***Freight transport:*** The share of electric trucks in the freight transport is assumed to increase to 70% by 2060, while hydrogen fuel cell trucks will start operation in 2030 and increase to 20% by 2060.
Rail transportation	● ***Fuel economy improvement:*** Fuel economy of the train is assumed to increase by 1.05% annually from 2018 to 2060. ● ***Promotion of electric train:*** - ***Passenger transport:*** The share of electric trains in passenger-kilometer (total distance travelling of passengers per year) is gradually increasing to 80% by 2060. - ***Freight transport:*** The share of electric train in metric ton-kilometer (total distance travelling of freight per year) is gradually increase to 50% by 2060.
Air transportation	● ***Fuel economy improvement:*** Fuel economy of airplane is assumed to increase by 1.5% annually between 2018 and 2060.
Water transportation	● ***Fuel economy improvement:*** Fuel economy of ships is assumed to increase by 1.5% annually between 2018 and 2060.

Source: Authors' assumptions

e) Power Sector

The power sector is playing a crucial role in providing electricity supply to other economic sectors. This sector generates the highest emissions of GHG. Under the NZE scenario, the projection of future electricity generation by fuel type is determined by the NEMO optimization tool to select the least-cost capacity expansion and dispatch for the system. However, there are some constraints that need to be defined for running the optimization model.

- **Maximum capacity constraints:** The maximum capacity of each technology, especially the maximum potential capacity of renewable energy technology, is crucially needed for generating the optimal result. The ASEAN Centre of Energy (ACE) incorporated with the International Renewable Energy Agency (IRENA) to investigate the potential of renewable energy in ASEAN countries (IRENA & ACE, 2022). Table 6.2 shows the maximum installed capacity of renewable energy technologies in Thailand.

Table 6.2: Potential technical installed capacity of renewable energy in Thailand

Type of RE	Biomass	Geothermal	Hydropower	Wind	Solar
Total (GW)	18.0	-	15.0	63.0	3,509

Source: (IRENA & ACE, 2022)

- **Phase out of fossil-based technologies:** In this scenario, diesel/oil power installed capacity will be phased out by 2030. Furthermore, coal power plants will no longer exist in 2050.

- **Renewable electricity limitations:** The electricity generation from renewable energy is assumed to reach 70% by 2050, consisting of solar photovoltaic, wind onshore, biomass, and hydropower.

- **Advanced technology:** Advanced technology, including carbon capture and storage (CCS) in natural gas power plants and clean hydrogen power plants, is assumed to take place in the electricity generation mix starting in 2030.

- **Costs of Technologies:** The projections of technology cost of each power plant such as capital cost (Table 6.3) and fixed and variable operation and maintenance cost (Table 6.4) are gathered from multiple reliable sources such as the 2023 Electricity Annual Technology Baseline (ATB 2023) from the National Renewable Energy Laboratory (NREL, 2023).

Table 6.3: Capital cost of each power plant

Technology	Capital cost of technology (thousand USD/MW)				
	2018	2030	2040	2050	2060
Coal	3549	3395	3140	2824	2508
NG-CT	1120	1050	961	872	783
NG-CC	1248	1161	1062	971	880
NG-CC-CCS	2661	2255	1887	1658	1430
Diesel/Fuel oil	1150	1150	1150	1150	1150
Biomass	5391	4489	4186	3871	3556
Hydropower	6660	6660	6660	6660	6660
Solar PV	1291	1038	764	632	500
Geothermal	6750	5926	5421	5156	4891
Wind onshore	1363	1150	1037	924	811
Nuclear	9440	7730	7209	6668	6127
Hydrogen[a]	1600	700	650	500	450
Import	6710	6710	6710	6710	6710

Source: (NREL, 2023)

Table 6.4: Fixed and variable O&M costs.

Technology	Fixed O&M cost (USD/kW-year)			Variable O&M (USD/MWh-year)		
	2018	2050	2060	2018	2050	2060
Coal	78	64	58	8.46	7.6	7.33
NG-CT	24	20	18	6.44	6.44	6.44
NG-CC	31	24	22	1.96	1.62	1.52
NG-CC-CCS	27	27	27	6	6	6
Diesel	34.5	34.5	34.5	40	40	40
Biomass	157	157	157	5	5	5
Hydropower	33	33	33	0	0	0
Solar	23	13	11	0	0	0
Geothermal	114	104	104	0	0	0
Wind onshore	30	23	21	0	0	0
Wind offshore	113	74	67	0	0	0
Nuclear	152	152	152	2	2	2
Hydrogen	18	18	18	0	0	0
Import	35	35	35	0	0	0

Source: (NREL, 2023)

- **Fuel prices:** The projection of fuel prices between 2018 and 2050 is gathered from the ASEAN Energy Outlook 2023 (ACE, 2020). The price in 2060 is forecast using trends from previous years. The costs of various power generation technologies are illustrated in Table 6.5.

Table 6.5: Fuel price projections

Fuel type	2018	2030	2040	2050	2060
Biogas	2.30	2.30	2.30	2.30	2.30
Biomass	0.60	0.60	0.60	0.60	0.60
Coal	9.80	7.05	7.05	7.05	7.05
Crude oil	27.60	52.40	61.90	61.90	61.90
Diesel	10.20	13.30	14.10	14.10	14.10
Hydrogen*	4.00	3.00	2.00	1.50	1.00
Imported Electricity	50.00	44.00	40.00	35.00	30.00
Natural gas	28.40	27.90	27.90	27.90	27.90
Nuclear	3.80	7.20	10.80	14.40	17.90

Unit: USD/MWh, *USD/kg
Source: (ACE, 2020)

6.2 Results of the NZE Scenario

a) Electricity Demand

The results from the LEAP-NEMO illustrate that the total electricity consumption is expected to increase by 2.74% per year between 2018 and 2060 (Figure 6.1). In 2030, the country's electricity demand is expected to rise dramatically to 320 TWh, which is approximately 63% increase compared to the 2018 demand. The drastic increase is a result of the electric vehicles penetration in the transport sector and the increase of electricity utilization in other sectors (agriculture, commercial, industrial, and residential). The electricity demand is projected to increase to 573 TWh by 2050 and 602 TWh by 2060. In comparison to the EXT and MAP scenarios, despite having a very high share of electric vehicles and a notable increase in electrification, the total demand for electricity in 2060 under the NZE scenario is estimated to be only 7.22% and 1.79% greater than the other two scenarios, respectively. This is an indication of the improvement in the efficiency of electric appliances and the replacement of efficient technology over conventional ones.

In 2018, the consumption of electricity in the transport sector was negligible. However, with the progress of battery electric vehicles promotion together with the increase of electric trains, this sector is expected to consume electricity around 45 TWh by 2030. In 2060, the transport sector's electricity demand will be 164 TWh, or 27% share of the 2060 total electricity consumption, which drives this sector to be the second-largest electricity consumption. The industrial sector was the largest electricity consumer in 2018. Over the study period, this sector will remain the largest consumer of electricity with a 2.53% increasing rate per annum. The total demand for electricity in the industrial sector will be 229 TWh or 38% of the total demand. The commercial and residential sectors are forecast to consume 19% and 12%, respectively, of the 2060 total electricity demand, while other sectors (agriculture, public lighting, etc.) will account for the smallest proportion of electricity consumption.

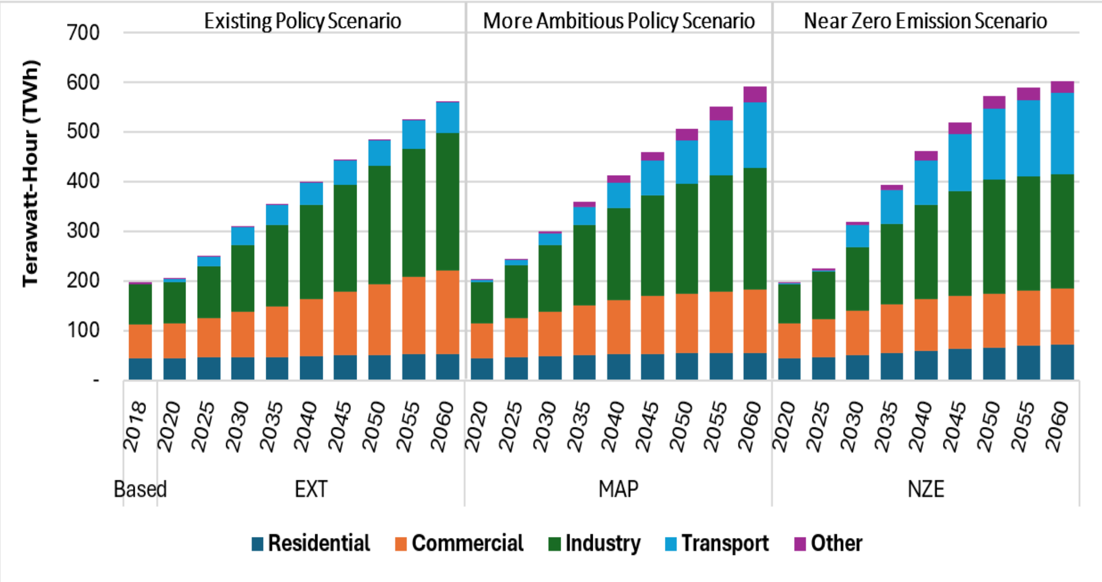

Figure 6.1: Electricity consumption by sector

b) Installed Capacity of Power Generation

According to the LEAP-NEMO optimization results, the total installed capacity of power plants in the NZE scenario skyrocketed from 43.37 GW in 2018 to 82.09 GW in 2030, which is 25% greater than the EXT scenario and 18% higher than the MAP scenario (Figure 6.2). The total installed capacity is expected to grow significantly by approximately 2.85% per year between 2030 and 2050. From 2050 to 2060, the total capacity of power plants is estimated to have a minor increase because of reaching the maximum potential of renewable energy in the country, together with the limitation of fossil fuel utilization. By 2050 and 2060, the country is projected to have total installed capacities of 185 GW and 189 GW, respectively. In the NZE scenario, the total capacity for 2060 exceeds that of the EXT and MAP scenarios by 67% and 50%, respectively.

In 2018, natural gas power plants (without CCS) had the largest total installed capacity compared to other types of fuel. Under the NZE scenario, the natural gas power installed capacity is projected to peak at 35.77 GW by 2030, then gradually decrease to 19 GW by 2060, representing 10% of the total capacity for that year. On the other hand, with the introduction of carbon capture and storage (CCS) technology in the natural gas power plant in 2030, the natural gas-CCS installed capacity is expected to be 4.5 GW in 2035, and it will increase to 14.10 GW in 2060 (7% of total capacity). In Thailand, coal power plants have been the primary source of electricity generation for the last few decades. However, this source of generation has a huge impact on the environment. Hence, in the NZE scenario simulation results, the total capacity of coal power plants will peak between 2025 and 2030 at 6.10 GW. Its capacity will tremendously decrease until it phases out by 2050.

Renewable energy is a great option for achieving sustainable energy development. In Thailand, solar is the best renewable energy domain, with the highest technical installed capacity. The installed capacity of this power source is expected to significantly increase to 65 GW between 2050 and 2060 (34% share of the total capacity). Wind energy is estimated to be the second-largest share of installed capacity after solar photovoltaic between 2050 and 2060. The total wind installed capacity is projected to be 45 GW in 2060, or 24% of the total power capacity. The country is estimated to have 10% of its total installed capacity from biomass, 3% from hydropower, and 2% from biogas by 2060.

The new hydrogen power plant is expected to start in 2030, and the capacity of this type of power plant will increase to 5% of the total capacity. The country's remaining capacity to generate electricity will originate from imported electricity from neighboring countries.

By 2060, the NZE scenario is estimated to have a 70% share of renewable energy installed capacity, the MAP scenario 65%, and the EXT scenario 37%.

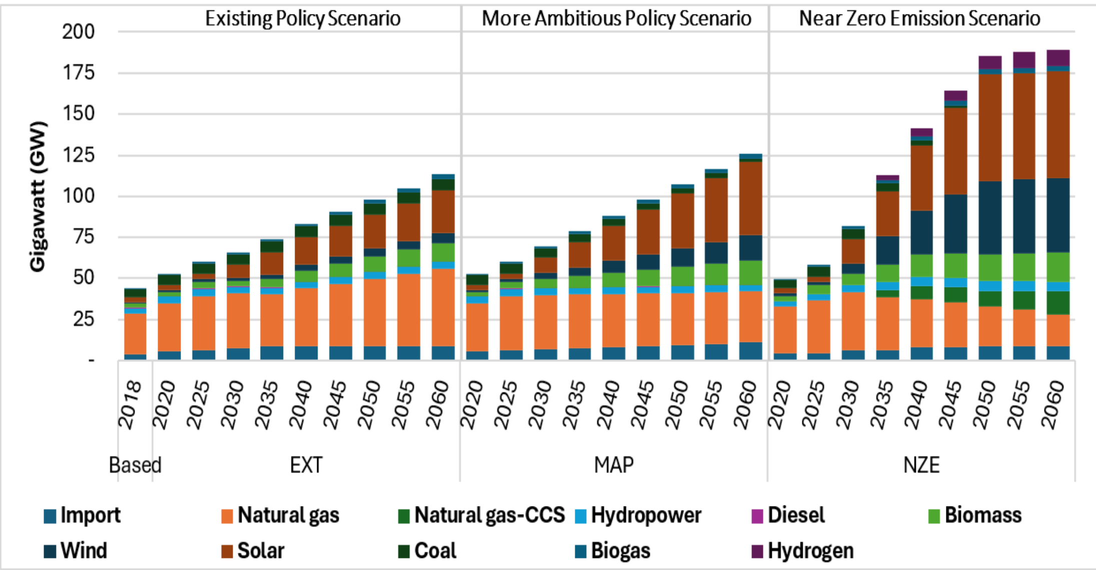

Figure 6.2: Installed capacity of power generation

c) Electricity Generation

Under the NZE scenario (Figure 6.3), electricity generation is projected to increase by 2.98% annually from 2018 to 2060. In 2030, the total generation is expected to reach 376 TWh, then increase to 662 TWh by 2050, and further to 693 TWh by 2060. Compared to the EXT and MAP scenarios, the total generation under the NZE scenario in 2060 will be higher by 13.64% and 12.18%, respectively.

In the NZE scenario, natural gas is expected to grow in electricity generation to around 197 TWh in 2030, then decline to 29 TWh in 2060. On the other hand, the generation from natural gas-CCS increase to 42 TWh in 2060, or 6% of the total generation. Coal power generation is expected to be around 13.81 TWh in 2025, which is the peak generation from coal power plants. The generation from coal will gradually decrease, and there will be no more generation from coal after 2050.

Solar power generation shows great expansion in the NZE scenario. In 2030, the generation from this source will increase by sevenfold compared to the based year. Further, the total generation from this source is projected to skyrocket to around 265 TWh in 2050 and 285 TWh in 2060. Besides this, electricity generation from wind power plants will be the second largest in electricity production by 2060, accounting for 118 TWh, or 17% of the total generation. Biomass is expected to account for 10% of the total electricity generation in 2060, making it the third-largest source, while biogas and hydropower contribute only 3% and 2%, respectively.

The remaining 2060 generation will be generated by a hydrogen power plant of around 9% and 8% from electricity imports.

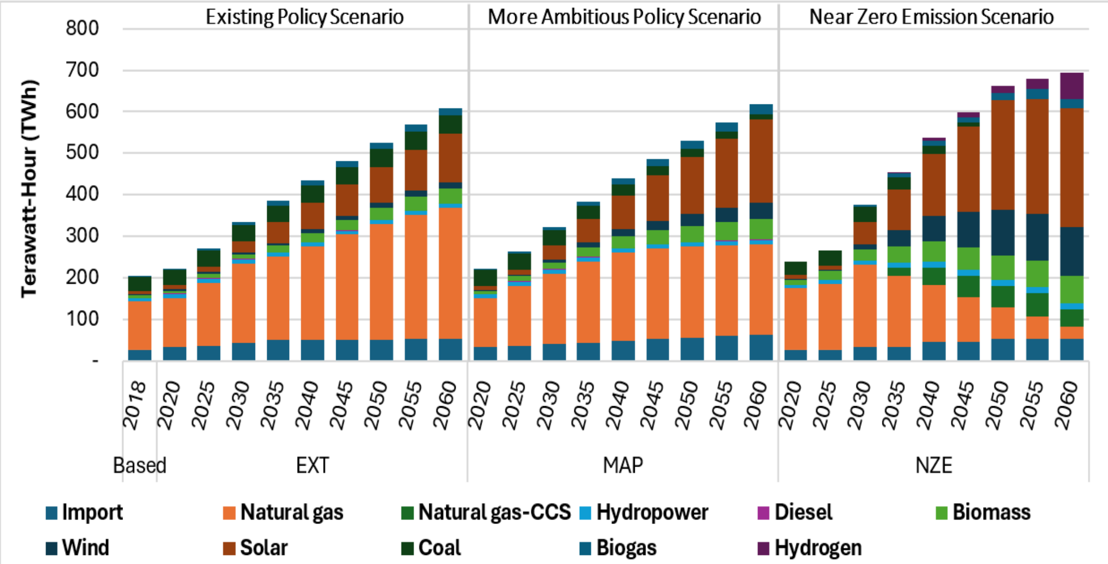

Figure 6.3: Electricity generation by fuel type

d) Cost of Electricity Production

The cost of electricity production is determined by the combination of the cost of installed capacity, the cost of fixed and variable O&M, and the cost of fuel utilization for generating electricity supply. The simulation results under the NZE scenario indicate a dramatic increase in the total electricity production cost over the study period. In 2030, the total cost of electricity production will be 35.42 billion USD, which is 7.49 billion USD and 6.64 billion USD greater than the total amount of 2030 electricity production cost in the EXT and MAP scenarios, respectively (Figure 6.4). Natural gas generation is estimated to share the largest proportion of cost, accounting for 42%. The total electricity generation cost is expected to grow significantly by 2050—an approximately 12.12 billion USD increase compared to the total electricity generation cost in 2030. After 2050, the cost of electricity production shows a moderate decline to 44.63 billion USD by 2060.

Fossil fuel prices are projected to increase in the study period (Table 6.5), while the price of renewable energy sources is less expensive. Therefore, the decrease in total electricity production costs is a result of the transition from fossil fuel-based power generation to renewable energy-based generation. In 2060, biomass electricity generation and imported electricity are estimated to be the first and second-largest sources of electricity production costs, accounting for 21% and 18%, respectively. The total cost of electricity production from natural gas is estimated to drop to 10%, while the cost of natural gas with CCS in electricity production is projected to be 11% by 2060. Despite having a great amount of electricity production, solar and wind power generation together is forecasted to share approximately 20% of the total electricity production cost by 2060.

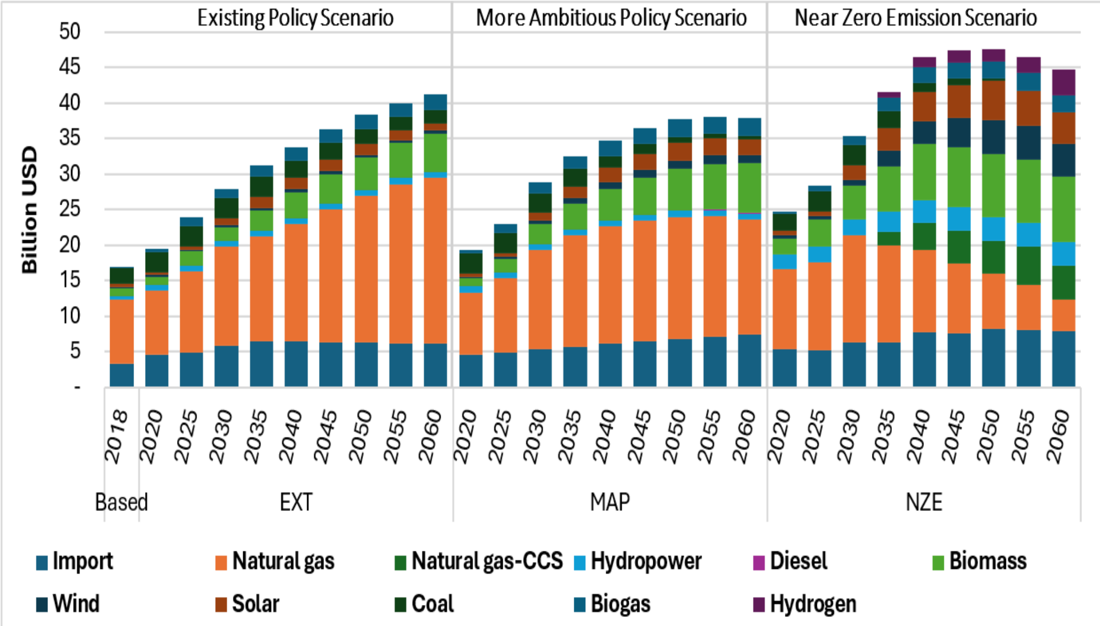

Figure 6.4: Electricity production cost

e) GHG Emissions

In the NZE scenario, the simulation from LEAP-NEMO indicates that the total amount of GHG emissions in power generation increased between 2018 and 2030, from 100 MtCO2eq to 126 MtCO2eq (Figure 6.5). The increase in total GHG emissions is caused by an increase in electricity generation proportional to the increase in electricity demand. Furthermore, the structure of electricity production will rely on natural gas in 2030. In 2030, total GHG emissions in the NZE scenario are 1.60% lower than the total emissions in the EXT scenario and 9.10% higher than total GHG emissions in the MAP scenario.

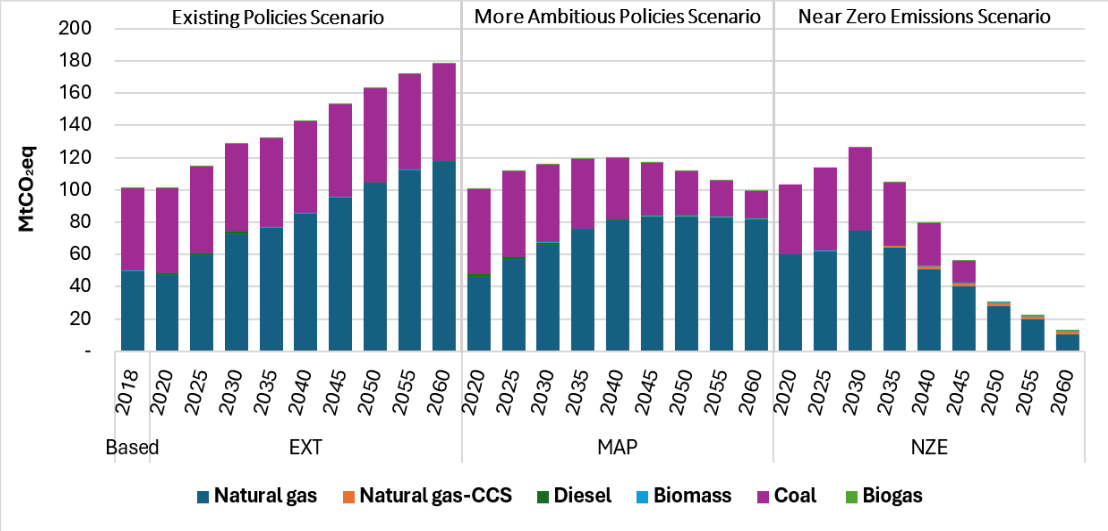

Figure 6.5: Total GHG emissions from electricity generation

After 2030, the total GHG emissions from electricity generation in the NZE scenario are estimated to greatly decrease to around 31 MtCO2eq by 2050 and 13 MtCO2eq by 2060 due to the significant growth of renewable energy in electricity production, the utilization of carbon capture and storage technology in natural gas-based power plants, the integration of clean hydrogen power generation, and the term phasing out of coal generation. Natural gas electricity production is expected to emit 10.69 MtCO2eq in 2060, making it the main source of GHG emissions. Natural gas with CCS, biomass, and biogas generation are estimated to produce 1.54 MtCO2eq, 0.64 MtCO2eq, and 0.33 MtCO2eq, respectively.

7. SUMMARY

The report on Thailand's power sector modeling contains the results and analysis of the two study phases: ASEAN Green Future Phase 2.1 (AGF 2.1) and ASEAN Green Future Phase 2.2 (AGF 2.2).

The AGF 2.1 discusses power sector modeling in Thailand under the review of the Existing Policy and the More Ambitious Policy. The Existing Policies refer to the existing energy and power development plan from Thailand's government and stakeholders, whereas the More Ambitious Policies illustrate the extension of the existing government's plans in the energy and power sector in the county for observing the sectoral electricity demand, the structure of power generation, and the amount of GHG emissions in the power sector.

The AGF 2.2 determines the near-zero emissions pathway in electricity generation by using least-cost optimization power generation. The model is built in the LEAP-NEMO analysis tool with the integration of different types of low-carbon technology, including renewable energy, carbon capture and storage (CCS), and clean hydrogen power plants in the power sector.

The simulation results illustrate that the total electricity demand in Thailand is estimated to dramatically increase to around 602 TWh by 2060 in the NZE scenario. This total demand is expected to grow by 7.22% and 1.59% higher than the 2060 total electricity consumption in the EXT and MAP scenarios, respectively. The industrial sector is forecast to have the highest electricity consumption in all scenarios. The commercial sector is expected to be the second-largest share of electricity demand in the EXT scenario; however, under the MAP and NZE scenarios, the transport sector will be the second highest electricity consuming sector after the industrial sector due to the increasing electric vehicles in road transportation and the increasing electric railways.

The total electricity generation in 2060 in the EXT, MAP, and NZE scenarios is estimated to be 609 TWh, 618 TWh, and 693 TWh, respectively. Under the NZE scenario, the share of renewable energy in 2060 electricity generation will be 73%, where solar and wind are the first and second highest shares in the total generation, accounting for 41% and 17%, respectively. In the MAP scenario, the share of electricity generation from renewable energy is projected to be 52%, consisting of solar, biomass, wind, biogas, and hydropower. The total renewable energy generation share in the EXT scenario is expected to be 32% in 2060.

The total cost of electricity production in the NZE scenario is estimated to increase to 47.54 billion USD in 2050, then slightly decrease to 44.63 billion USD. On the other hand, in the MAP scenario, the electricity generation cost will increase to 37.99 billion USD by 2055 and decrease to 37.89 billion USD in 2060. By 2060, a continuously increasing electricity production cost in the EXT scenario will reach 41.20 billion USD.

The total amount of GHG emissions is one of the main objectives to be determined. Under the EXT scenario, the amount of GHG emissions is forecast to be increased to around 178 MtCO_2eq by 2060. Beside this, the total emissions in the MAP scenario show a gradual increase to 120 MtCO_2eq in 2040, then drop to around 100 MtCO_2eq in 2060. Additionally, the results in the NZE scenario indicate that the amount of GHG emissions will increase to approximately 126 MtCO_2eq by 2030, then remarkably drop to 31 MtCO_2eq in 2050 and 13 MtCO_2eq in 2060.

Besides the GHG emissions mitigation in the power sector, the LEAP-NEMO simulation also provides the results of decarbonizing the transport sector in Thailand under the NZE scenario.

Based on the results, the total GHG emissions reduction in the road transportation mode by the utilization of electric vehicles and fuel economy efficiency improvement is expected to be 24 $MtCO_2eq$, 92 $MtCO_2eq$, and 110 $MtCO_2eq$ in 2030, 2050, and 2060, respectively, compared to the emissions in the EXT scenario (Figure 6.6). On the other hand, the total emissions from electricity generation for supporting electric vehicle charging are forecasted to be 15 $MtCO_2eq$, 7 $MtCO_2eq$, and 3 $MtCO_2eq$ by 2030, 2050, and 2060, respectively, in the NZE scenario. Therefore, the avoided emissions from EV penetration in Thailand are significantly greater than the emissions caused by EV charging. It is clearly indicated that the utilization of electric vehicles in Thailand is the main pillar of decarbonizing road transportation.

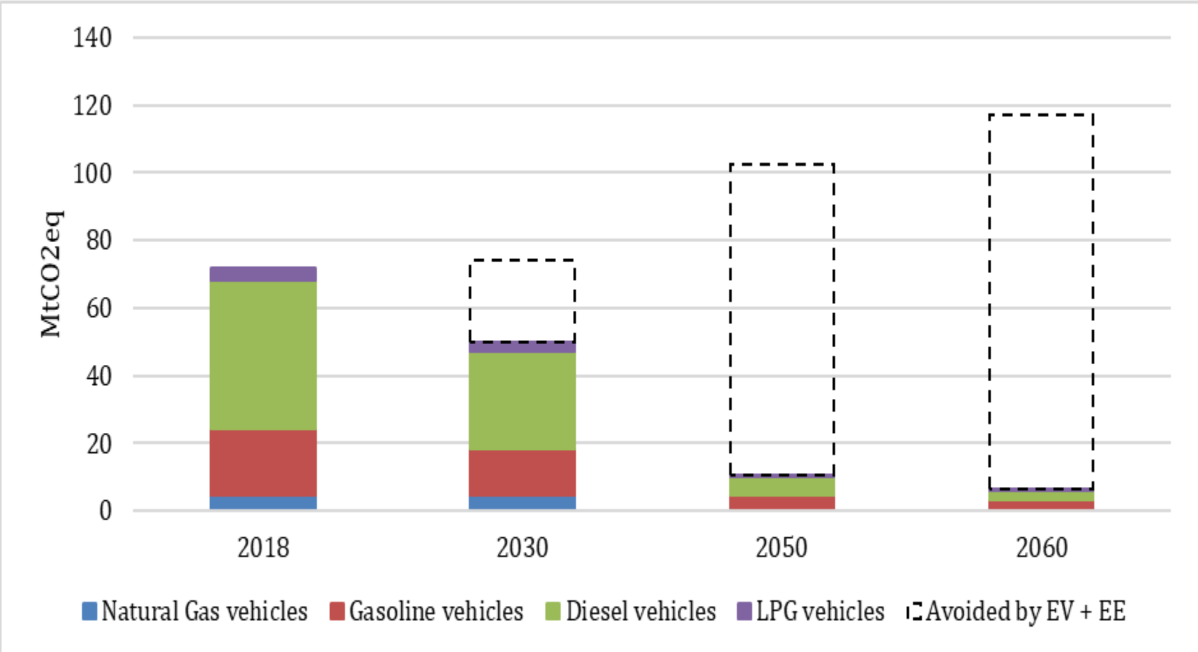

Figure 7.1: GHG emissions in road transportation in the NZE scenario and the emissions reduction by EV compared to the EXT scenario.

Finally, key policies and measures to achieve net zero emissions in energy systems are recommended in the following table.

Table 7.1: Key policy recommendations by sector

Sector	Policy recommendations
Residential	- Increasing the utilization of energy-efficient appliances - Promoting electric cooking to replace biomass stoves and LPG stoves - Raising the awareness and behavior changes regarding energy-savings
Commercial	- Increasing the energy efficiency of electric and heating services - Promoting the utilization of solar, heating, and cooling systems - Enforce National Building Energy Code for new large commercial buildings
Industrial	- Increasing energy efficiency and labeling for lighting, cooling, electric motors, and industrial boilers - Increasing the share of electricity utilization in the manufacturing process (heating services) - Phasing out of coal and petroleum by 2050 - Considering the potential application of green hydrogen fuel in some industries (i.e., the iron and steel industry), starting in 2030
Transport	- Promoting electric vehicles in road transportation for both passenger and freight services - Increasing the electric train - Improving fuel economy for international combustion engine vehicles - Promoting mass public transportation such as buses and trains and transit-oriented development (TOD)
Power	- RE is the key measure to decarbonize power generation. - Phasing out of coal power generation by 2050 - Phasing out of oil power generation by 2030 - Implement CCS technology in new and old natural gas power plants by 2030 - Implement green hydrogen (H_2) after 2030 - Implement grid modernization as soon as possible

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