# ALTERNATIVES FOR POWER GENERATION IN THE GREATER MEKONG SUB-REGION

**Volume 5:**

**Power Sector Vision for the Kingdom of Thailand**

**Final**

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# Acronyms

| | |
|---|---|
| AD | Anaerobic Digestion |
| ADB | Asian Development Bank |
| AEDP | Alternative Energy Development Plan |
| ASEAN | Association of Southeast Asian Nations |
| ASES | Advanced Sustainable Energy Sector |
| BAU | Business As Usual |
| BCM / Bcm | Billion Cubic Metres |
| BNEF | Bloomberg New Energy Finance |
| BTU / Btu | British Thermal Unit |
| BP | British Petroleum |
| CAGR | Compound Annual Growth Rate |
| CAPEX | Capital Expenditure |
| CCGT | Combined Cycle Gas Turbine |
| CCS | Carbon Capture and Storage |
| COD | Commercial Operations Date |
| CSP | Concentrated Solar Panel |
| DEDE | Department of Alternative Energy Development and Efficiency |
| DNI | Direct Normal Irradiation |
| DTU | Technical University of Denmark |
| EE | Energy Efficiency |
| EEDP | Energy Efficiency Development Plan |
| EGAT | Electricity Generation Authority of Thailand |
| EIA | Energy Information Administration |
| ENCO | Energy Conservation Promotion Fund |
| EPPO | Energy Policy and Planning Office |
| ERC | Energy Regulatory Commission |
| ESB | Enhanced Single Buyer Model |

| | |
|---|---|
| ESCO | Energy Service Company |
| FIT | Feed-in Tariff |
| FOB | Free on Board |
| FOM | Fixed Operating and Maintenance |
| GDP | Gross Domestic Product |
| GHI | Global Horizontal Irradiance |
| GMS | Greater Mekong Subregion |
| GSP | Gas Subcooled Process |
| GT | Gas Turbine |
| HV | High Voltage |
| HVDC | High Voltage Direct Current |
| IAEA | International Atomic Energy Agency |
| IEA | International Energy Agency |
| IES | Intelligent Energy Systems Pty Ltd |
| INIR | Intergraded Nuclear Infrastructure Review |
| IPP | Independent Power Producer |
| IRENA | International Renewable Energy Agency |
| LCOE | Overall Levelised Cost of Electricity |
| LNG | Liquefied Natural Gas |
| MEA | Metropolitan Electricity Authority MEA |
| MKE | Mekong Economics |
| MOU | Memorandum of Understanding |
| MTPA | Million Tons per Annum |
| MV | Medium Voltage |
| NASA | National Aeronautics and Space Administration (the United States) |
| NGV | Natural Gas Vehicle |
| NPV | Net Present Value |
| NREL | National Renewable Energy Laboratory (the United States) |
| OECD | Organisation for Economic Co-operation and Development |

| | |
|---|---|
| OPEC | Organisation of the Petroleum Exporting Countries |
| OPEX | Operational Expenditure |
| PDP | Power Development Plan |
| PDR | People's Democratic Republic (of Laos) |
| PEA | Provincial Electricity Authority |
| PPA | Power Purchase Agreement |
| PRC | People's Republic of China |
| PTT | Petroleum Authority of Thailand |
| PTTEP | PTT Exploration and Production |
| PV | Photovoltaic |
| RE | Renewable Energy |
| ROR | Run of River |
| RPR | Reserves to Production Ratio |
| SES | Sustainable Energy Sector |
| SPP | Small Independent Power Producer |
| SWERA | Solar and Wind Energy Resource Assessment |
| SWH | Solar Water Heating |
| TCF / Tcf | Trillion Cubic Feet |
| TNB | Tenaga Nasional Berhad (Malaysia) |
| UN | United Nations |
| USD | United States Dollar |
| VOM | Variable Operating and Maintenance |
| VSPP | Very Small Independent Power Producers |
| WEO | World Energy Outlook |
| WWF | World Wide Fund for Nature |
| WWF-GMPO | WWF – Greater Mekong Programme Office |

# Table of Contents

# 1 Introduction

Intelligent Energy Systems Pty Ltd ("IES") and Mekong Economics ("MKE") were retained by WWF – Greater Mekong Programme Office ("WWF-GMPO") to undertake a project called "Produce a comprehensive report outlining alternatives for power generation in the Greater Mekong Sub-region". This was to develop scenarios for the countries of the Greater Mekong Sub-region (GMS) that are as consistent as possible with the WWF's Global Energy Vision to the Power Sectors of all Greater Mekong Subregion countries. The objectives of WWF's vision are: (i) contribute to reduction of global greenhouse emissions (cut by >80% of 1990 levels by 2050); (ii) reduce dependency on unsustainable hydro and nuclear; (iii) enhance energy access; (iv) take advantage of new technologies and solutions; (v) enhance power sector planning frameworks for the region: multi-stakeholder participatory process; and (vi) develop enhancements for energy policy frameworks.

The purpose of this report is to provide detailed country-level descriptions of three scenarios for the power sector of Thailand:

- Business as Usual (BAU) power generation development path which is based on current power planning practices, current policy objectives;
- Sustainable Energy Sector (SES) scenario, where measures are taken to maximally deploy renewable energy[1] and energy efficiency measures to achieve a near-100% renewable energy power sector; and
- Advanced Sustainable Energy Sector (ASES) scenario, which assumes a more rapid advancement and deployment of new and renewable technologies as compared to the SES.

The scenarios were based on public data, independent assessments of resource potentials, information obtained from published reports and power system modelling of the GMS region for the period 2015 to 2050.

## 1.1 Report Structure

This report has been organised in the following way:

- Section 2 sets out recent outcomes for Thailand's electricity industry;
- Section 3 summarises the main development options covering both renewable energy and fossil fuels;
- Section 4 provides a brief summary of the scenarios that were modelled and a summary of the assumptions in common;
- Section 5 sets out the key results for the business as usual scenario;

[1] Proposed but not committed fossil fuel based projects are not developed. Committed and existing fossil fuel based projects are retired at the end of their lifetime and not replaced with other fossil fuel projects. A least cost combination of renewable energy generation is developed to meet demand.

- Section 6 sets out the key results for the sustainable energy sector scenario;
- Section 7 sets out the key results for an advanced sustainable energy sector scenario;
- Section 8 provides comparative analysis of the three scenarios based on the computation of a number of simple metrics that facilitate comparison;
- Section 9 provides analysis of the economic implications of the scenarios; and
- Section 10 provides the main conclusions from the modelling.

The following appendices provide some additional information for the scenarios:

- Appendix A contains the technology cost assumptions that were used;
- Appendix B provides the fuel price projections that were used; and
- Appendix C sets out information used to estimate jobs creation potential for each scenario.

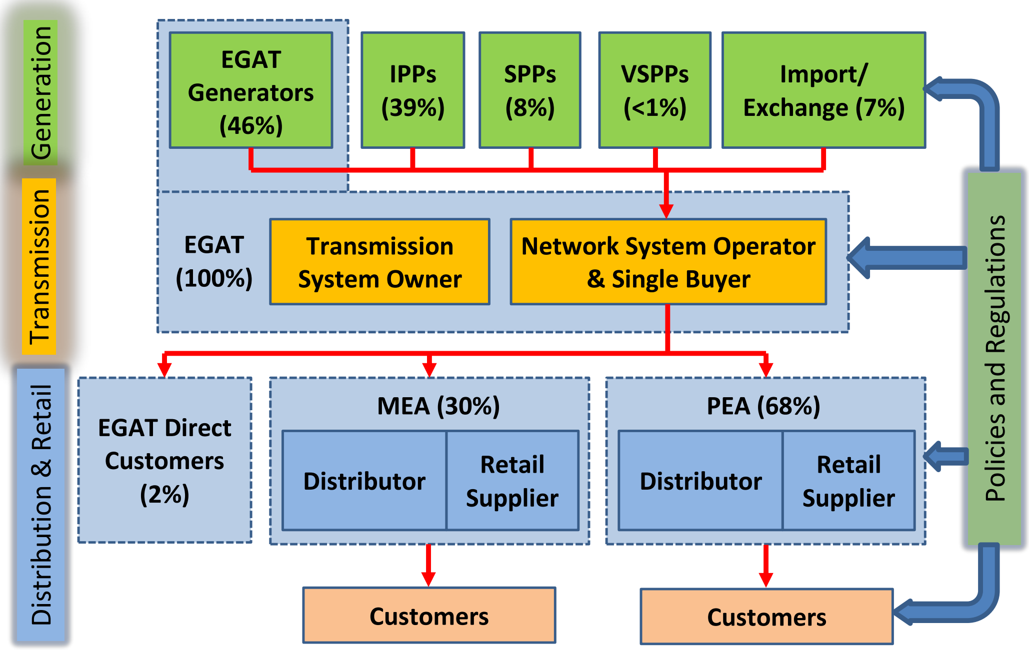
Note that unless otherwise noted, all currency in the report is Real 2014 United States Dollars (USD).

# 2 Background: Thailand's Electricity Sector

## 2.1 Overview

Thailand's electricity industry is managed under the so-called "Enhanced Single Buyer Model (ESB)". The structure of the ESB is provided in Figure 1 below.

**Figure 1 Thailand Electricity Industry Structure**




*Source: Replicated by Consultant based on ERC Data*

Under the ESB model, the government-owned Electricity Generating Authority of Thailand (EGAT) is the single buyer, purchasing bulk electricity from private power producers and neighbouring countries and sells wholesale electric energy to two distributing authorities and a small number of direct industrial customers as well as neighbouring utilities[2]. EGAT itself is the largest power producer owning and operating plants with a total installed capacity over 15,000 MW[3], or about 46% of the entire generation system. In addition, EGAT owns and operates the Thailand's high voltage transmission network.

Private power producers in Thailand are comprised of Independent Power Producers (IPPS) selling electricity to EGAT at capacity greater than 90 MW, Small Independent Power Producers (SPPPs) with capacity sold to EGAT equal or less than

[2] http://www.egat.co.th/en/index.php
[3] As of January 2016, EGAT's installed capacity was 16,376 MW.

90 MW and Very Small Independent Power Producers (VSPPs) with capacity sold to EGAT equal or less than 10 MW.

The two distribution authorities in Thailand are Metropolitan Electricity Authority (MEA) responsible for power supply to Bangkok, Nonthaburi and Samut Prakarn, and Provincial Electricity Authority (PEA) is responsible for power supply to the rest of the country. The market shares of these entities are as at December 2012. Note that non-firm SPPs and VSPPs can sell electricity directly to the distribution utilities.

Thailand's electricity system is a medium size system having total installed capacity of 34,681 MW as at the end of 2014. It has a moderate demand growth rate, with electricity consumption increasing from 100.1 TWh to 168.2 TWh at the compound annual growth rate (CAGR) of 4.44% over the period from 2002 to 2014.

Energy Regulatory Commission (ERC) was established in 2008 to perform the role of the regulator in electricity pricing and in ensuring sufficient supply of energy and quality of the energy services supplied.

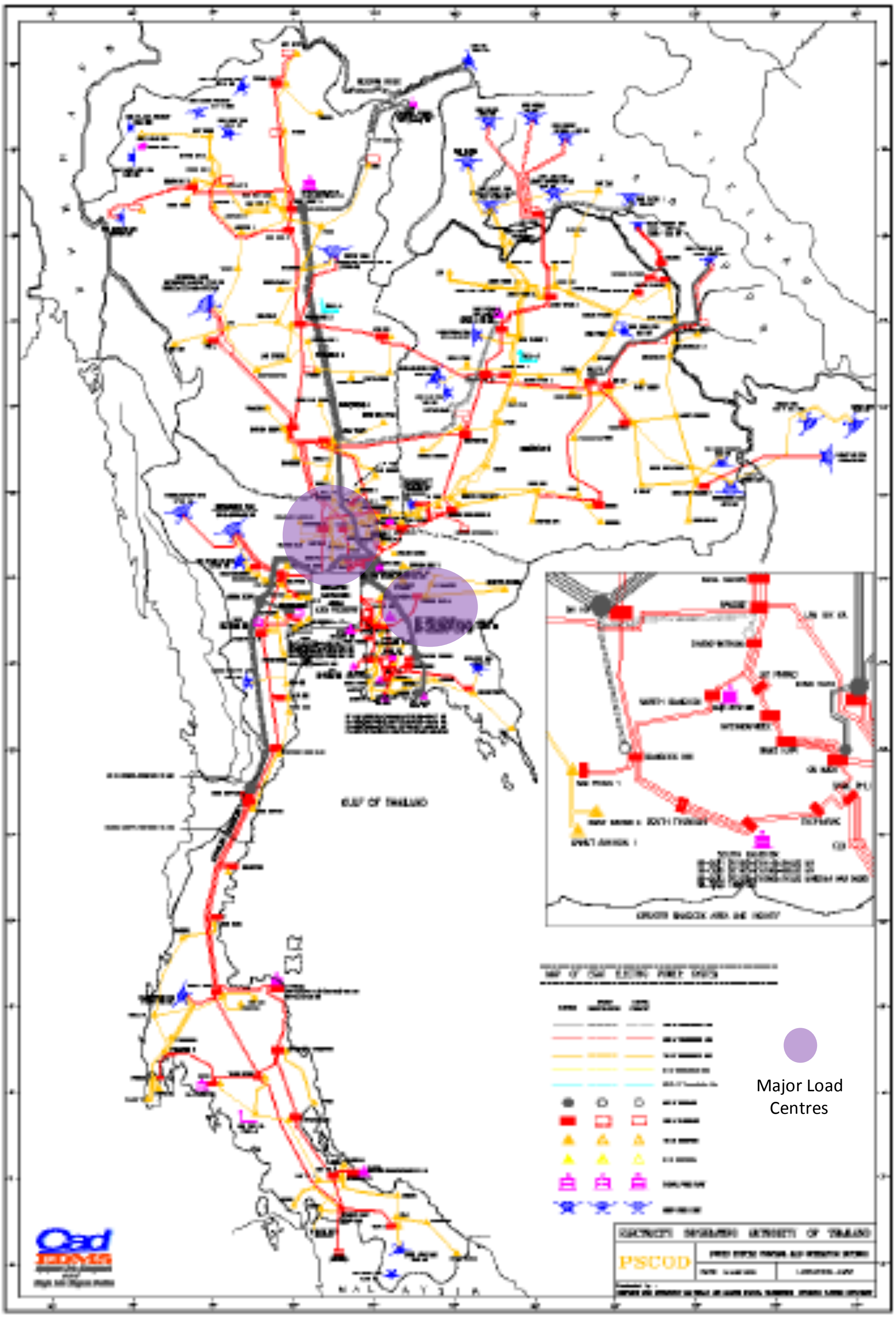
## 2.2 Power System

A representation of Thailand's power system is illustrated in Figure 2. The diagram highlights the present statehood of the country's national system in terms of the main generation resources and 230/500 kV transmission lines that are used in the power system and their locations within the country. We have also highlighted the main demand centres within the country.

Thailand's electricity system is of medium size. As of December 2014, the total installed capacity was 34,681 MW including generation from EGAT power plants, IPPs, SPPs and power imports from neighbouring Lao PDR and Malaysia. EGAT and IPPs are the major generation suppliers accounting for around 45% and 40% of the total electricity demand respectively. The major primary resource used for electricity production in Thailand are natural gas, which shares about two thirds of the fuel mix. Thailand imports electricity from Lao PDR via 230 kV and 500 kV transmission lines of capacity up to 1,800 MW through the Northeast region of the country. Thailand exchanges power in the south with Malaysia via a HVDC transmission system with capacity of 300 MW.

Electricity Generating Authority of Thailand (EGAT) owns and operates the fully integrated national transmission network which includes transmission lines and substations of various high voltage levels throughout the country. The highest, 500 kV transmission lines carry bulk electricity from generation sources located in the North, East and West to the major demand centres in the Bangkok metropolitan and central areas. The 230 kV lines are distributed throughout the country. Northern region and Central region are the source while Bangkok metropolitan and the vicinity are the major load relying on power import from other regions.

## Figure 2 Thailand Power Generation System (2013)



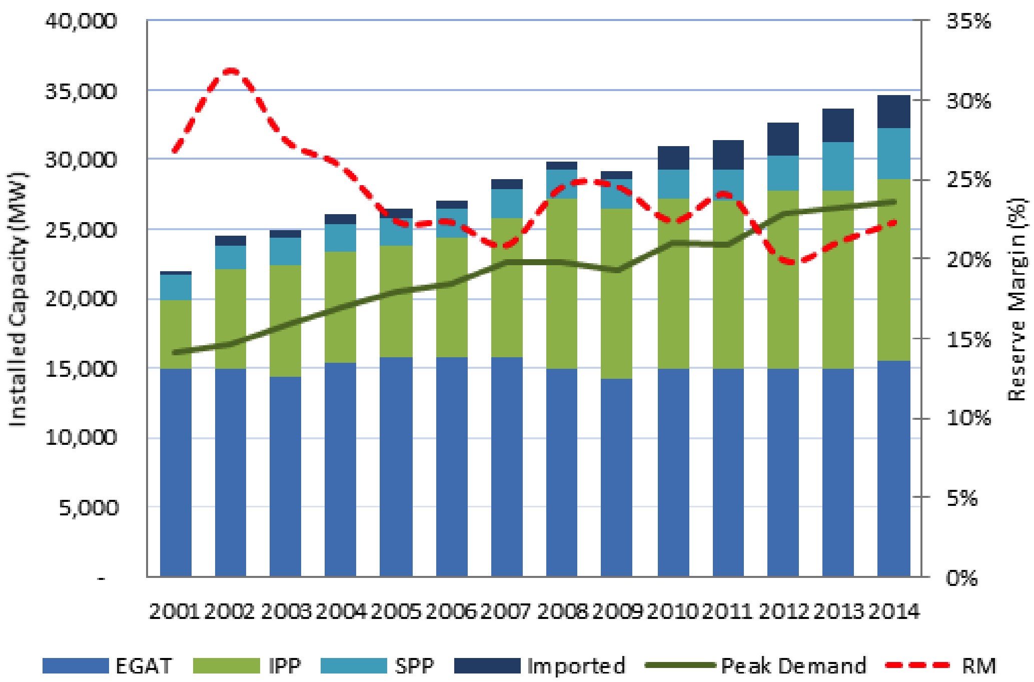

*Source: EGAT Power System Dispatching under Rapidly Changing Electricity Demand, 2013*

## 2.3 Installed Capacity

Figure 3 shows the installed capacity and peak demand on a national level by ownership; the reserve margin (based on nameplate capacity) is also shown. This illustrates that the system reserve margin in the recent past has been within a 20-25% range. It should be acknowledged that due to the predominance of gas fired generating capacity, supply and demand balance in the power system is critical on natural gas supply.

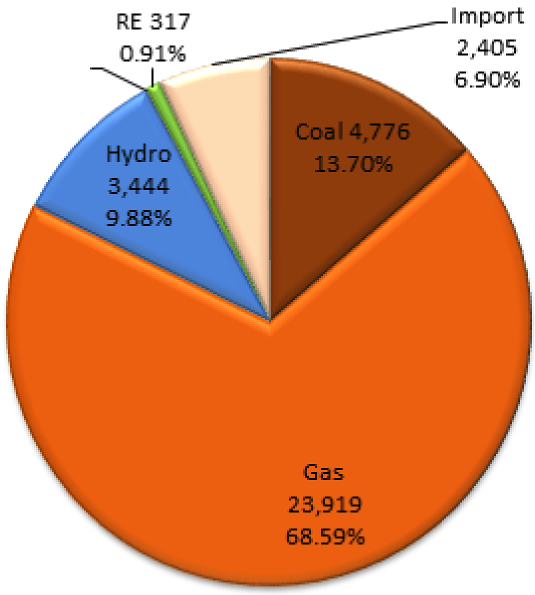
Figure 4 illustrates the capacity mix in MW and percentage. By end of 2014, the system's combined grid-connected installed capacity is 34,870 MW comprising of 23,919 MW gas-fired capacity, 4,776 MW coal-fired capacity, 3,444 MW hydropower capacity, 317 MW non-hydro RE capacity and 2,405 MW import power. This in showing that natural gas is the main power production technology accounting for 68.69% of the total grid-connected capacity, followed by coal at 13.7%.

**Figure 3 Installed Capacity and System-wide Reserve Margin (2000-14)**




*Source: EPPO Statistics (2015)*

**Figure 4 Thailand Capacity Mix by Type of Generation (2014)[4]**



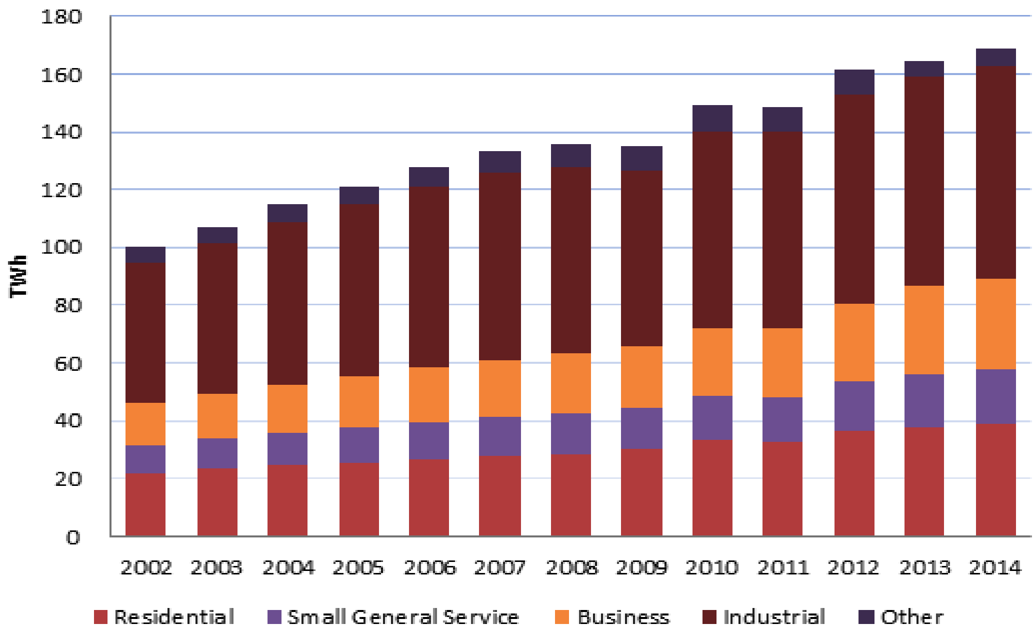

*Source: Compiled by Consultant*

## 2.4 Electricity Demand

Figure 5 shows Thailand's final electricity consumption by the end use categories from 2002 to 2014. Over this period, electricity consumption increased from 100.1 TWh to 168.2 TWh, with a CAGR of 4.44%. The industrial sector makes up the largest portion, consuming some 73.8 TWh, or 43.8% of the total consumption in 2014. This is followed by the residential sector (23.1%), commercial sector (18.6%) and small general services (11.2%). The changes in electricity demand composition shown in Figure 6 indicate that the industry share in the total consumption has been slightly decreasing as opposed to gradual increases in percentage for consumption by the other sectors.

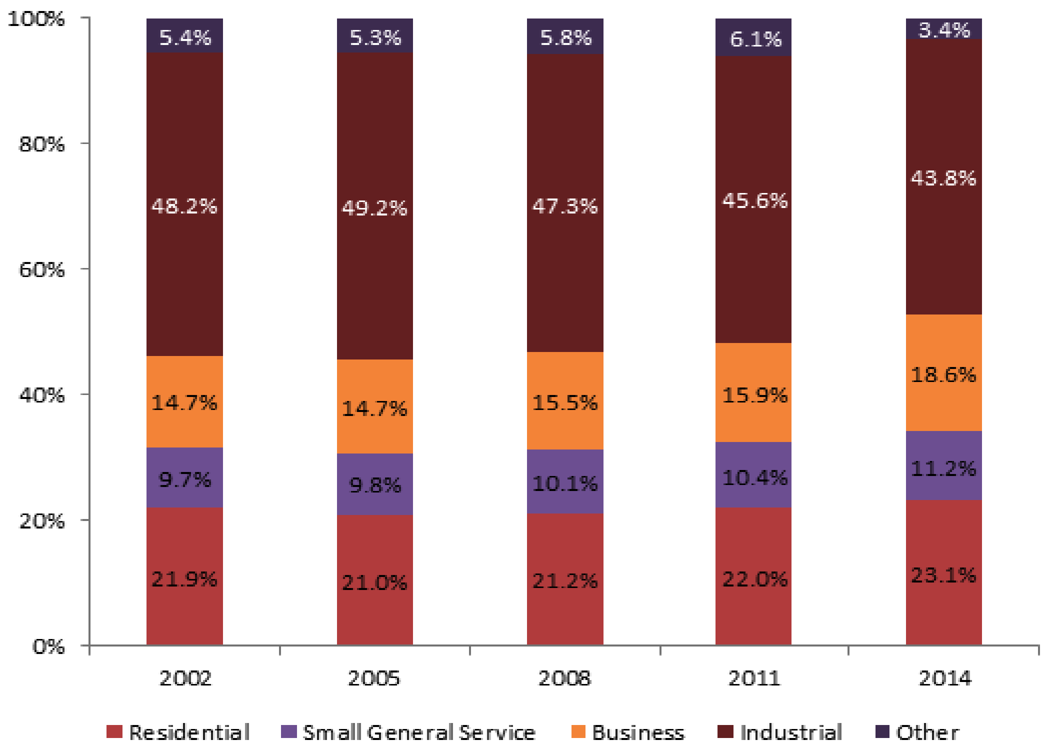
[4] The legend shows the installed MW of each technology and the percentage of the installed capacity for that technology.

**Figure 5 Electricity Demand by Category (2002-14)**




*Source: EPPO Statistics (2015)*

**Figure 6 Electricity Demand Shares by Category for Selected Years**




*Source: EPPO Statistics (2015)*

## 2.5 Generation Supply

Figure 7 shows generation by fuel type over the last 15 years, illustrating how natural gas increasingly dominates the Thailand fuel mix. In 2014, the total production of electricity was 180,945 GWh, 120,315 GWh or 66.5% of which was generated from natural gas. The next major type of fuel is coal, 120,314 GWh or 20.8% of the 2014 generation mix. The contribution of imports and other fuel sources has become more significant, increasing from 3,461 GWh (3.5%) in 2010 to 16,252 GWh (9.0%) in 2014. Generation proportions of all fuel types in 2014 are shown in Figure 8.

**Figure 7 Generation by Fuel Type (2000-2014)**

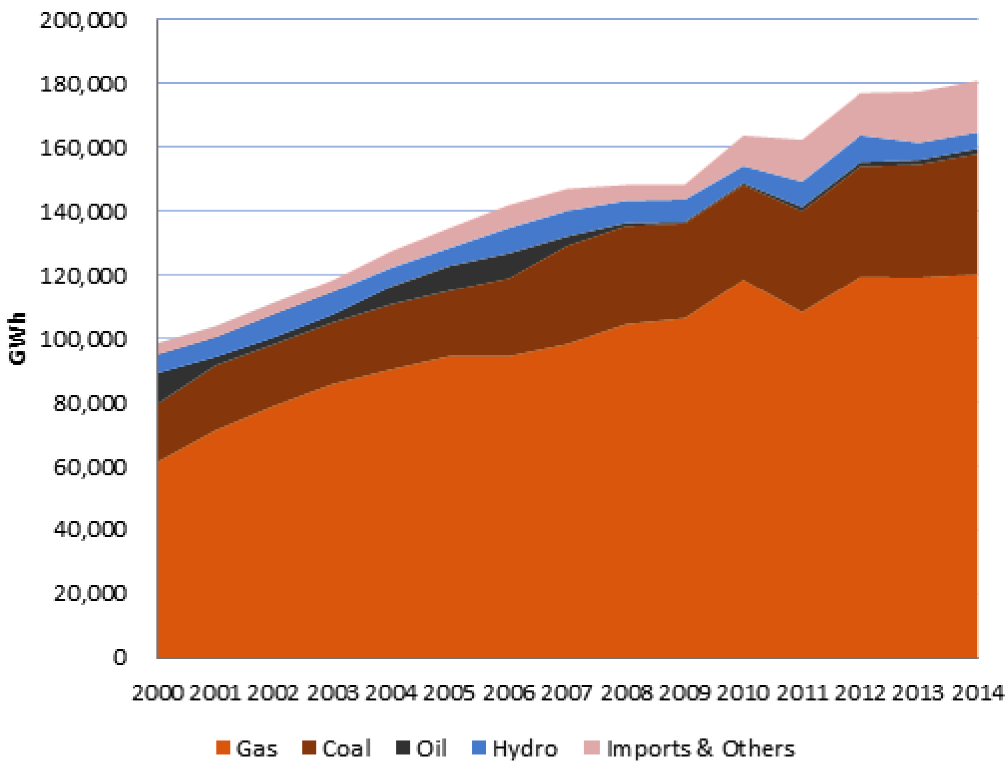
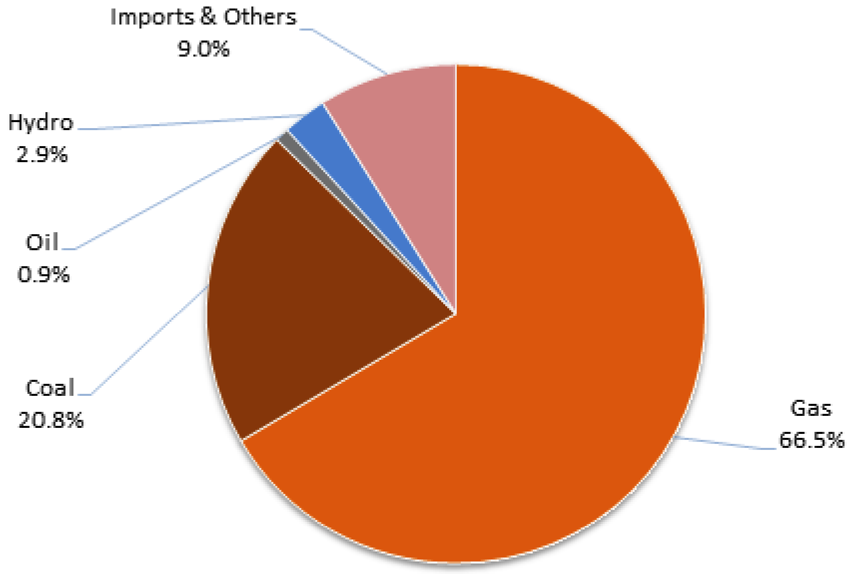


**Figure 8 Generation Mix Proportion by Fuel Type (2014)**

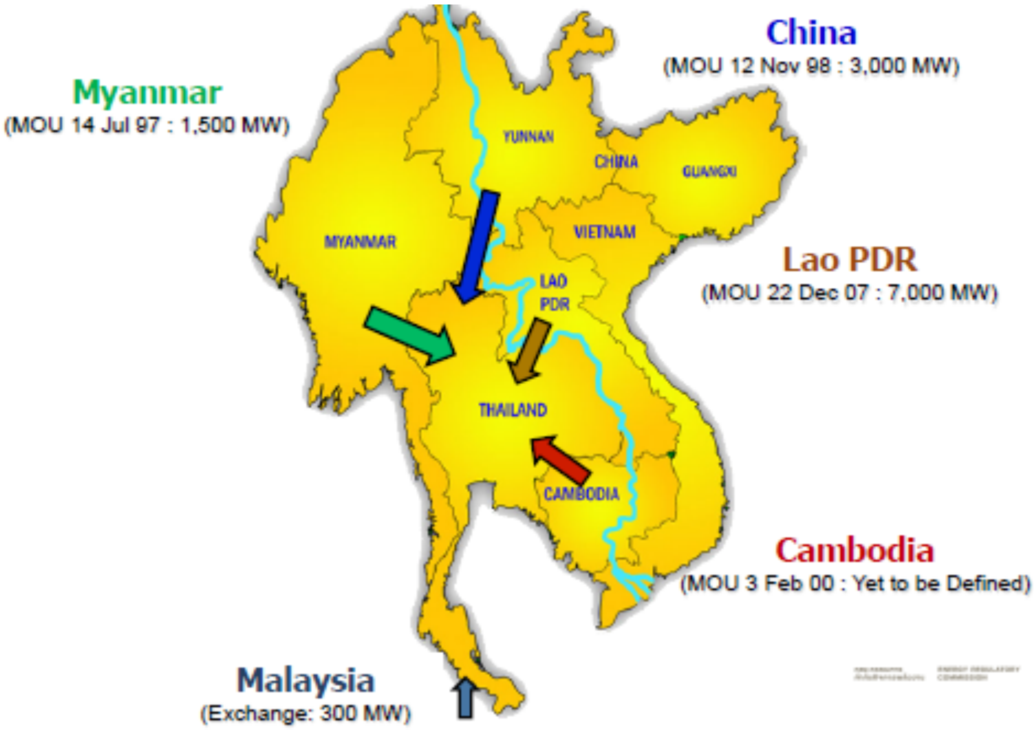



*Source: EPPO Statistics (2015)*

## 2.6 Imports and Exports

Thailand has MOUs with four neighbouring countries (China, Myanmar, Laos and Cambodia) for importing electricity. Thailand is also exchanging power with Malaysia. Figure 9 shows the general status of power imports into the country.

**Figure 9 Power Purchase from Neighbouring Countries**




*Source: ERC / EGAT*

In the GMS Thailand's transmission system has interconnections with Laos People's Democratic Republic (Laos PDR) via 230 kV and 500 kV transmission lines of capacity up to 1,800 MW through the Northeast region of the country.

In the south Thailand exchanges power with Malaysia via a HVDC transmission system with capacity of 300 MW. The MOUs with China, Myanmar and Cambodia have not been implemented yet but the new Power Development Plan (PDP 2015) indicates that electricity will be imported from Lao PDR and China's Yunnan province[5].

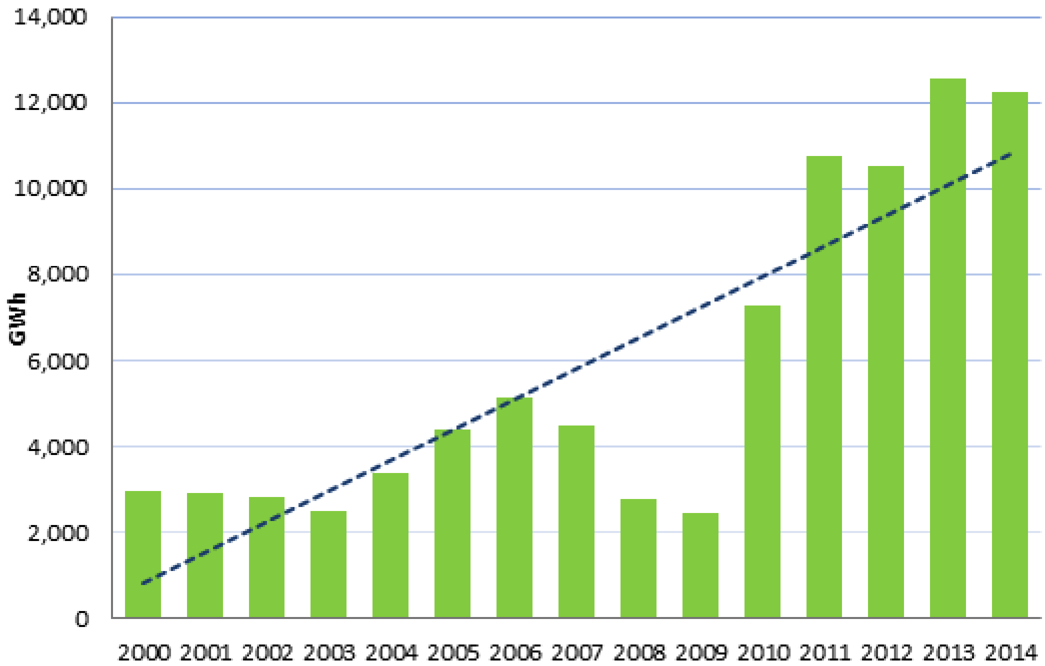
Figure 10 illustrates the trend of annual electricity imports from 2000 to 2014. It shows that the volumes of imported power have increased significantly over the last five years, from 2,460 GWh in 2009 to over 12,000 GWh in 2013/14.

Table 1 provides the list of all existing, confirmed (with signed PPA) and longer term prospective projects for electricity imports in Thailand. Note that the table limits the capacity of the Hong Sa project just to what is available for export to Thailand. The mine-mouth Hong Sa coal project, powered on reserves of lignite coal, had its first unit come online in 2015 with an additional two units expected to follow in 2016. Note that 80% (1,473 MW) of the total installed capacity of 1,878 MW from project is under a PPA with EGAT for imports to Thailand.

[5] http://www.chiangraitimes.com/thailands-new-power-development-plan-death-sentence-for-mekong.html

It was announced in August 2015 by proponent Impact Energy Asia Co that a windfarm to be developed in southern Lao PDR with an intention to export power to neighbouring countries The planned a 600 MW wind project is designed to leverage monsoonal wind patterns. Under an agreement signed by the Lao government and the Thai renewables firm, the wind farm would be located near the Mekong River across from Ubon Ratchathani, and is expected to commence operation for 2019. Around 95% of the power output from the windfarm is expected to be sold to countries bordering the Mekong, with Thailand likely to offtake some 90% of its output.

**Figure 10 Thailand Electricity Imports (2000-2014)**




*Source: EPPO Statistics (2015)*

## Table 1 Electricity Import Projects for Thailand

| No | Project Name | Capacity, MW | Fuel Type | Country of Export | COD[6] |
|---|---|---|---|---|---|
| **IN OPERATION** | | | | | |
| 1 | Nam Theun - Hinboun Hydropower | 434 | Hydro | Lao PDR | 1998, 2012 |
| 2 | Huoi Hoa Hydropower | 126 | Hydro | Lao PDR | 1999 |
| 3 | Nam Theun 2 | 948 | Hydro | Lao PDR | 2010 |
| 4 | Nam Ngum 2 | 597 | Hydro | Lao PDR | 2011 |
| 5 | Hongsa Thermal #1 | 491 | Coal | Lao PDR | 2015 |
| 6 | Khlong Ngae-Gurun Interconnection | 300 | EGAT-TNB HVDC Interconnection | Malaysia | 2005 |
| **PPA SIGNED** | | | | | |
| 7 | Su-ngai Kolok - Rantau-Panjang | 100 | EGAT-TNB 132 kV Interconnection | Malaysia | 2015 |
| 8 | Impact Energy Wind Farm[7] | 540 | Wind | Lao PDR | 2019 |
| 9 | Hongsa Thermal #2, 3 | 2x491 | Coal | Lao PDR | 2016 |
| 10 | Xe-pian Xe-Namnoi | 354 | Hydro | Lao PDR | 2019 |
| 11 | Nam Ngeip 1 | 269 | Hydro | Lao PDR | 2019 |
| 12 | Xayaburi | 1,220 | Hydro | Lao PDR | 2019 |
| **LONGER TERM PROSPECTS*** | | | | | |
| 13 | Dawei | 1,800 | Hydro | Myanmar | 2018 |
| 14 | Jing Hong (Yunnan) | 3,000 | Hydro | China | 2019 |
| 15 | Xe Kong 4-5 | 570 | Hydro | Lao PDR | 2021 |
| 16 | Coal fired | 800 | Coal | Malaysia | 2021 |
| 17 | Nam Kong 1 | 75 | Hydro | Lao PDR | 2022 |
| 18 | Semakan | 660 | Hydro | Lao PDR | - |
| 19 | Don Sahong | 240 | Hydro | Lao PDR | 2023 |
| 20 | Pak Beng | 912 | Hydro | Lao PDR | - |
| 21 | Hutgi | 1,190 | Hydro | Myanmar | 2023 |
| 22 | Mai Khot | 390 | Coal | Myanmar | - |
| 23 | Mong Ton | 6,300 | Hydro | Myanmar | 2026 |

[6] Note that CODs of 2016 and beyond are the earliest expected years of expected commercial operation.
[7] Based on the following reference, the PPA for this project has been signed: http://renewables.seenews.com/news/thai-company-to-build-600-mw-wind-farm-in-laos-report-487806.

# 3 Development Options for Thailand's Electricity Sector

## 3.1 Overview

Compared to other GMS countries, the development of traditional primary energy resources in Thailand for electricity generation face a number of challenges. Thailand's proven offshore gas reserves in the Gulf of Thailand and Thailand-Malaysia Joint Development Area (JTA) are being utilised with contracted gas from these reserves expected to be depleted by 2030. Liquefied natural gas (LNG) has been available since 2011 as a stop-gap measure with terminal sized at an initial capacity of 5 MTPA[8] and an option to double capacity to 10 MTPA. Reserves of domestic coal consist mainly of lignite to sub-bituminous grade concentrated around two main reserves: Mae Moh in the north and Krabi in the south, with the former being exploited, and the latter being considered for exploitation.

There has been a focus on developing an option for Nuclear Power with efforts over the last decade taken by Thailand to enhance knowledge and capability to enable nuclear power to be a long-term option should it be needed to address power supply shortages. Nuclear Power has, however, faced public opposition particularly in the wake of the Fukushima crisis. Nevertheless, nuclear power has appeared in all recent power development plans although in general the commercial operating date for the first nuclear power plant has occurred later in time in each power development plan, with PDP2015 having the first plant scheduled for 2035.

In contrast to the fossil fuel situation, Thailand has substantial potential for the development of hydro and other sources of renewable energy; most notably, biomass, solar, and wind. Large scale hydro power potential in Thailand is estimated to be around 15 GW. However, the environmental externalities associated with exploiting hydro beyond the current 3.5 GW of large scale hydro already developed is regarded to be unsustainable and there is strong resistance to further developments. The government has therefore focused on and promoted small hydro power projects. The AEDP2012 proposed a target of 1,608 MW of small hydro by 2021, although, this was revised in the AEDP2015 to 376 MW by 2036. There has in the past been the development of pumped storage hydro, with the 1000 MW Lam Ta Khong hydro project having pumped storage capability of 500 MW added in 2001 and Srinagarind having some 360 MW of pumped storage capability of its rated capacity of 720 MW.

Thailand has an annual average wind speed of 4-5 meters per-second at an elevation of 90 meters above sea level. Higher wind speeds of 6-7 meters per second can be found in mountain ranges in the south and the northeast during the period of the monsoons. There is potential for the deployment of wind turbines for power generation throughout the country, particularly along the sea shores and on

[8] Million Tons per Annum

islands either in the Gulf of Thailand or Andaman Sea. Under the 2015 Alternative Energy Development Plan (AEDP2015), Thailand targets some 3,002 MW of wind farm installed capacity by 2036.

Being located near to the equator area, Thailand has substantial potential for solar photovoltaic development. Areas in Thailand that have been identified to have the greatest potential include the southern and northern parts of the Northeast region of the Udon Thani province and substantial potential has been identified across the Central region. In the recent past a number of initial large scale solar developments have been put in operation and expectations are that this trend will continue into the near-term. The AEDP2015 has set a target for 6000 MW of solar photovoltaics by 2036.

Thailand, having a number of large areas with Direct Normal Irradiation (DNI) in the range of 1600 to as high as 1950 kWh/m^2/year, located mostly in the north western part of the country shows some promise for Concentrated Solar Power (CSP). In general, the literature suggests that the minimum level for CSP to be feasible is around 1700 to 1800 kWh/m^2/year but preferably higher; in this study we have assumed that the technological challenges of areas with DNI levels that are not significantly beyond this range for a technology that is currently in its infancy, will be overcome within a 10 to 15 year timeframe.

As an agricultural country, Thailand's potential for biomass in the form of agricultural residues is significant. With the abundance of industrial waste and livestock manure, Thailand also has significant biogas potential. The AEDP2015 suggests installed capacity targets for 2036 of 5,600 MW of biomass with agricultural residues as the primary feedstock, 600 MW of biogas resources, and 500 MW of municipal waste. Based on various studies, the potential for geothermal and ocean energy appears to be limited for Thailand. The AEDP2015 has set modest targets for these technologies as they are unlikely to be deployed on a large scale.

## 3.2 Natural Gas

Thailand is estimated to have some 285 Bcm (10.1 Tcf) of proved reserves, or around 6.8% of the total proved natural gas reserves of the GMS. Table 2 and Figure 11 summarise proved natural gas reserves for the GMS countries. The figure also shows the reserves to production ratio (RPR). Thailand has a low RPR number, meaning that the majority of fields with proven reserves have already been put into production.

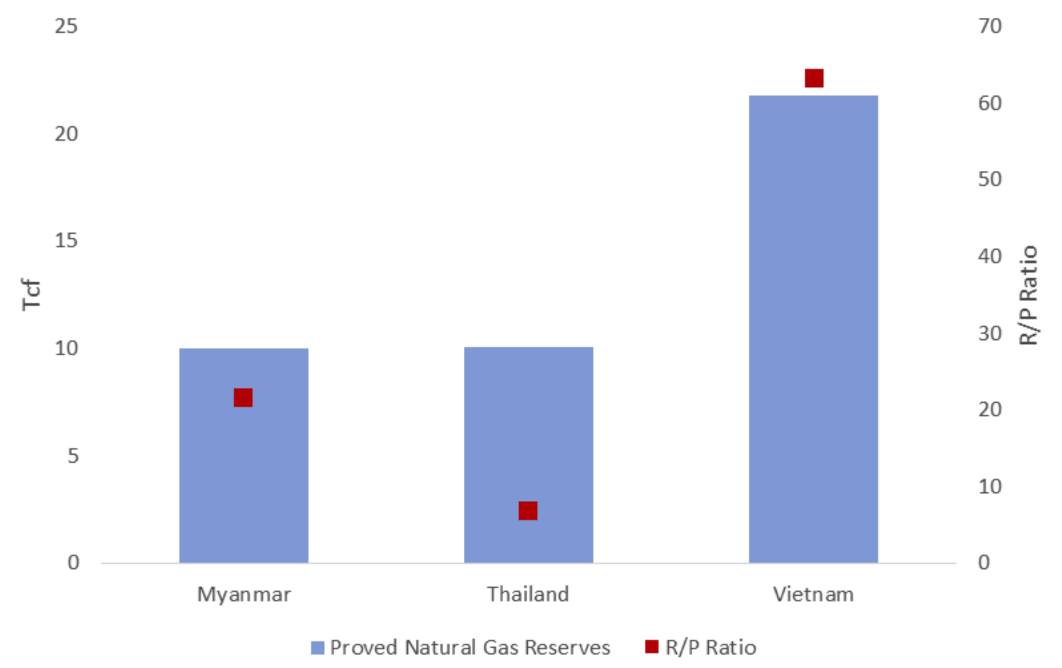
**Table 2 Proved Natural Gas Reserves in GMS Countries**

| | Proved Reserves | | RPR |
|---|---|---|---|
| | Bcm | Tcf | Years |
| Myanmar | 283.2 | 10.0 | 22 |
| Thailand | 284.9 | 10.1 | 7 |

| | | | |
|---|---|---|---|
| Viet Nam | 617.1 | 21.8 | 63 |

*Source: BP Statistics 2014*

**Figure 11 Proved Gas Reserves of GMS Countries**



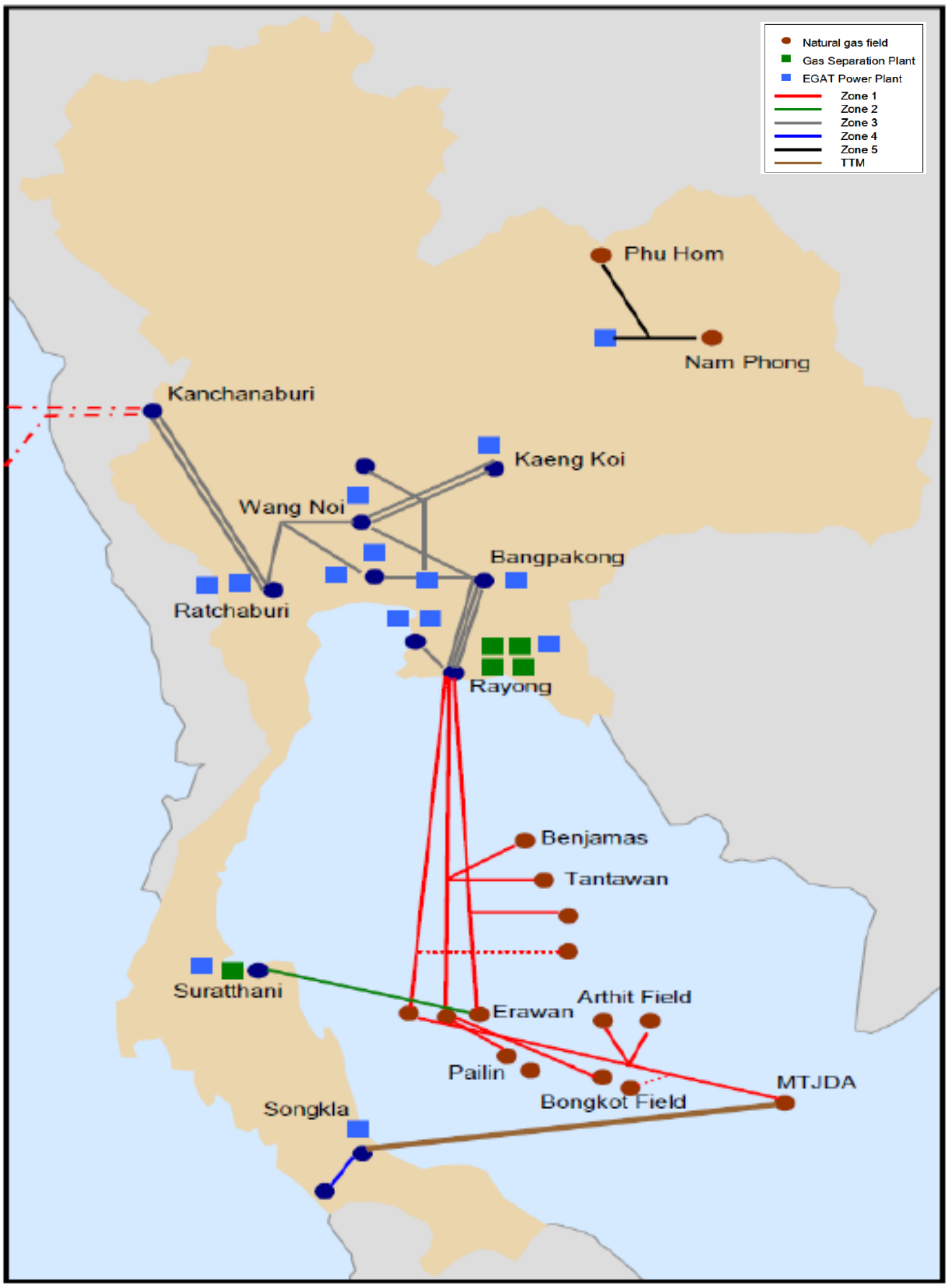

*Source: BP Statistics 2014*

### 3.2.1 Natural Gas Production and Imports

Upstream oil and gas activities are dominated by PTT Exploration and Production (PTTEP), a subsidiary of PTT Public Company Limited (PTT). The PTT Group, whose business areas range from supply procurement, transportation, distribution, gas processing, investment in natural gas vehicle (NGV) service stations, and investments in related businesses through the Group's subsidiaries. Eighty-five per cent of Thailand's petroleum reserves are located in the Gulf of Thailand, which is characterised by clusters of small wells in shallow water and over 300 platforms[9]. An illustration of Thailand's gas infrastructure is provided in Figure 12.

[9] Austrade, 2015: http://www.austrade.gov.au/Export/Export-Markets/Countries/Thailand/Industries/Oil-and-gas#.VWaIrfmqpBd

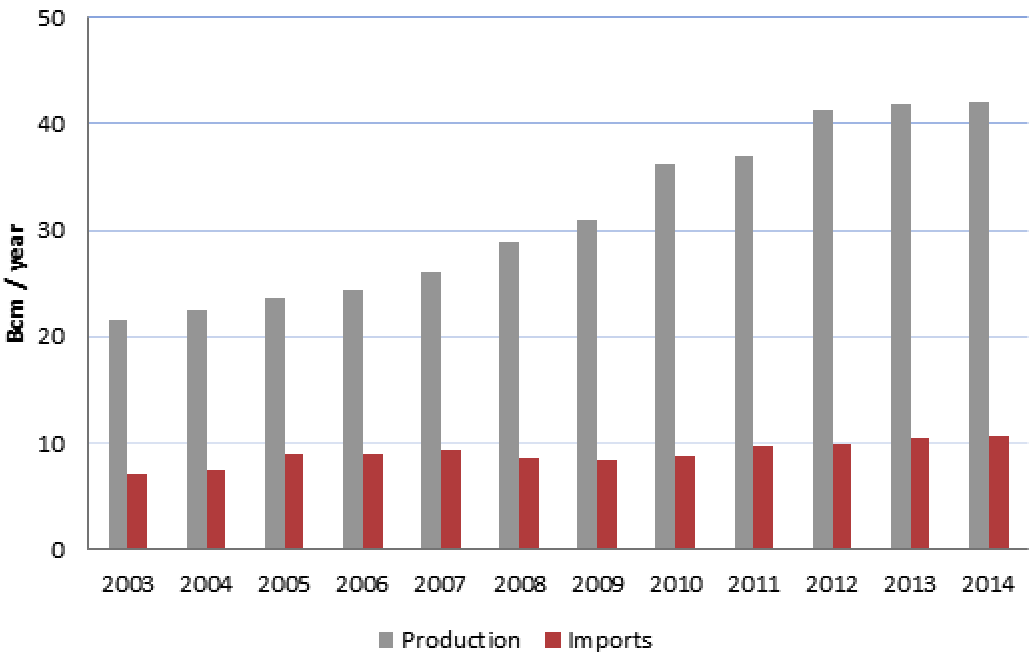
**Figure 12 Thailand's Gas Fields and Infrastructure (2014)**




*Source: T. Parkinson, "Natural Gas and LNG Market in Thailand", 2014*

Figure 13 shows the trend in gas production and imports in Thailand. In 2014, the total natural gas production in Thailand was 42.1 billion cubic metres, which was nearly twice as much the 2003 production volume of 21.5 Bcm. Despite increases in production, Thailand is relying on gas imports from Myanmar to meet the domestic demand. In 2014, it imported 10.6 Bcm of natural gas in LNG purchases and via pipelines from Yadana, Yetakun and Zawtika gas fields in Myanmar. Current imported volumes account for around 20% of the total natural gas supply. It is evident that future gas demand growth will have to be met by increased gas imports, and particularly LNG, as domestic supplies progressively deplete[10].

**Figure 13 Gas Production in Thailand (2003-2014)**




*Source: BP Statistics (2014) and EPPO Statistics (2015)*

### 3.2.2 Liquefied Natural Gas in Thailand

Thailand has Map Ta Phut LNG facility in the eastern province of Rayong but it has been operating only at a partial output as domestic demand is being met primarily by imported supplies. According to PTT, its imports of LNG reached around 2 million tonnes over the last year and it is planning to more than double this volume for 2015, partly to help replace potential declines in pipeline imports from Myanmar. Current LNG suppliers for Thailand include Qatar Liquefied Gas Company Limited; it is also reported to be in talks with other suppliers from Mozambique, United States, Australia and Russia to secure additional long term supply contracts.

The existing import terminal has a capacity of 5 million tonnes a year, and PTT is constructing a second LNG terminal at the same location and of the same capacity, with completion expected in 2017. In preparation for falling imports from Myanmar and declining domestic output from the Gulf of Thailand, PTT is also considering a

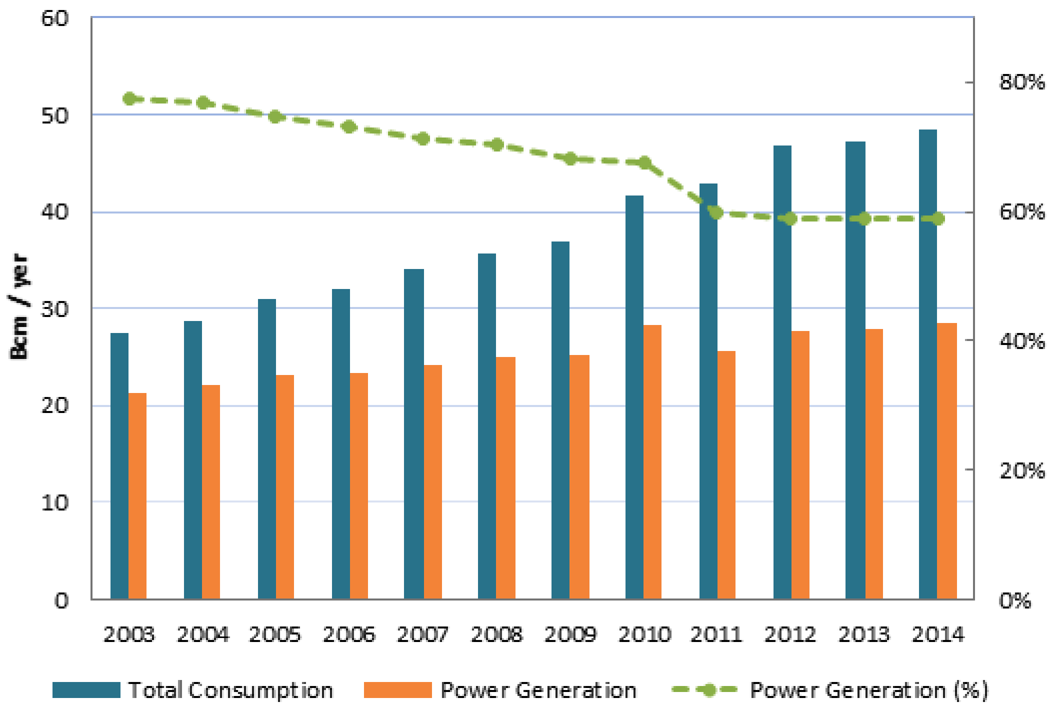
[10] Enerdata, 2014: http://www.enerdata.net/enerdatauk/press-and-publication/energy-news-001/thailand-natural-gas-conundrum_29249.html

plan to build an LNG receiving terminal adjacent to a gas pipeline linked to gas fields in Myanmar. PTT's argument has been that such a site on the coast of Myanmar would offer a more convenient delivery point for LNG from Middle East suppliers.

### 3.2.3 Natural Gas Use in Electricity Generation

Figure 14 shows the gas consumption trend in general and in the electricity sector for the period 2003 to 2014 as published by EPPO. The total consumption in 2014 was some 48.4 Bcm, of which 28.5 Bcm was used for electricity generation. Although gas consumption by the power sector has increased one third in volume over the given period, its share in the total consumption declined, from 77% in 2003 to 59% in 2014. This indicates that use of natural gas by the other sectors including industry, GSP and NGV has been growing at faster rates.

**Figure 14 Gas Consumption in Thailand (2003-2014)**




*Source: EPPO Statistics (2015)*

## 3.3 Coal Resources

### 3.3.1 Coal Reserves and Supply

According to BP Statistics, Thailand proven coal reserves at end of 2013 were estimated at 1,239 million tons, consisting of lignite and sub-bituminous grades of coal. The country's major coal sites include the Mae Moh basin operated by the Electricity Generating Authority of Thailand (EGAT), the Krabi basin, the Saba Yoi and Sin Pun basins in the southern area, and the Wiang Haeng, Ngao and Mae Than basins in the north.

Figure 15 shows the location of some large strategic coal mines and deposits. These include Mae Moh (the largest basin), Mae Than and Li in the north, and Krabi in the south. Table 3 provides data on Thailand coal reserves as of 2010 according to the Ministry of Energy’s statistics. Figure 16 shows the annual volumes of coal supply in Thailand for the period 2013-14. This indicates that the production of domestic lignite was stable at around 18 million tons per year, whereas the coal imports have substantially increased, from 7 million tons in 2003 to 20.9 million in 2014, surpassing the domestic supply. According to EPPO statistics, most of the domestic lignite supply (17.1 out of 18 million tons in 2014) is produced by EGAT owned and operated Mae Moh Mine, which then is fully consumed by EGAT coal fired power plants.

## Figure 15 Location of Thailand Strategic Coal Deposits

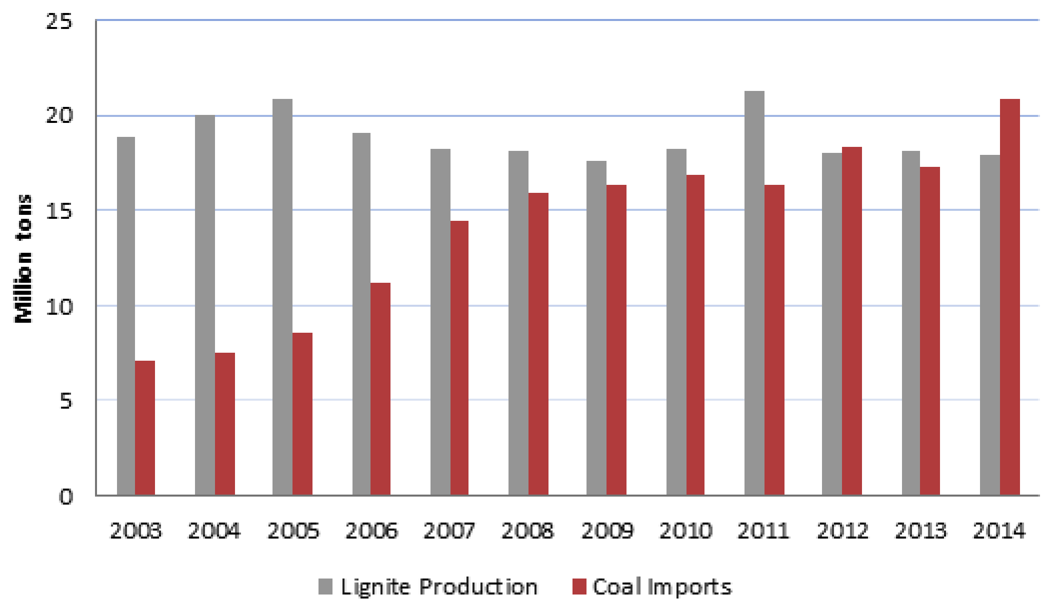

*Source: EPPO and EGAT*

**Table 3 Thailand Coal Reserves (2010)**

| Basin | Location | | Reserve | | Coal Rank | Age | Concessionaire |
|---|---|---|---|---|---|---|---|
| | District | Province | Produced | Remaining | | | |
| **Northern Region** | | | | | | | |
| Na Hong | Mae Chaem | Chiang Mai | 2.5 | - | Lignite to sub-bituminous | Tertiary | Non active |
| Bo Luang | Hod | Chiang Mai | 1.8 | - | Lignite to sub-bituminous | Tertiary | Non active |
| Mae Teep | Ngao | Lampang | 2.2 | - | Lignite to bituminous | Tertiary | Active |
| Mae Than | Sop Prap | Lampang | 35.5 | 0.5 | Lignite to Bituminous | Tertiary | Active |
| Mae Moh | Mae Moh | Lampang | 338.0 | 1,050 | Lignite to sub-bituminous | Tertiary | EGAT, Active |
| Li | Li | Lamphun | 39.7 | - | Lignite to Bituminous | Tertiary | Active |
| Chiang Muan | Chiang Muan | Phayao | 4.5 | - | Lignite to Bituminous | Tertiary | Suspended |
| Mae Tun | Mae Ramat | Tak | 0.4 | 0.8 | Lignite to Bituminous | Tertiary | Non active |
| Mae Lamao | Mae Sod | Tak | 1.2 | - | Lignite to bituminous | Tertiary | Non active |
| **Central Region** | | | | | | | |
| Nong Ya Plong | Nong Ya Plong | Phetchaburi | 1.2 | 0.5 | Lignite to bituminous | Tertiary | Non active |
| **Southern Region** | | | | | | | |
| Krabi | Muang | Krabi | 8.7 | 111.3 | Lignite to sub-bituminous | Tertiary | EGAT, suspended |
| Kantang | Kantang | Trang | 0.01 | - | Lignite | Tertiary | Non active |
| **Northeastern Region** | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Na Duang | Na Duang | Loei | 0.2 | - | Anthracite | Pre-tertiary | Non active |
| Na Klang | Na Klang | Nong Bualumphu | 0.07 | - | Anthracite | Pre-tertiary | Non active |
| | | **Totals** | **436** | **1,164** | | | |

**Figure 16 Coal Supply in Thailand (2003-2014)**

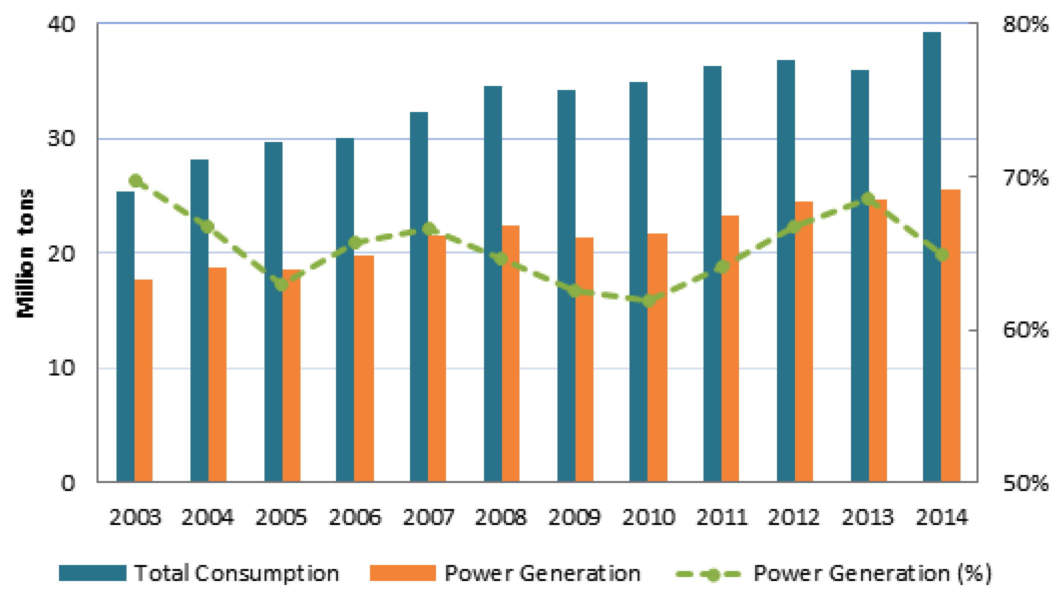



*Source: EPPO Statistics (2015)*

### 3.3.2 Existing Coal Consumption

Figure 17 shows the yearly consumption of coal in Thailand and for power generation in particular, for the period 2013 -2014. This indicates that around two thirds of the total consumption is attributed to electricity generation.

**Figure 17 Coal Consumption in Thailand (2003-2014)**




*Source: EPPO Statistics (2015)*

## 3.4 Nuclear Power

Nuclear power was included in the Thailand's Power Development Plan 2007-2021 (PDP 2007). This planned to have 2,000 MW of nuclear capacity in operation by 2020 and another 2,000 MW the following year. The PDP has been revised a number of times due to the change in the electricity demand, all revised PDPs have considered nuclear power[11].

Thailand had carried out the self- evaluation on Intergraded Nuclear Infrastructure Review (INIR) and submitted a report to the International Atomic Energy Agency (IAEA) in October 2010. IAEA experts conducted a mission to Thailand during December 2010 to conclude that "Thailand can make a knowledgeable decision on the introduction of nuclear power".

According to the PDP2010 – Revision 3, the first NPP project was postponed for 6 years until 2026 to promote greater public understanding of NPP and fill major gaps identified by Intergraded Nuclear Infrastructure Review (INIR) mission. A pre-project phase is now underway with the following ongoing activities:

- Preparation of laws and regulations for nuclear power;
- Technical and safety reviews;
- Site selection reviews (to meet Emergency Preparedness and Response requirements);
- Public communication, education and participation; and
- Human resource development.

Nevertheless, the latest PDP2015 has nuclear power generators occurring at later periods of time, with the first unit in 2035 and the second in 2036.

## 3.5 Hydro Power

The potential of hydropower in Thailand is estimated at 15,155 MW[12]. Hydropower has been developed for power generation since 1964 with the construction of several large hydropower projects throughout the country. As of December 2014, hydro installed capacity was 3,444 MW, accounting for 10% the total system capacity. It is noted that the annual volume of electricity generation from hydro has not changed much since decades ago. In 2014, the hydropower generated 5,163 GWh, accounting for fewer than 3% of the total generation of 180,945 GWh, compared to around 20% back in 1986[13].

Hydropower resources are difficult to exploit due to the environmental impact on the resource areas a power project would entail. Future development of hydropower resources in Thailand is limited to a small number of small-scale projects which are considered to be economical.

[11] IAEA, 2013: https://www.iaea.org/NuclearPower/Downloadable/Meetings/2014/2014-03-17-03-21-WS-INIG/DAY3/COUNTRY/Thailand_v1.pdf
[12] Greenline Energy: http://www.greenlineenergy.com.au/index-4.html
[13] EPPO 2015 Statistics: http://www.eppo.go.th/info/5electricity_stat.htm

The government has been sponsoring development projects of small hydro power plants for a new planned capacity of 350 MW. The Department of Alternative Energy Development and Efficiency (DEDE) and the Provincial Electricity Authority (PEA) are the main institutions involved with mini- and micro-hydro power plants. DEDE has also installed many village-level hydropower plants, and there is considerable potential for village-scale small hydro in east and central Thailand. According to the 2012 Alternative and Renewable Energy Development Plan (AEDP2012), Thailand planned to increase small hydropower capacity from 102 MW in 2012 to 1,608 MW by 2021[14]. Nevertheless, the latest AEDP2015 has reduced this target to 376 MW for 2036.

## 3.6 Wind Power

Thailand has an annual average wind speed of 4-5 meters per second at an elevation of 90 meters above sea level. Higher wind speeds of 6-7 meters per second can be found in mountain ranges in the south and the northeast during the period of the monsoons. There is potential for utilisation of wind turbines for power generation throughout the country, particularly along the sea shores and on islands either in the Gulf of Thailand or Andaman Sea. Low-speed wind turbines can start rotating at wind speeds of 2.5 meters per second and generate a full load of electricity at 9 meters per-second. Wind speed in Thailand is mainly influenced by the northeast monsoon, the southwest monsoon and local topography. The total onshore wind potential in Thailand is estimated at up to 30,000 MW and 7,000 MW for offshore wind around the Gulf of Thailand[15].

Figure 18 shows average monthly wind speed measurements for Thailand as reported by NASA Atmosphere Science Data Centre for the locations that have the highest average wind speeds throughout the year. This shows that a number of locations in Thailand records high wind speeds during the periods of June to August and November to December. When these locations are shaded over the map of Thailand, as illustrated in Figure 19, we can see that in the main the locations are along the country’s southern and central regions which are close to the metropolitan load centre. There are also some locations with significant wind potential further to the north.

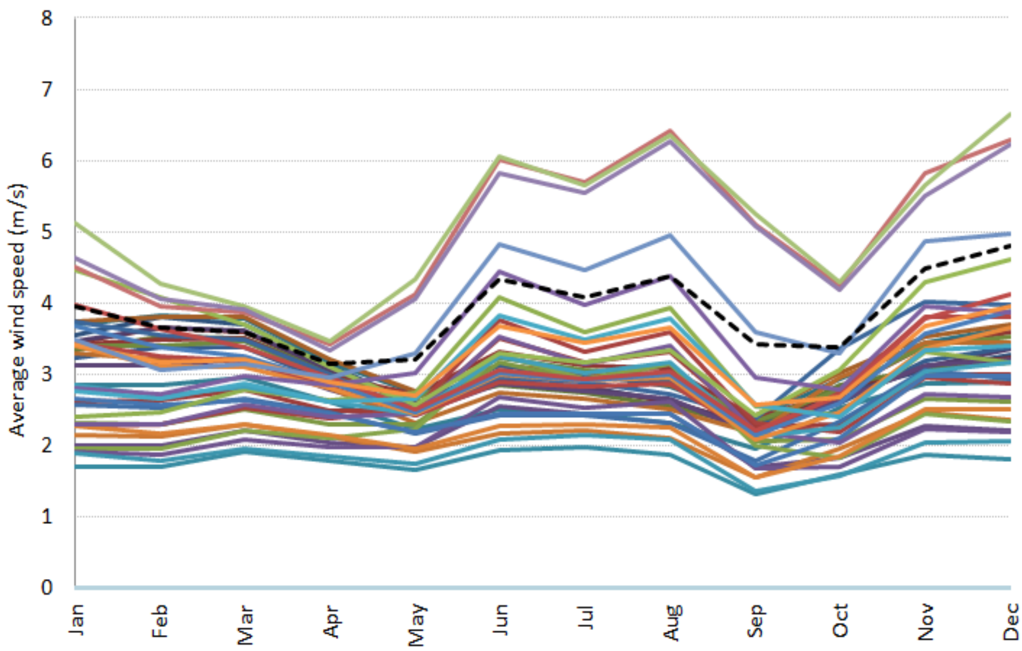
Key activities regarding wind power potential survey in Thailand over the past years include the conduct of a map in 2001 that demonstrated wind power potential in Thailand, based on DEDE’s wind speed statistics at the 10-meter height wind measurement posts and from other data sources. The survey found that potential wind power sources located in the Gulf of Thailand-from Nakornsritammarat, Songkla, to Pattany, as well as some areas in Petchburi and Doi Intanon, with an average wind speed of 6.4 meters per second at 50-meter height.

[14] Thailand Alternative Energy Industry: http://www.slideshare.net/boinyc/thailands-alternative-energy-industry
[15] Wind Energy Resource Atlas of Southeast Asia (TrueWind Solutions, 2001), Renewable Energy Developments in the Greater Mekong Subregion (ADB, 2015), Offshore wind power potential of the Gulf of Thailand (Waewsak, Landry, Gagnon, 2015)

The Thai government supports investors with special incentives for investing in wind energy. In addition, the DEDE has initiated the Demonstration Project on (Micro) Wind Power Generation at a Community Level, since 2007, by supporting the installation of micro wind turbine sets for one kilowatt power generation. The targeted areas are 60 communities nationwide. This effort is intended to promote production of wind turbines and increased use of wind energy in the future. Wind Energy Holding Co., Ltd, a wind project developer, has already finished installing windfarm projects called “West Huay Bong 3” and “West Huay Bong 2”. Both wind farm projects, located in Nakhon Ratchasima, have capacity of 103.5 MW each and started commercial operation since November 2012 and February 2013, respectively. Additionally, the company has a long-term investment plan for wind farms with a total installed capacity of 1,000 MW by 2017.

Under the 2015 Alternative Energy Development Plan (AEDP2015), Thailand targets some 3002 MW of wind farm installed capacity by 2036.

**Figure 18 Monthly Wind Speeds for Selected Locations in Thailand**




*Source: NASA Atmosphere Science Data Centre, obtained via the SWERA Geospatial Toolkit*

**Figure 19 Locations in Thailand with Highest Wind Potential**

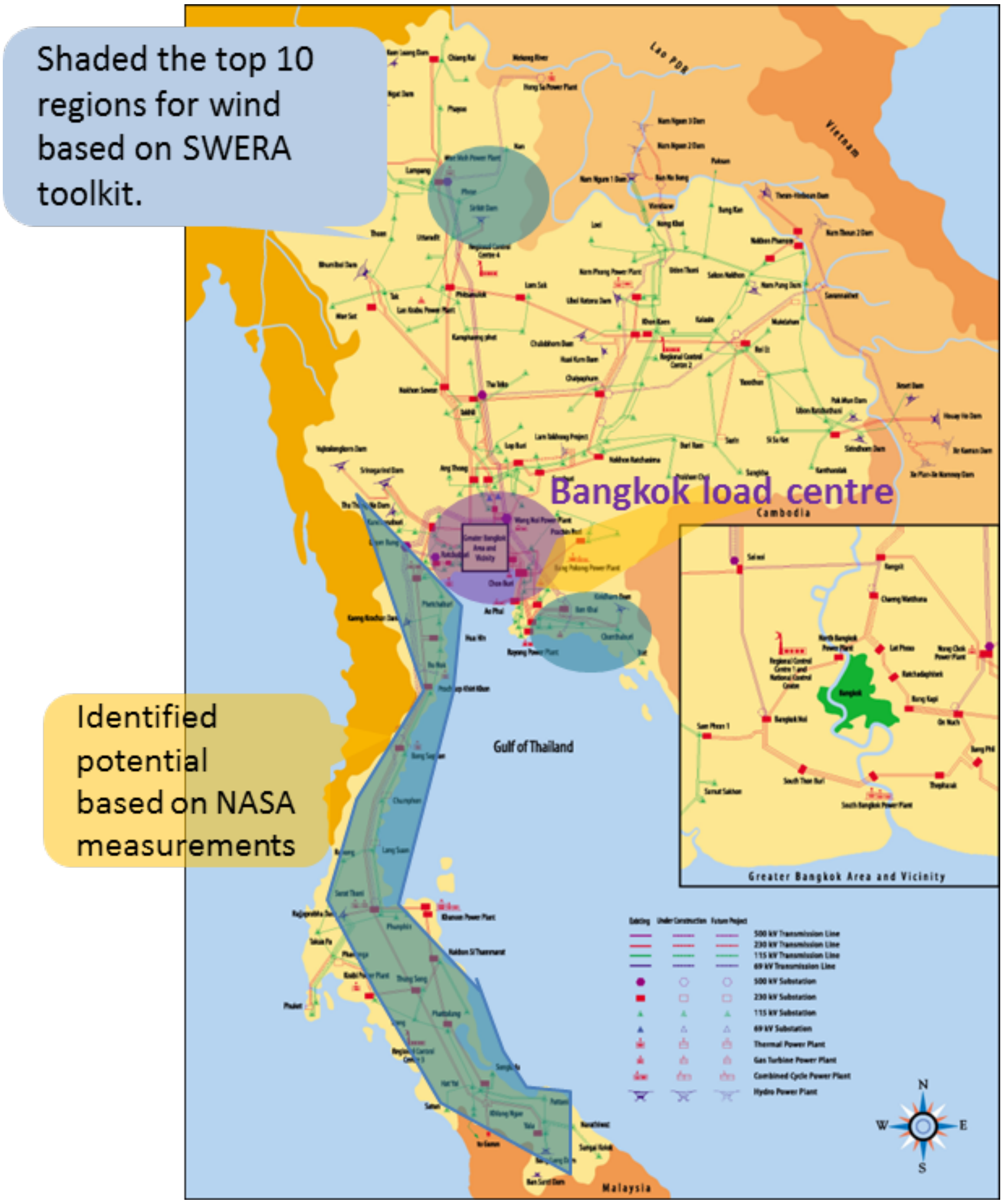
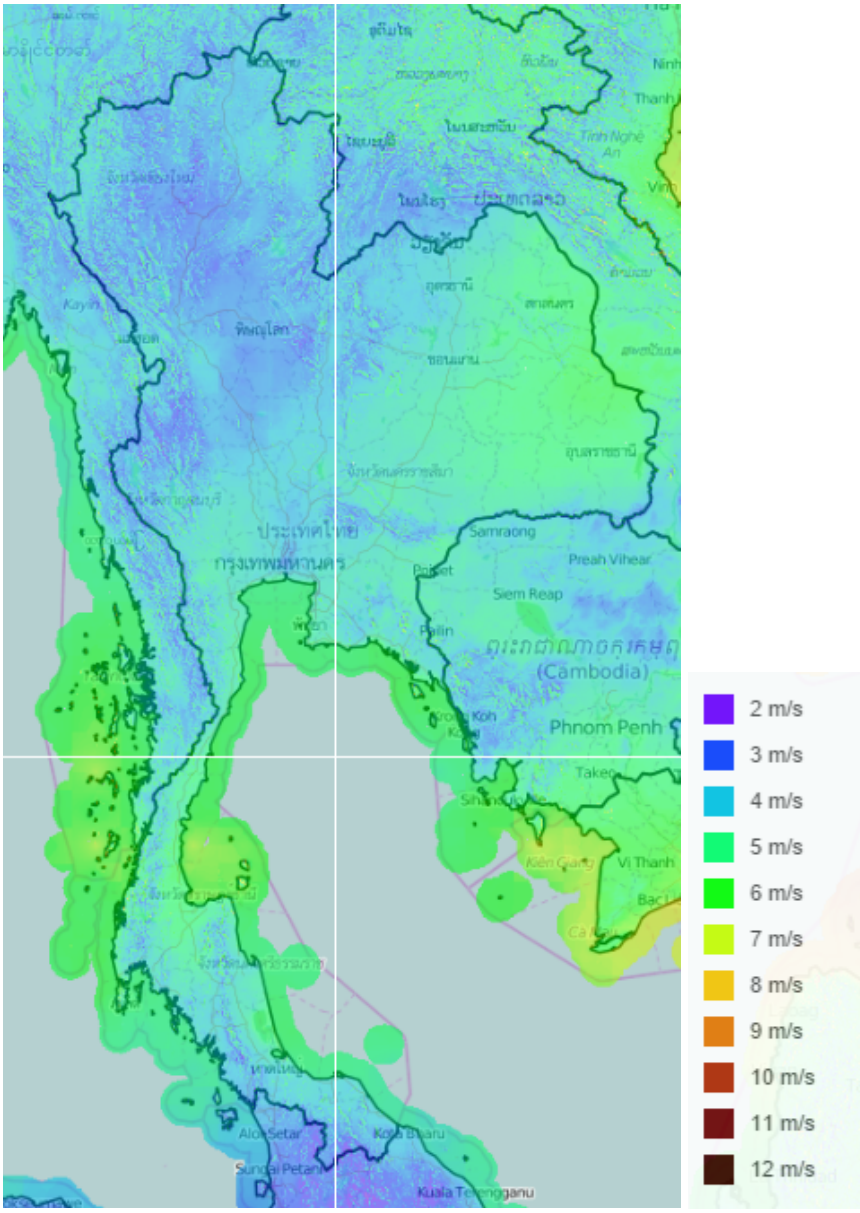



Figure 20 shows the DTU Global Wind Atlas[16] onshore and 30 km offshore wind climate dataset which accounts for high resolution terrain effects for 100 m above ground level. According to the IRENA global atlas description: "this was produced using microscale modelling in the Wind Atlas Analysis and Application Program and capture small scale spatial variability of winds speeds due to high resolution orography (terrain elevation), surface roughness and surface roughness change effects. The layers shared through the IRENA Global Atlas are served at 1km spatial

[16] See: http://globalwindatlas.com/.

resolution. This is quite consistent with the lower resolution assessment of potential presented in Figure 19, and it highlights offshore potential exists to both the east and west coastlines of the Thailand's peninsular in the south. Another chart to show the onshore dispersion of wind potential charted in Figure 21. This shows 3TIER's Global Wind Dataset[17], which provides average annual wind speed at 80 meters above ground level.

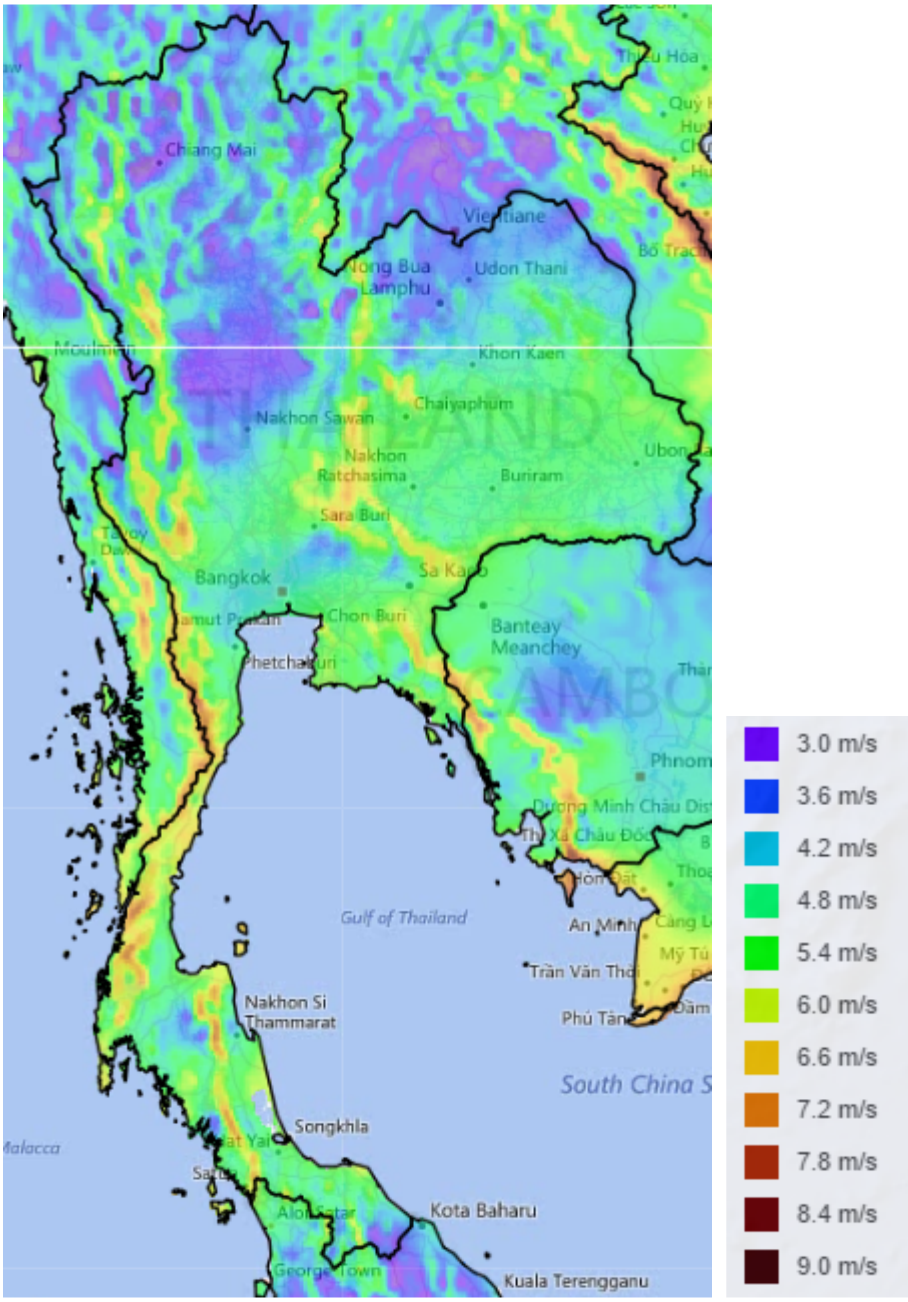
**Figure 20 Average Wind Speed 1km at 100 m AGL DTU (2015)**




*Source: IRENA Global Atlas and Global Wind Atlas (2015)*

[17] Source: 3TIER data set was accessed via the IRENA Global Atlas Server: http://irena.masdar.ac.ae/.

## Figure 21 3TIER's Global Wind Dataset 5km onshore wind speed at 80m height[18]




Source: 3TIER's Global Wind Dataset (accessed via IRENA Global Atlas)

[18] Average for period from 1980 to 2011.

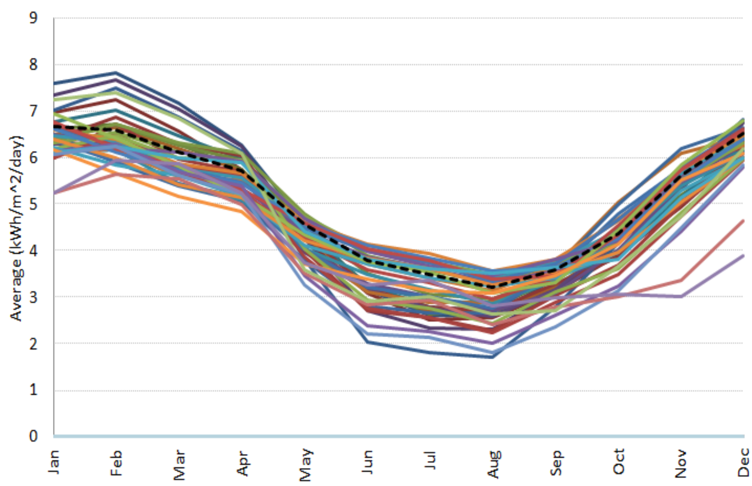
## 3.7 Solar Power

Located in the tropics, Thailand has excellent potential for largescale integration of solar resources. Thailand is estimated to have solar PV potential greater than 50,000 MW[19]. The annual average of total daily solar radiation in Thailand is 5.06 kWh/m2 or 18.2 MJ/ m2. Most of the country receives the maximum solar radiation during April / May, ranging from 5.56 to 6.67 kWh/m2 per day. The North-eastern and central regions are among those locations that have greater solar power potential. Figure 22 plots the monthly average direct normal irradiation (DNI) levels for selected sights with the highest annual average irradiation levels in Thailand. This shows the monthly variation throughout the year for solar irradiation and that November through to April have excellent solar conditions.

The chart also shows monthly DNI levels for various sites in Thailand. Sites with the highest DNI levels average 5.3kWh/m^2/day (with a deviation of approximately 1kWh/m^2/day) across the year. In general, DNI measurements in excess of about 4.95 kWh/m^2/day are deemed appropriate for the deployment of concentrating solar power (CSP). Figure 23 shows a map of Thailand shading the locations where solar potential is at its highest. This highlights that the greatest potential for solar lies in the central and eastern region of the country. Figure 24 plots measurements of Global Horizontal Irradiance (GHI) based on the 3TIER high resolution dataset accessed via the IRENA Global Atlas. This map shows that the GHI potential is significant throughout the entire country as well.

According to the AEDP2015 data, as of end 2014, Thailand had 1,299 MW of solar power production capacity installed. The plan has set a target for solar energy capacity of 6,000 MW by 2036, with the technology considered to be photovoltaics.

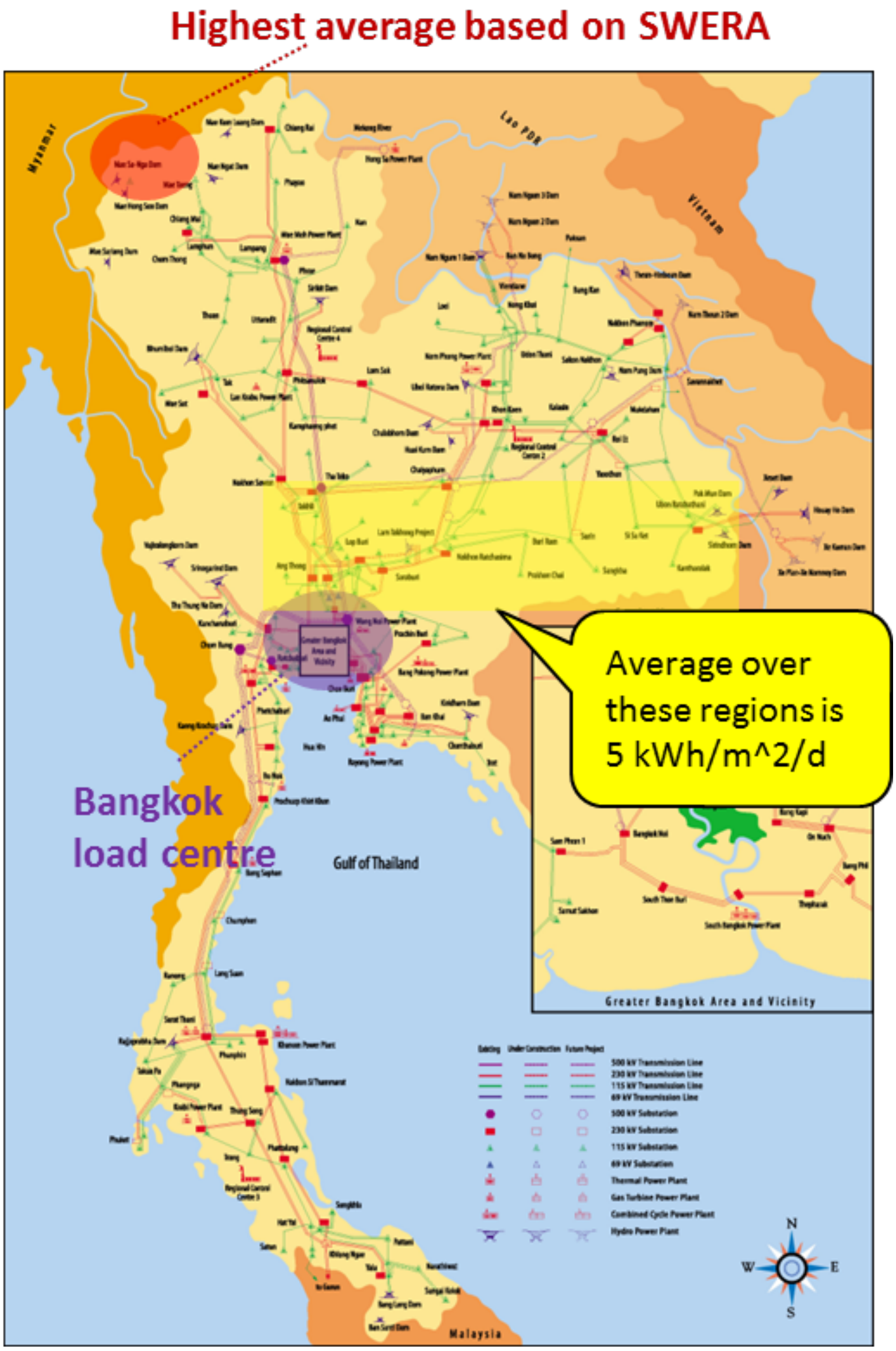
**Figure 22 Monthly DNI for Selected Locations in Thailand**



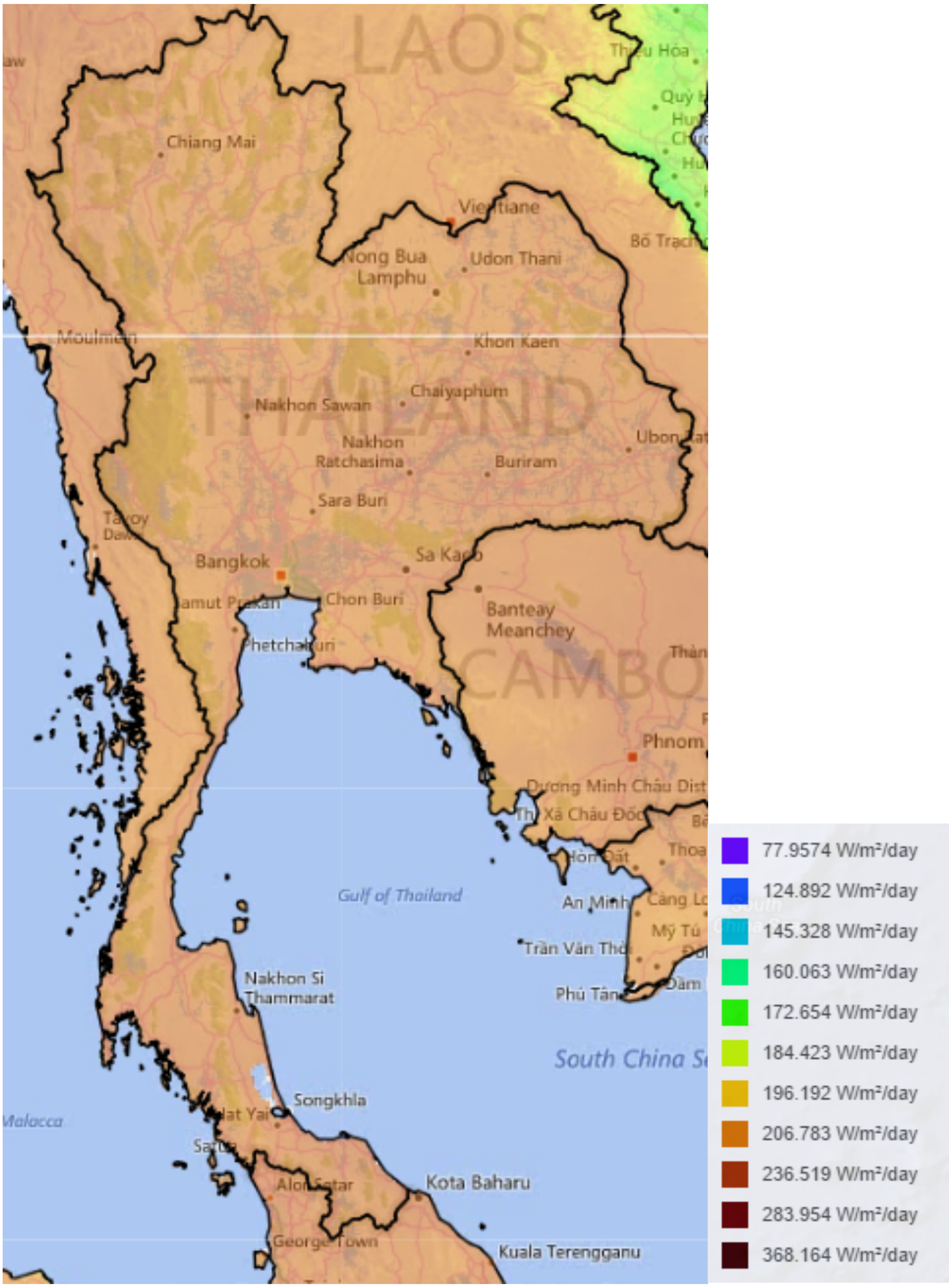

*Source: NASA Atmosphere Science Data Centre, obtained via the SWERA Geospatial Toolkit*

[19] See Section 3.13.

**Figure 23 Main Locations with Solar Power Potential based on DNI in Thailand**



## Figure 24 3TIER's Global Solar Dataset (3km in W/m^2) for GHI



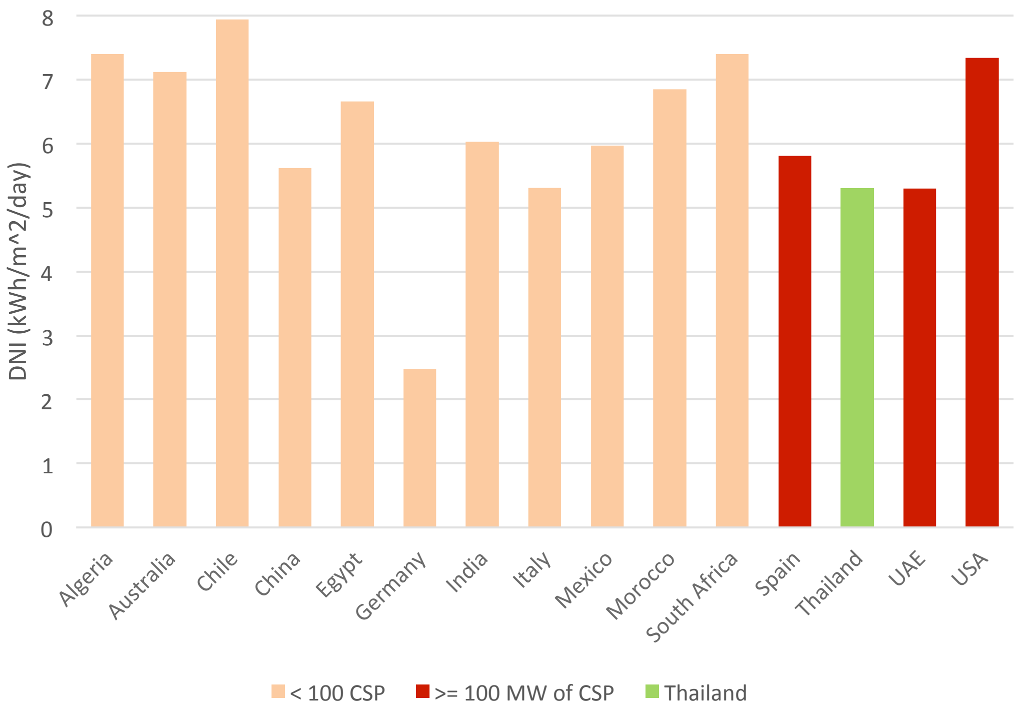

Source: 3TIER's Global Solar Dataset (accessed via IRENA Global Atlas)

### 3.7.1 Concentrated Solar Power

Table 4 provides a list of countries (including Thailand) that have CSP installations. This table shows the installed capacity of CSP and planned capacities as of about 2014, and the corresponding DNI for the country. The data is also represented visually in Figure 25, including Thailand. The chart plots the countries with more than 100 MW of CSP in red to highlight those where it can be argued to have been successfully deployed. It can be seen that Thailand's average DNI for the locations that we have identified (and shaded in Figure 21) while on the lower side of the range compared to countries that have already deployed CSP is still within the range that would allow CSP deployment. This suggests that CSP in Thailand would be a technology that would face some technical barriers, but could be feasible. Other surveys of DNI on a global level suggest that in locations in Thailand, the DNI may vary in the range of 1600-1800 kWh/m^2/year (or 4.4 to 4.9 kWh/m^2/day). In particular, the DNI heat maps are illustrated in

Figure 26 and Figure 27, which show the same graph but has zoomed into the GMS region.

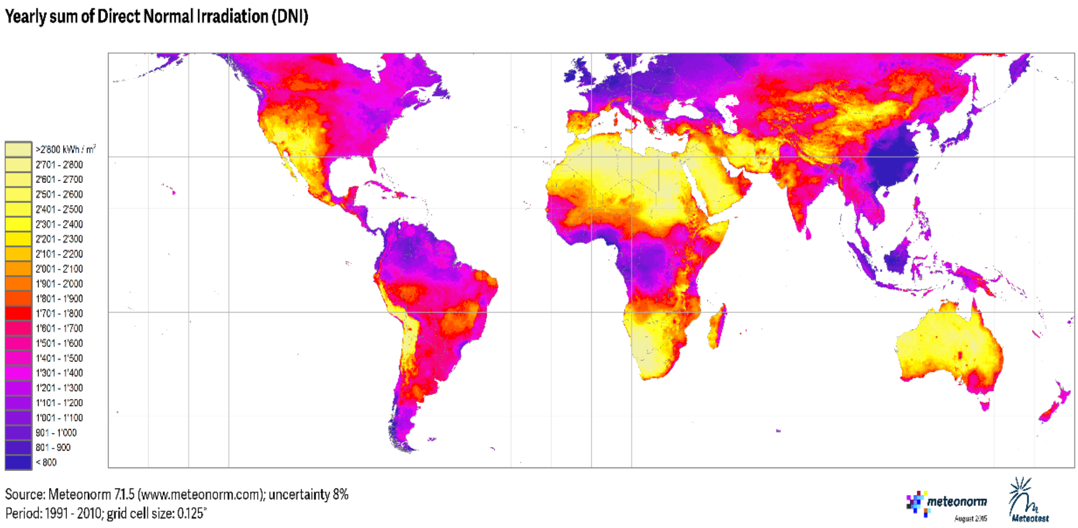
**Figure 25 DNI of Countries with CSP Installations including Thailand**



## Table 4 List of Countries with CSP Projects or Planning CSP Projects and DNI[20]

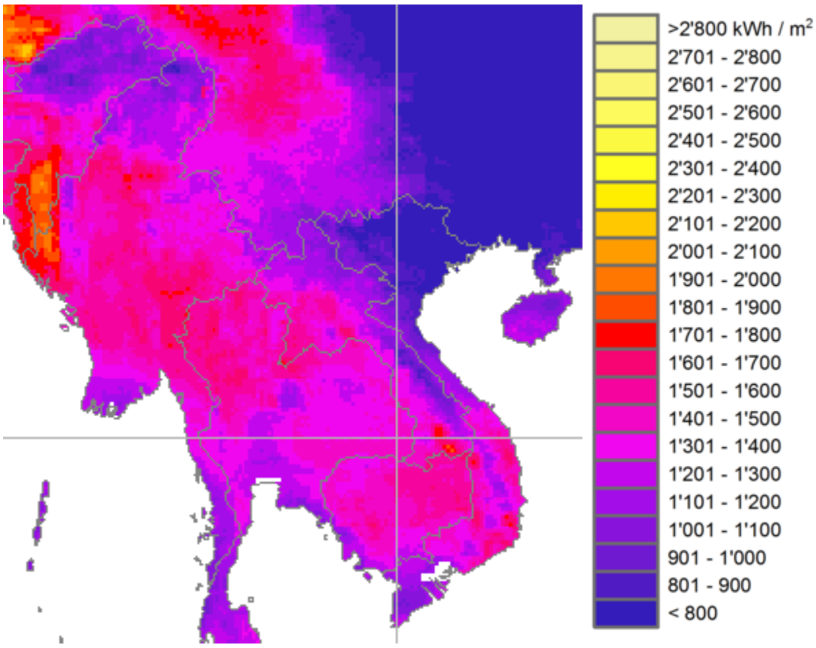
| Country | Start Year | Installed Capacity (MW) | Under Construction (MW) | DNI Value (kWh/m^2/yr) | DNI Value (kWh/m^2/d) |
|---|---|---|---|---|---|
| Algeria | 2011 | 25 | - | 2,700 | 7.4 |
| Australia | 2011 | 12 | 44 | 2,600 | 7.1 |
| Chile | 2015 | - | 360 | 2,900 | 7.9 |
| China | 2012 | 2 | 50 | 2,050 | 5.6 |
| Egypt | 2011 | 20 | - | 2,431 | 6.7 |
| Germany | 2008 | 2 | - | 902 | 2.5 |
| India | 2011 | 3 | 425 | 2,200 | 6.0 |
| Italy | 2010 | 5 | - | 1,936 | 5.3 |
| Mexico | 2013 | - | 14 | 2,178 | 6.0 |
| Morocco | 2010 | 2 | 164 | 2,500 | 6.8 |
| South Africa | 2014 | - | 200 | 2,700 | 7.4 |
| Spain | 2007 | 2,057 | 250 | 2,121 | 5.8 |
| Thailand | 2012 | 5 | - | 1,935 | 5.3 |
| UAE | 2013 | 100 | - | 1,934 | 5.3 |
| USA | 1984 | 650 | 3,202 | 2,681 | 7.3 |

## Figure 26 World Map of DNI[21]




[20] R. Affandi, C. K. Gan, and M. R. A. Ghani, "Prospective of Implementing Concentrating Solar Power (CSP) in Malaysia Environment", World Applied Sciences Journal 32 (8): pp. 1690-1697, 2014.
[21] This map was sourced from: http://meteonorm.com/images/uploads/demo_uploads/dni_v715_hr.png.

**Figure 27 DNI in the GMS**




*Source: Meteonorm (2015)*

## 3.8 Geothermal Energy

There are approximately 64 geothermal resources in Thailand, but major ones are in the north of the country, especially the geyser field at Fang District in Chiangmai Province. Survey on the potential of geothermal energy development at Fang District commenced in 1978, with technical assistance and experts from France later in 1981. Currently, EGAT is operating a 300 kW binary cycle geothermal power plant at Fang District, generating electricity at about 1.2 million kWh per year, which helps reduce oil and coal consumption for power generation.

In addition, other benefits can be derived from the waste heat of hot water used in the power plant. The temperature of hot water, after being used in the power plant, will decrease from 130°C to 77°C, which can be used for drying agricultural products and feeding the cooling system for EGAT's site-office space. Some other non-energy uses of hot water from geothermal sources are for physical therapy and tourism.

Thailand's AEDP2012 set a target of 1 MW of geothermal and 2 MW of tidal capacity built by 2021. Nevertheless, this target has been removed from AEDP2015.

## 3.9 Biomass

Thailand is an agricultural country with a huge agricultural output, such as rice, sugarcane, rubber sheets, palm oil and cassava. Part of the harvest is exported each year, generating billions of baht revenues for the country. In processing these agricultural products, a large amount of residues are generated which can be exploited as a feedstock to generate electricity. For example, paddy husks can be burned to produce steam for turbine operation in rice mills; bagasse and palm residues are used to produce steam and electricity for on-site manufacturing process; and rubber wood chips are burned to produce hot air for rubber wood seasoning. Moreover, the remaining biomass can be used for power generation, with the following potential[12]:

- Paddy husks, biomass from rice mills: each ton of paddy requires 30-60 kWh of energy for all stages of processing, yielding about 650-700 kilograms of rice and residue, that is, about 220 kilograms of paddy husks which can be used to generate 90-125 kWh of energy.
- Bagasse, biomass from sugar mills: each ton of sugarcane requires 25-30 kWh of energy and 0.4 ton of steam for all stages of processing, yielding about 100-121 kilograms of sugar and residue, that is, about 290 kilograms of bagasse which can be used to generate about 100 kWh of energy.
- Palm outer-covering fibre, shells and empty bunches, biomass from palm oil extracting plants: each ton of palm requires 20-25 kWh of energy and 0.73 ton of steam for all stages of processing, yielding about 140-200 kilograms of palm oil and residues, that is, about 190 kilograms of palm outer-covering fibre and shells and 230 kilograms of emptied palm bunches which can be used to generate about 120 kWh of energy. In addition, there will be about 20 cubic meters of wastewater from the processing which can be used for biogas generation.
- Woodchips, biomass from sawmills: one cubic meter of wood requires 34-45 kWh of energy for all stages of processing, yielding about 0.5 cubic meter of processed wood and residue, that is, about 0.5 cubic meter of woodchips which can be used to generate about 80 kWh of energy.

As of end 2014, Thailand is estimated to have some 400 MW of biomass power production capacity installed. The AEDP2015 has put in place a target for biomass power capacity of 5,570 MW by 2036.

IES projected estimates based on the ADB study "Renewable Energy Developments and Potential in the Greater Mekong Subregion" suggest an energy potential of around 120,000 GWh/yr or up to 17,000 MW.

## 3.10 Biogas and Waste

In Thailand, there has been development of the biogas technology using biogas generated from animal manure, especially that of pigs and cows, as fuel in power generation and in cooking. Development has also been undertaken on power generation from landfill biogas. The major financial resource is the Energy Conservation Promotion Fund (ENCON Fund) of the government. Several biogas projects have been supported by the ENCON Fund, such as the biogas from animal manure for power generation in livestock farms, research and development on the feasibility of biogas generation from wastewater treatment systems in factories, and the development of a biogas map providing information on pig farms and dairy farms nationwide in order to facilitate the planning of biogas utilization in the future.

Biogas power has high potential in Thailand due to the abundant availability of industrial waste and livestock manure. According to AEDP2015, the installed capacity of Thai biogas sources was 312 MW at end of 2014 and has set a target of 600 MW by 2036. This could be supplemented by some 500 MW of installed capacity that would be based on power generation from municipal waste. IES projected estimates based on the ADB study suggest an energy potential of around 10,500 GWh/yr or up to 1,500 MW.

## 3.11 Ocean Energy

Earlier studies on Thailand's ocean energy potential concluded no exploitable potential, however, further studies and research is in progress on the eastern and upper side of the Gulf of Thailand. A paper on ocean energy in Southeast Asia reported up to 0.001 ktoe and 0.5 ktoe of tidal and wave energy available in Thailand[22]. As such, our modelling has not factored in any ocean/marine energy potential in Thailand.

## 3.12 Alternative Energy Development Plan 2015

The Alternative Energy Development Plan 2012-2021 has been revised and incorporated as part of the new Power Development Plan (PDP 2015). The new AEDP targets an installed capacity of alternative energy at 19,635 MW in 2036 from 7,279 MW in 2014. The target for each type of renewable energy is shown in Table 5.

**Table 5 Renewable Energy Targets by 2036[23]**

| Type | Waste | Biomass | Biogas | Hydro | Wind | Solar | Energy crops | Total (MW) |
|---|---|---|---|---|---|---|---|---|
| 2014 Capacity | 48 | 2,199 | 226 | 3,016 | 220 | 1,570 | - | 7,279 |
| **2036 Targets** | **501** | **5,570** | **600** | **3,283** | **3,022** | **6,000** | **680** | **19,635** |

This AEDP 2015 was updated according to the following principles:

- Focus on power generation from waste, biomass and biogas as priority.
- Allocation of renewable energy generation capacity according to the demand and potential in regions/provinces.

[22] Ocean renewable energy in Southeast Asia: A review (Quirapas, Lin, Abundo, Brahim, Santos, 2014)
[23] http://www.thai-german-cooperation.info/download/20150520_pdp_re_%20policy%20factsheet.pdf

- Solar and wind power to be promoted at a later stage "once the cost is competitive with the power generation from Liquefied Natural Gas (LNG)".
- Competitive bidding will be employed as a selection process for FIT application instead of first-come first-serve.
- Community energy production will be encouraged to reduce fossil fuel usage; and
- RE consumption will increase from 8% to 20% of final energy consumption in 2036.

## 3.13 Renewable Energy Potential and Diversification

In summary, the renewable energy potentials that are estimated for Thailand are provided in Table 6. The numbers presented here have been drawn from multiple sources and informed by analysis of IRENA Global Atlas data. Figure 28plots the seasonal variation of renewable energy generation profiles in Thailand for solar and wind. This shows that there is very good seasonal diversification across these two forms of renewable energy. The annual maximum solar irradiation is in January and the minimum in July to August. Wind fluctuations are not as predictable but as illustrated, generation from wind reaches its maximum between June and August and complements solar resources very well.

**Figure 28 Seasonal Renewable Energy Generation Profiles**

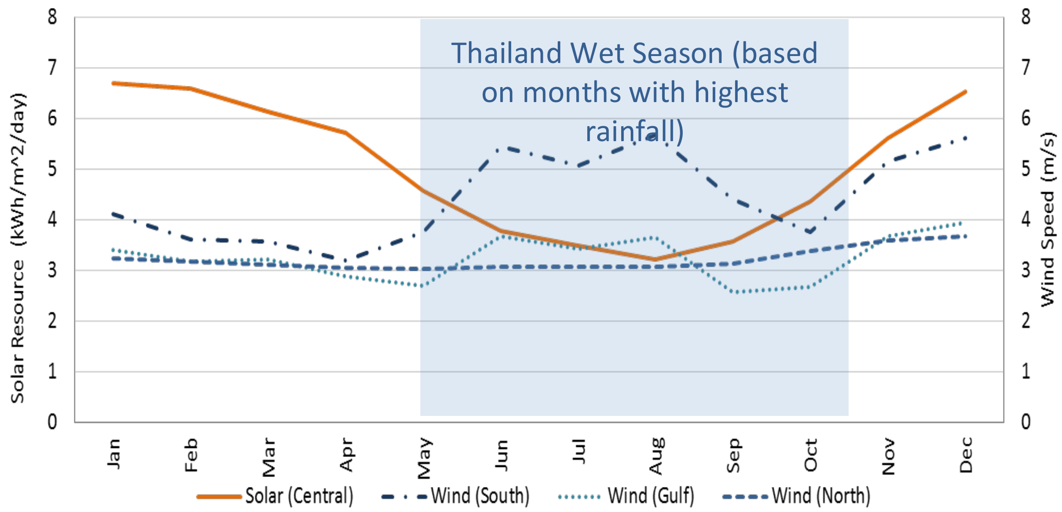



**Table 6 Summary of Estimated Renewable Energy Potential (Compiled from Various Sources and Analysis)**

| Resource | Potential (MW) | Source and comments |
|---|---|---|

| Resource | Potential (MW) | Source and comments |
|---|---|---|
| Hydro (Large) | 15,155 | K. Aroonat and S. Wongwises, "Current status and potential of hydro energy in Thailand: a Review", Renewable and Sustainable Energy Reviews, Vol. 36, June 2016, pp. 70-78.<br>Greenline Energy: http://www.greenlineenergy.com.au/index-4.html |
| Hydro (Small) | - | Lack of data |
| Pump Storage | 10,807 | The Small Hydropower Project as the Important Renewable Energy Resource in Thailand (Chamamahattana, Kongtahworn, Pan-aram, 2005) |
| Solar | More than 50,000 | See resource maps and detailed analysis of solar density data, Figure 24. |
| Wind Onshore | Up to 30,000 | Potential resource above 6m/s. Wind Energy Resource Atlas of Southeast Asia (TrueWind Solutions, 2001), Renewable Energy Developments in the Greater Mekong Subregion (ADB, 2015). It is understood that there are difficulties in Thailand in terms of mountainous and remote areas for the locations that have high wind potential, but have assumed that these are not insurmountable in the SES and ASES. |
| Wind Offshore | 7,000 | Offshore wind power potential of the Gulf of Thailand (Waewsak, Landry, Gagnon, 2015) |
| Biomass | 17,032 | IES projections based on data from Renewable Energy Developments and Potential in the Greater Mekong Subregion (ADB, 2015) |
| Biogas | 1,507 | IES projections based on data from Renewable Energy Developments and Potential in the Greater Mekong Subregion (ADB, 2015) |
| Geothermal | - | Not significant enough, with Geothermal targets removed from AEDP2015 |
| Ocean | - | Lack of studies available |

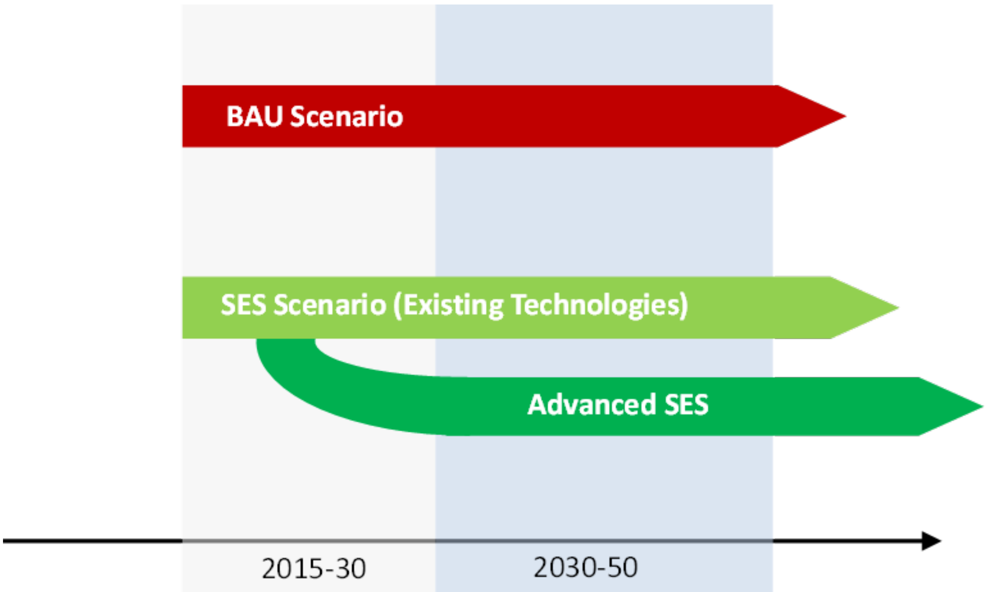
# 4 Thailand Development Scenarios

In this section, we define the three scenarios for Thailand's electricity sector that we have modelled: the Business as Usual (BAU), Sustainable Energy Sector (SES), and Advanced SES (ASES) scenarios. We also set out the assumptions made for technology costs (section 4.2) and fuel prices (section 4.3). Before providing the details for a number of Thailand-specific assumptions – in particular; our assumed economic outlook, generation projects that we consider as committed[24] and comments on the status of power import projects. Further assumptions that are specific to each scenarios are provided in sections 5, 6 and 7.

## 4.1 Scenarios

The three development scenarios (BAU, SES and ASES) for Thailand are conceptually illustrated in in Figure 29.

**Figure 29 GMS Power Sector Scenarios**




The BAU scenario is characterised by electricity industry developments consistent with the current state of planning within the GMS countries and reflective of growth rates in electricity demand consistent with an IES view of base development, existing renewable energy targets, where relevant, aspirational targets for electrification rates, and energy efficiency gains that are largely consistent with the policies seen in the region.

[24] That is, construction is already in progress, the project is near to commissioning or it is in an irreversible / advanced state of the planning process.

In contrast, the SES seeks to transition electricity demand towards the best practice benchmarks of other developed countries in terms of energy efficiency, maximise the renewable energy development, cease the development of fossil fuel resources, and make sustainable and prudent use of undeveloped conventional hydro resources. Where relevant, it leverages advances in off-grid technologies to provide access to electricity to remote communities. The SES takes advantage of existing, technically proven and commercially viable renewable energy technologies.

Finally the ASES assumes that the power sector is able to more rapidly transition towards a 100% renewable energy technology mix under an assumption that renewable energy is deployed more than in the SES scenario with renewable energy technology costs declining more rapidly compared to BAU and SES scenarios. A brief summary of the main differences between the three scenarios are summarised in Table 7.

Table 7 **Brief Summary of Differences between BAU, SES and ASES**

| Scenario | Demand | Supply |
|---|---|---|
| BAU | Demand is forecast to grow in line with historical electricity consumption trends and projected GDP growth rates in a way similar to what is often done in government plans. Electric vehicle uptake was assumed to reach 25% across all cars and motorcycles by 2050. | Generator new entry follows that of power development plans for the country including limited levels of renewable energy but not a maximal deployment of renewable entry. |
| SES | • Assumes a transition towards energy efficiency benchmark for the industrial sector of Hong Kong[25] and of Singapore for the commercial sector by year 2050.<br>• For the residential sector, it was assumed that urban residential demand per electrified capita grows to almost 1,000 kWh pa by 2050, 45% less than in the BAU. | • Assumes no further coal and gas new entry beyond what is already understood to be committed.<br>• A modest amount of large scale hydro (between 4,000 to 5,000 MW) is deployed in Lao and Myanmar above and beyond what is understood to be committed hydro developments in these countries[27].<br>• Supply was developed based on a least cost combination of renewable generation sources |

[25] Based on our analysis of comparators in Asia, Hong Kong had the lowest energy to GDP intensity for industrial sector while Singapore had the lowest for the commercial sector.
[27] This is important to all countries because the GMS is modelled as an interconnected region.

| Scenario | Demand | Supply |
|---|---|---|
| | • Demand-response measures assumed to be phased in from 2021 with some 15% of demand being flexible[26] by 2050.<br>• Slower electrification rates for the national grids in Cambodia and Myanmar compared to the BAU, but deployment of off-grid solutions that achieve similar levels of electricity access.<br>• Mini-grids (off-grid networks) are assumed to connect to the national system in the longer-term.<br>• Electric vehicle uptake as per the BAU. | limited by estimates of potential rates of deployment and judgments in on when technologies would be feasible for implementation to deliver a power system with the same level of reliability as the BAU.<br>• Technologies used include: solar photovoltaics, biomass, biogas and municipal waste plants, CSP with storage, onshore and offshore wind, utility scale batteries, geothermal and ocean energy.<br>• Transmission limits between regions were upgraded as required to support power sector development in the GMS as an integrated whole, and the transmission plan allowed to be different compared to the transmission plan of the BAU. |
| ASES | The ASES demand assumptions are done as a sensitivity to the SES:<br>• An additional 10% energy efficiency applied to the SES demands (excluding transport).<br>• Flexible demand assumed to reach 25% by 2050.<br>• Uptake of electric vehicles doubled by 2050. | ASES supply assumptions are also implemented as a sensitivity to the SES, with the following the main differences:<br>• Allow rates of renewable energy deployment to be more rapid as compared to the BAU and SES.<br>• Technology cost reductions are accelerated for renewable energy technologies.<br>• Implement a more rapid programme of retirements for fossil fuel based power stations.<br>• Energy policy targets of 70% renewable generation by 2030, 90% by 2040 and 100% by 2050 across the region are in place.<br>• Assume that technical / |

[26] Flexible demand is demand that can be rescheduled at short notice and would be implemented by a variety of smart grid and demand response technologies.

| Scenario | Demand | Supply |
|---|---|---|
| | | operational issues with power system operation and control for a very high level of renewable energy are addressed[28]. |

[28] In particular: (1) sufficient real-time monitoring for both supply and demand side of the industry, (2) appropriate forecasting for solar and wind and centralised real-time control systems in place to manage a more distributed supply side, storages and flexible demand resources, and (3) power systems designed to be able to manage voltage, frequency and stability issues that may arise from having a power system that is dominated by asynchronous technologies.

## 4.2 Technology Cost Assumptions

Technology capital cost estimates from a variety of sources were collected and normalised to be on a consistent and uniform basis[29]. Mid-points were taken for each technology that is relevant to the GMS region. The data points collated reflect overnight, turnkey engineering procurement construction capital costs and are exclusive of fixed operating and maintenance costs, variable operating and maintenance costs and fuel costs. The capital costs by technology assumed in the study are presented in Figure 30 for the BAU and SES scenarios. For the ASES scenario, we assumed that the technology costs of renewable technologies decline more rapidly. These technology cost assumptions are listed in Figure 31. Note that the technology capital costs have not included land costs, transmission equipment costs, nor decommissioning costs and are quoted on a Real USD 2014 basis.

Comments on the various technologies are discussed below in relation to the BAU and SES technology costs:

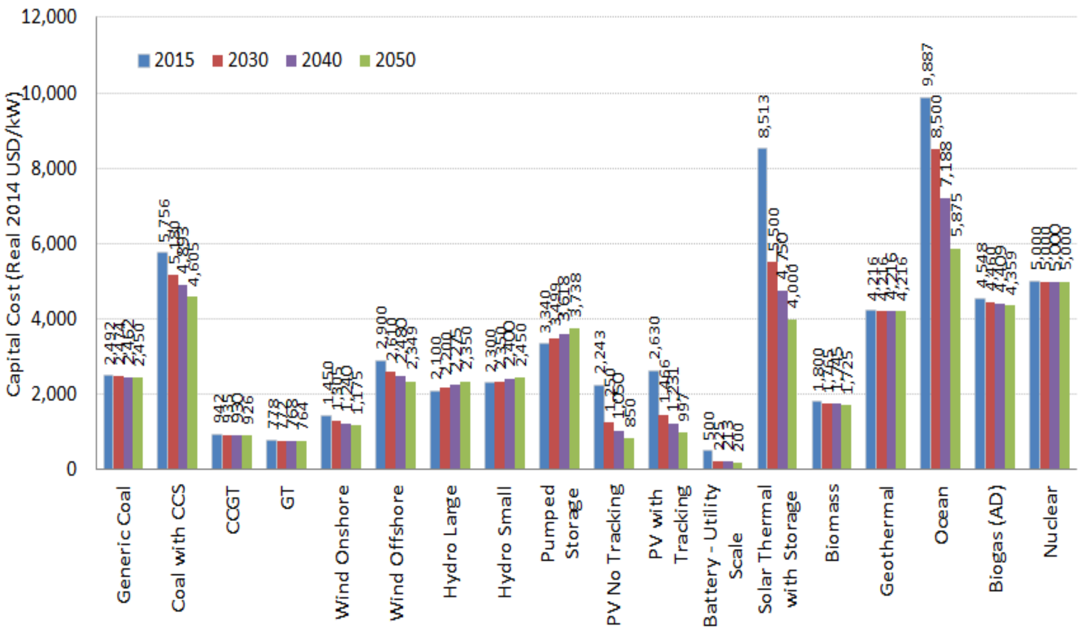
- Conventional thermal technology costs are assumed to decrease at a rate of 0.05% pa citing maturation of the technologies with no significant scope for cost improvement.
- Onshore wind costs were based on the current installed prices seen in China and India with future costs decreasing at a rate of 0.6% pa. Future offshore wind costs were developed by applying the current percentage difference between current onshore and offshore capital costs for all future years.
- Large and small-scale hydro costs are assumed to increase over time reflecting easy and more cost-efficient hydro opportunities being developed in the first instance. IRENA reported no cost improvements for hydro over the period from 2010 to 2014. Adjustments are made in the case of Lao PDR and Myanmar where significant hydro resources are developed in the BAU case[30].
- Solar PV costs are based on the more mature crystalline silicon technology which accounts for up to 90% of solar PV installations (IRENA, 2015), and forecast to continue to drop (2.3% pa) albeit at a slower pace than in previous years.
- Utility scale battery costs are quoted on a \$/kWh basis, and cost projections based on a report by Deutsche Bank (2015) which took into account several forecasts from BNEF, EIA and Navigant.
- Solar thermal (CSP) capital costs are projected to fall at 2.8% pa on the basis of the IRENA 2015 CSP LCOE projections. While globally there are many CSP installations in place, the technology has not taken off and the cost of CSP technology over the past 5 years has not been observed to have fallen as rapidly as solar PV.

[29] We standardised on Real 2014 USD with all technologies costs normalised to reflect turnkey capital costs.
[30] Capital costs for large scale hydro projects are assumed to increase to \$3,000/kW by 2050 consistent with having the most economically feasible hydro resources developed ahead of less economically feasible resources.

- Biomass capital costs are based on costs observed in the Asia region which are significantly less than those observed in OECD countries. Capital costs were assumed to fall at 0.1% pa. Biogas capital costs were based on anaerobic digestion and assumed to decline at the same rate as biomass.
- Ocean energy (wave and tidal) technologies were based on learning rates in the 'Ocean Energy: Cost of Energy and Cost Reduction Opportunities' (SI Ocean, 2013) report assuming global installation capacities increase to 20 GW by 2050[31].
- Capital costs were discounted at 8% pa across all technologies over the project lifetimes. Decommissioning costs were not factored into the study.
- For technologies that run on imported coal and natural gas, we have factored in the additional capital cost of developing import / fuel management infrastructure in the modelling.

For reference, Appendix A tabulates the technology cost assumptions that we have used in the modelling.

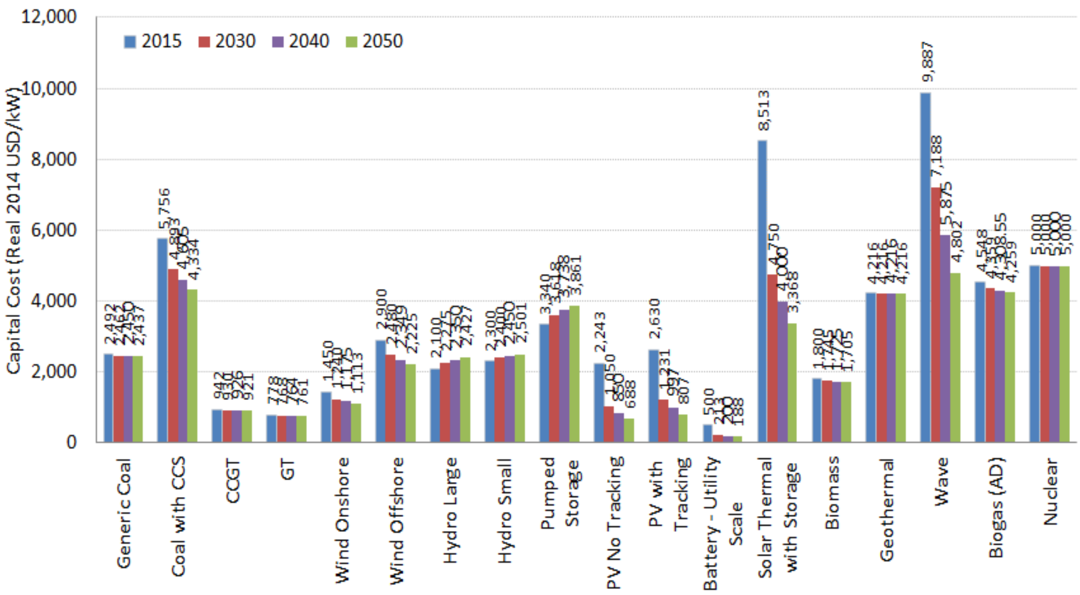
**Figure 30 Projected Capital Costs by Technology for BAU and SES**




** Battery costs are quoted on a Real 2014 USD $/kWh basis.*

[31] Wave and tidal costs were averaged.

**Figure 31 Projected Capital Costs by Technology for ASES**




** Battery costs are quoted on a Real 2014 USD $/kWh basis.*

## 4.3 Fuel Pricing Outlook

IES has developed a global fuel price outlook which are based on short-term contracts traded on global commodity exchanges before reverting towards long-term price global fuel price forecasts based on the IEA's World Energy Outlook (WEO) 2015 450 scenario[32] and a set of relationships between different fuels that have been inferred from historical relations between different types of fuels. A summary of the fuel prices expressed on an energy-equivalent basis ($US/MMBtu HHV) is presented in Figure 32 below.

The 30% fall from 2014 to 2015 for the various fuels was the result of a continued weakening of global energy demand combined with increased stockpiling of reserves. Brent crude prices fell from $155/bbl in mid-2014 to $50/bbl in early 2015. OPEC at the November 2014 meeting did not reduce production causing oil prices to slump. However, fuel prices are then assumed to return from the current low levels to formerly observed levels within a 10 year timeframe based on the time required for there to be a correction in present oversupply conditions to satisfy softened demand for oil and gas[33].

To understand the implications of a lower and higher global fuel prices we also perform fuel price sensitivity analysis. One of the scenarios is based on a 50% fuel

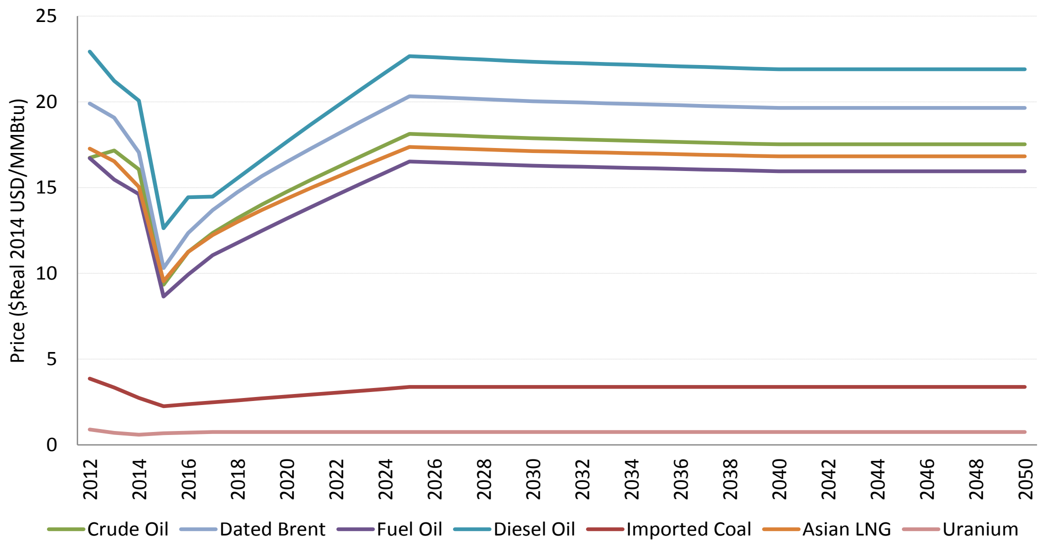
[32] The IEA's 450 scenario is an energy pathway consistent with the goal of limiting global increase in temperature to 2°C by limiting the concentration of greenhouse gases in the atmosphere to 450 parts per million CO2; further information available here: https://www.iea.org/media/weowebsite/energymodel/Methodology_450_Scenario.pdf.

[33] Reference: Facts Global Energy / Australian Institute of Energy, F. Fesharaki, "A New World Oil Order Emerging in 2016 and Beyond?", February 2016, suggest a rebound in prices levels over a 5 to 7 year period as the most "probable" scenario.

cost increase[34] to put the study's fuel prices in the range of the IEA's Current Policies scenario[35] which could be argued to be closer to the fuel pricing outlook that could be anticipated in a BAU outlook, while the SES and ASES scenarios could be argued to have fuel prices more consistent with the IEA's 450 scenario. We discuss the implications of fuel pricing on the BAU and SES within the context of electricity pricing in section 9.5.

For reference, we provide the fuel pricing outlook for each year that was used in the fuel price modelling in Appendix B. These fuel prices were held constant in the BAU, SES and ASES scenarios.

**Figure 32 IES Base Case Fuel Price Projections to 2050**

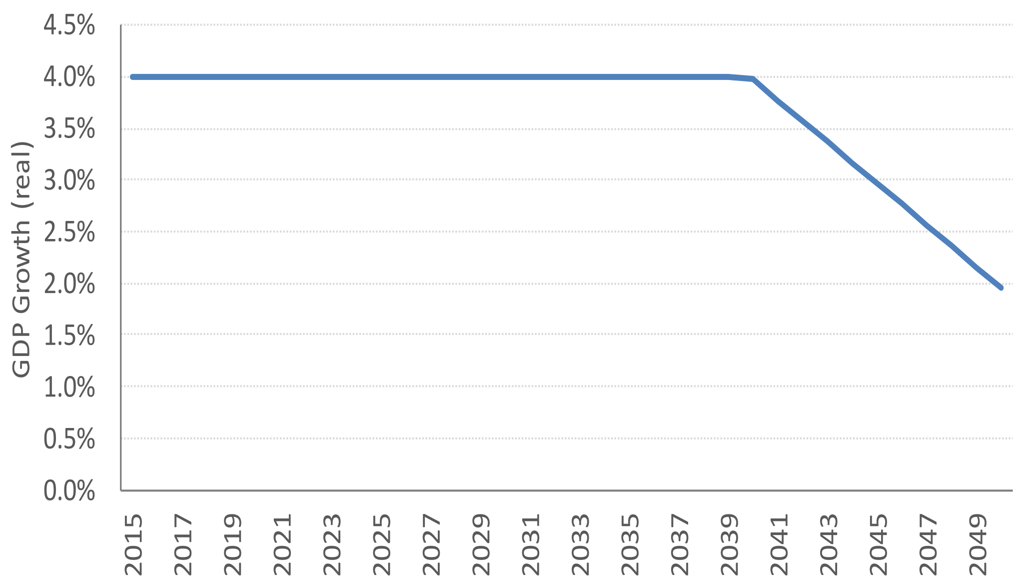



## 4.4 Thailand Real GDP Growth Outlook

Real GDP growth is assumed to maintain a 4% pa GDP growth rate to 2040 consistent with historical average growth[36]. Towards 2050, GDP growth is assumed to decline towards the world average of 1.96%[37] pa seen in Figure 33. The trend down was assumed to reflect the economic development outlook of the government to 2035, before there is a transition towards the world average GDP growth rate. GDP assumptions were kept constant between BAU, SES and ASES scenarios.

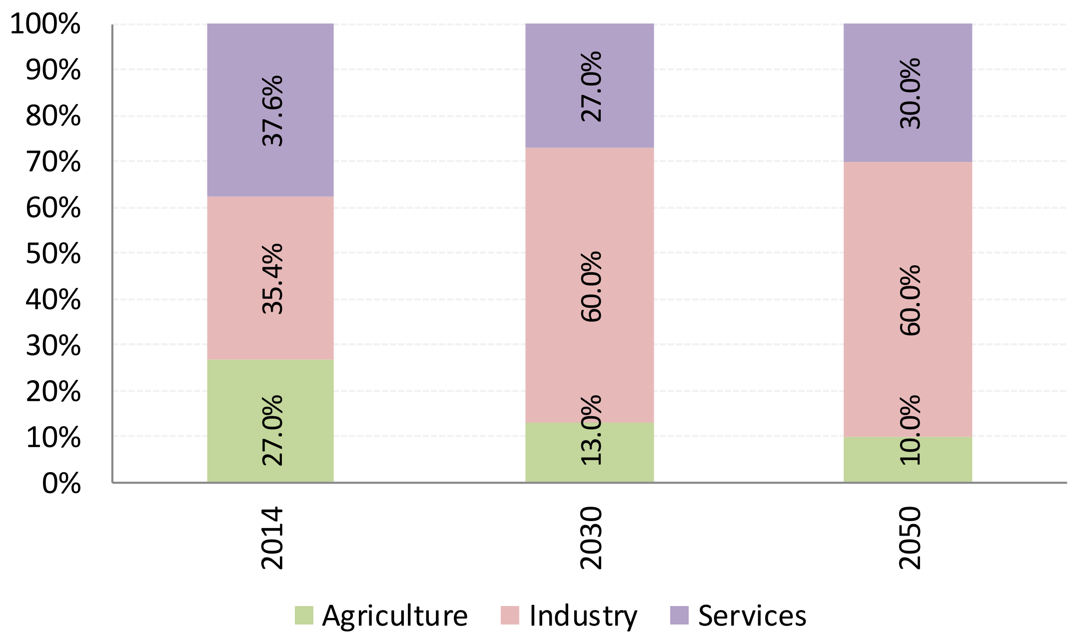
[34] Including biomass prices.
[35] The IEA's current policies scenario assumes no changes in policy from the year of WEO publication.
[36] 3.6% pa from 2005-2014.
[37] 1.96% reflects the previous 5 year GDP growth of the top 10 GDP countries in the world excluding Brazil, China and Russia.

**Figure 33 Thailand GDP Projection**




The GDP composition of Thailand is weighted towards industry in line with the strategic aspirations of each country. The industry share of GDP in Thailand is assumed to increase from 35% in 2014 to 60% in 2030. The GDP composition is plotted in Figure 34. Note that this assumption is held constant in all cases.

**Figure 34 Thailand GDP Composition**



## 4.5 Population Growth

Population was assumed to grow in line with the UN Medium Fertility scenario and is held constant across all scenarios[38].

## 4.6 Committed Generation Projects in BAU, SES and ASES Scenarios

Committed generation projects are the ones that are under construction or at a stage of development that is sufficiently advanced for decision for the project to come online to not be reversed. Table 6 lists committed generation projects in addition to the existing fleet of generation projects[39]. This is based on information from the PDP2015 as well as other research on the current status of various projects. The table shows the project's name, its understood capacity and the date it is expected to be commissioned by.

**Table 8 Thailand Committed Generation Projects**

| No. | Project | Capacity (MW) | Generation Type | COD[40] |
|---|---|---|---|---|
| 1 | Gulf JP UT | 800 | Gas | 2015 |
| 2 | Ratchaburi World Cogeneration Co.Ltd. (project 2) | 90 | Gas | 2015 |
| 3 | B. Grimm Power | 90 | Gas | 2015 |
| 4 | Kwae Noi Dam #1-2 | 30 | Hydro | 2015 |
| 5 | Sakae Solar Cell | 5 | Solar | 2015 |
| 6 | Prakarnchon Dam | 10 | Hydro | 2015 |
| 7 | Chulabhorn Hydropower | 10 | Hydro | 2015 |
| 8 | Other Hydro | 6.7 | Hydro | 2015 |
| 9 | Mae Hydro | 12 | Hydro | 2015 |
| 10 | Very Small Power Producers (VSPPs) | 271 | Gas | 2016 |
| 11 | Bang Lang Dam (upgrade) | 12 | Hydro | 2016 |
| 12 | Sirindhorn Dam Solar Cell | 0.3 | Solar | 2016 |
| 13 | EGAT Solar Project | 10 | Solar | 2016 |
| 14 | Other VSPPs | 283 | Gas | 2017 |
| 15 | Hydropower | 5.5 | Hydro | 2017 |
| 16 | Lamtakong Phase 2 | 24 | Wind | 2017 |
| 17 | Gulf JP UT Co., Ltd. #1-2 (Jun, Dec) | 1600 | Gas | 2018 |
| 18 | Other VSPPs | 288 | Gas | 2018 |
| 19 | Lamtakong Pump Storage #3-4 | 500 | Hydro | 2018 |
| 20 | Maw #4-7 Replacement | 600 | Coal | 2018 |

[38] UN Department of Economic and Social Affairs, World Population Prospects: The 2012 Revision.
[39] Thailand export projects in Lao PDR, Hong Sa Coal, Xayabouly (Xayaburi), Sepian-Xenamnoy and Nam Ngiep 1 are not included in the table.
[40] Commercial operation date.

| | | | | |
|---|---|---|---|---|
| 21 | Tron Dam Hydropower | 2.5 | Hydro | 2018 |
| 22 | Chulabhorn Dam Hydropower | 1.3 | Hydro | 2018 |
| 23 | EGAT Biomass | 4 | Bio | 2018 |
| 24 | EGAT Biogas | 5 | Bio | 2018 |

## 4.7 Regional Transmission System Integration

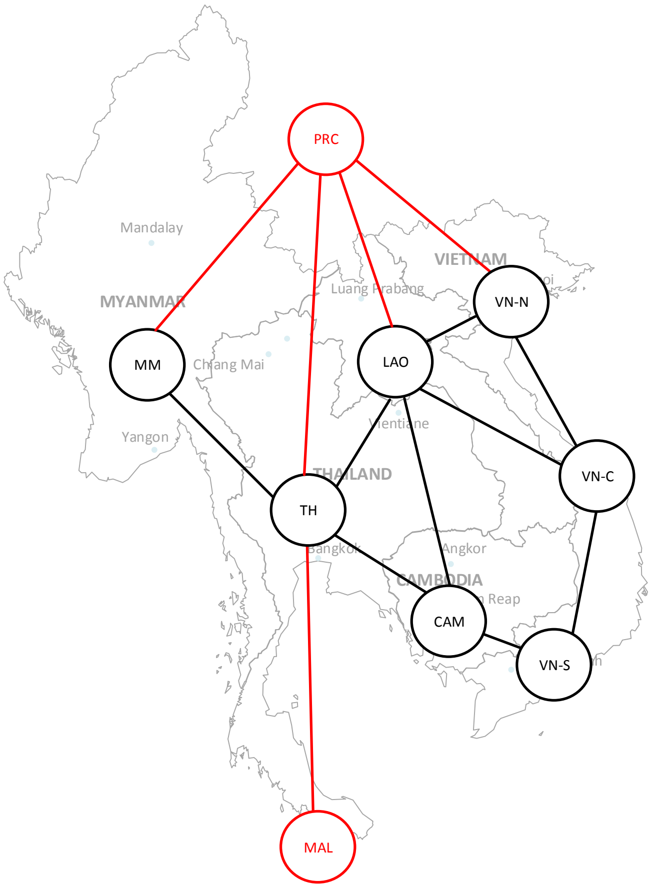
The modelling presented in this report assumes transmission in the GMS becomes more tightly integrated than at present. Given the modelling period is for 35 years, we use a very simple model for the interconnections as illustrated in Figure 35. The figure shows the assumed topology of the GMS as well as to countries outside the region (PRC and Malaysia). Initially, not all transmission connections shown in the diagram are in place. However, over the modelling period the transmission connections are expanded as required to allow power exchange between regions to minimise costs and take advantage of diversity in demand and resource availabilities. Each scenario therefore effectively has a different high-level transmission development plan[41].

The main differences in the assumptions behind the transmission system enhancements in each scenario were:

- In the BAU, it was assumed that transmission developments occur slowly and a tightly integrated regional power system is in place from about 2030, but the power sectors are developed so that there is only a limited level of dependency on imports from neighbouring countries. This is consistent with power sector planning that seeks to not be overly dependent on power imports from neighbouring countries.
- In the SES and ASES, the transmission system evolves from 2025 and we allow the transmission system (based on a simplified model of the region) to expand as needed to optimise the use of a geographically disperse set of renewable energy resources. A consequence of this is that some countries become significant exporters of power while others take advantage of power imports from neighbouring countries. In particular Myanmar and Lao PDR become major power exporters with the beneficiaries being the other GMS countries.

[41] We only consider a high-level transmission development plan based on the regional model shown in order to gain insight on interregional power flows.

**Figure 35 Simple Transmission System Model**




## 4.8 Imports and Exports

Thailand is connected to the Cambodian and Malaysian power grids and there are a number of projects under development in neighbouring countries that will export most if not all of their power output to Thailand. In section 2.6, we provided commentary on the current state of existing, and planned import projects and we have assumed the construction of the projects listed in Table 9. The capacities shown in the table have been de-rated based on the power purchase agreements that Thailand has with the host country for these projects.

**Table 9 Thailand Committed Import Projects**

| No. | Unit | Country | Capacity (MW) | Type | COD |
|---|---|---|---|---|---|
| 1 | Su-ngai Kolok - Rantau-Panjang | Malaysia (TNB) – Thailand (EGAT) 132 kV Interconnection | 100 | Grid-to-Grid | 2015 |
| 2 | Hongsa Thermal #1-2 | Lao PDR (power purchased from Lao PDR) | 982 | Coal | 2015 |
| 3 | Hongsa Thermal #3 | Lao PDR (power purchased from Lao PDR) | 491 | Coal | 2016 |
| 4 | Impact Energy Wind Farm | Most of the wind farm's output will be purchased by Thailand | 540 | Wind | 2019 |

## 4.9 Technical Economic Power System Modelling

Technical and economic modelling of the GMS was done in the PROPHET electricity planning and simulation models. It develops a least cost generation based plan and was used to simulate the operation of the GMS region as an integrated power system.

A brief overview of the various aspects is provided below:

- **Planning Module**: The Planning Module of Prophet allows for intertemporal constraints such as energy limits to be preserved when simulating the power system and developments. It also develops a least cost set of new entrants to satisfy demand over the 35-year modelling horizon.
- **Transmission**: The power system was modelled based on the configuration as per Figure 35 with fixed / scheduled flows (red lines) to power systems outside the GMS not being explicitly modelled while power transfers within the GMS countries were optimised as needed to allow supply and demand to balance. This is important with respect to modelling diversity in demand in the different regions and geographical variation in generation patterns from supply-driven renewable energy (solar and wind) and seasonal variation of inflows into the hydro storages (see section 3.13).
- **Economics:** Capital and operating costs relating to generation plants as per the assumptions covered in this report allow the Planning Module to model generation and transmission development in a least cost manner. On top of this, resource constraints had to be formulated to reflect actual limits such as the maximum renewable resource and development rates available to each country.
- **Demand:** Demand profiles were constructed from energy and peak demand forecasts for electricity based on regression models that were developed for each sector of the electricity industry (commercial, industrial, residential, agricultural and transport). The monthly and intraday construction of the profiles were performed in Prophet based on historical data and/or external data sources indicating the seasonal profile of demand for each country.
- **Flexible demand**: was modelled as MW and GWh/month quantities that can be scheduled as necessary to reduce system costs. This means that demand tends to be shifted from periods when supply and demand would otherwise be tight to other times. The technology for rescheduling demand was assumed to be in place from 2020 in the SES and ASES scenarios.
- **Supply:** The approach taken for modelling generation supply technologies varied according to the technology type. This is discussed further below:
  - *Conventional thermal plant*: is modelled as capacity limited plants, with fuel take-or-pay contracts applied to generators where relevant– for example, gas supply limits applied to LNG facilities or offshore gas fields. Examples of such plants include coal, biomass, gas, and diesel generators.

- *Energy limited plants*: such as large-scale hydros with reservoirs / storages and CSP have monthly energy limits corresponding to seasonal variations in energy inflows. The equivalent capacity factors are based on external reports for hydro and resource data for CSP (see next point).
- *Supply-driven generation forms*: Seasonal profiles for wind, solar and run of river hydros without reservoirs were developed on an hourly basis. For wind and solar they were derived from monthly resource data collected from a variety of sources including NASA, NREL[42] and accessed via the Solar and Wind Energy Resource Atlas (SWERA) Toolkit and IRENA Global Atlas. Resource amounts were matched against actual generation data for known plants to develop equivalent monthly capacity factors at various high resource pockets in each country. Several traces were built from known generation traces to provide diversification benefits.
- *Pump Storage and battery storage*: these are modelled in a similar way to flexible demand in that demand can be shifted with a capacity and energy limit but the scheduled demand is stored for generation later with an appropriate energy conversion efficiency (pumped storages assumed to be 70% and battery storage systems at 85%).

[42] DNI and Wind NASA Low Resolution and NREL DI Moderate Resolution data.

# 5 Business as Usual Scenario

## 5.1 Business as Usual Scenario

The BAU scenario assumes industry developments consistent with the current state of planning in Lao PDR and reflective of growth rates in electricity demand consistent with an IES view of base development, existing renewable energy targets, where relevant, aspirational targets for electrification rates, and energy efficiency gains that are largely consistent with the policies seen in the region.

## 5.2 Projected Demand Growth

Thailand's on-grid electricity demand (including transmission and distribution losses[43]) is plotted in Figure 36. Thailand's electricity demand is forecast to increase at a rate of 3.0% pa over the 35-year period to 2050 with a slowdown in growth post-2040 as the economy trends towards long-term global GDP growth rates. The electricity growth compared to other GMS countries is much lower due to the already industrialised economy, high electrification rates and declining population assumptions.

The industrial sector is forecast to grow the fastest at 3.3% pa followed by the commercial sector at 2.6%, residential at 2.4% and agriculture at 1.2% as the GDP composition shifts towards commerce/services and industry, equally accounting for a combined 90% of GDP by 2050. The transport sector is forecast to hit 28 TWh by 2050 as the number of cars and uptake of electric cars and motorbikes increase to 25% penetration. Thailand electricity demand is forecast to reach 532 TWh by 2050. Peak demand is plotted below in Figure 37 and shows peak demand growing at 3.0% pa reaching 81 GW by 2050. The load factor is assumed to trend towards 75% by 2040 mainly driven by additional industrial loads impacting the demand base.

Key drivers for demand growth and the demand projections are summarised in Table 10.

[43] Note that unless otherwise stated, all other demand charts and statistics include transmission and distribution losses.

**Figure 36 Thailand Projected Electricity Demand (2015-2050, BAU)**

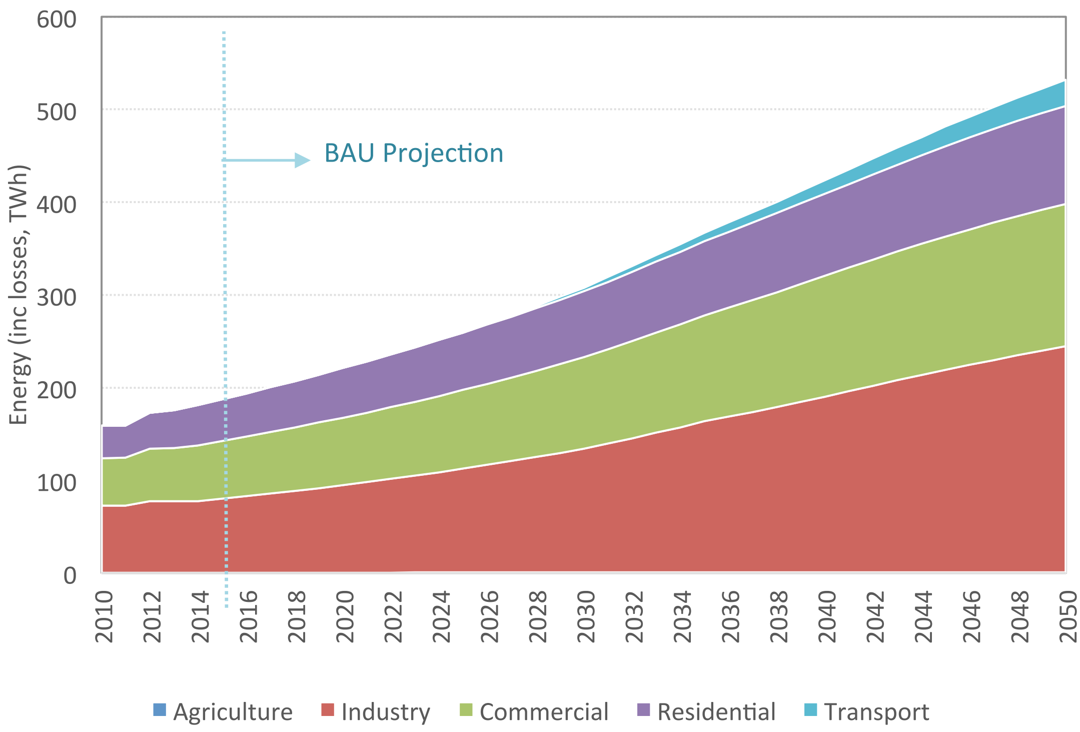



**Figure 37 Thailand Projected peak Demand (BAU)**

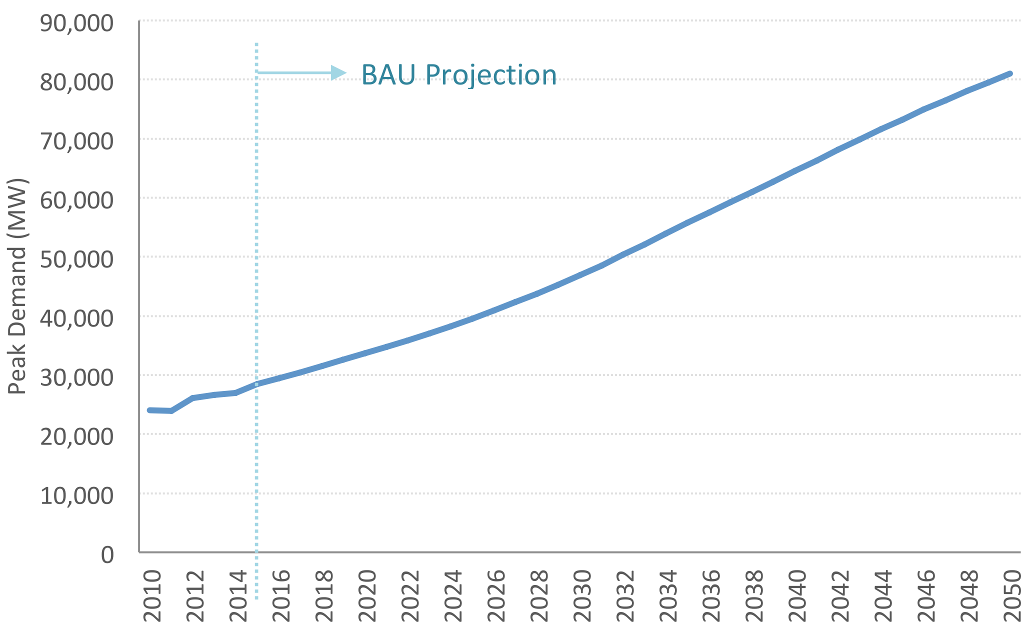


**Table 10 Thailand Demand and Demand Drivers (BAU)**

| No. | Aspect | 2015-30 | 2030-40 | 2040-50 |
|---|---|---|---|---|
| 1 | Demand Growth (pa) | 3.5% | 3.2% | 2.3% |
| 2 | GDP Growth (Real, pa) | 4.0% | 4.0% | 2.9% |
| 3 | Electrification Rate (Population) | 100.0% | 100.0% | 100.0% |
| 4 | Population Growth | 0.60% | 0.23% | -0.04% |
| 5 | Per Capita Consumption (kWh) | 3,117 | 4,324 | 6,020 |
| 6 | Electricity Elasticity* | 1.61 | 1.39 | 1.39 |
| 7 | Electricity Intensity (kWh/USD) | 0.310 | 0.292 | 0.303 |

** Electricity elasticity is calculated as electricity demand growth divided by the population growth over the same period*

## 5.3 Projected Installed Capacity Development

The BAU installed capacity (MW) for Thailand is plotted in Figure 38 and Figure 39 by capacity shares for selected years: 2010, 2015, 2020, 2030, 2040 and 2050. The former shows installed generation capacity by the main generation type categories. We provide corresponding statistics in Table 11 and Table 12. Note that the installed capacity numbers includes dedicated generation that is effectively available to Thailand as imports and where appropriate this has been de-rated to reflect supply agreements.

Installed capacity in 2014 increases from 37 GW to 116 GW with gas-fired generation accounting for 34% of total installed capacity. Gas-fired capacity increases from 26 GW of 39 GW by 2050 comprised of mainly CCGT. Over this period, significant gas generation is retired and replaced with new gas technology. New conventional coal technology is built in Thailand (Thailand PDP 2015) as a source of baseload generation from 2026, to reach some 16 GW, or 14% of the total installed capacity, by 2050. The notable ramp up in coal capacity from 2014 in 2015 and 2016 is related to the Hong Sa coal-fired stations which is developed in Lao PDR, and total some 1,470 MW[44] of power exports for Thailand.

Thailand is assumed to reach 20% renewable electricity generation by 2050 with solar PV ramping up from 2016 and providing the bulk of renewable capacity (16% of total installed capacity by 2050). Bio generation and wind energy also contribute to the target with 9 GW and 8 GW of installed capacity by 2050 respectively. Large hydro grows to 17 GW supported by projects from Lao PDR.

[44] Note that we have de-rated Hong Sa's capacity to the amount of power that is available to Thailand.

**Figure 38 Thailand Installed Capacity (BAU, MW)**

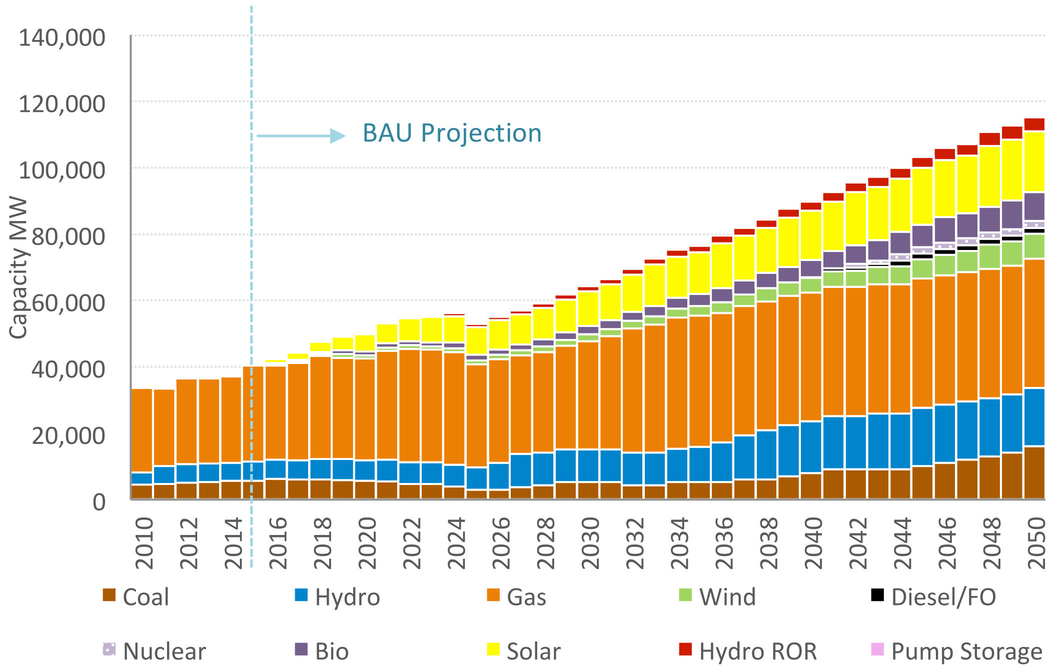
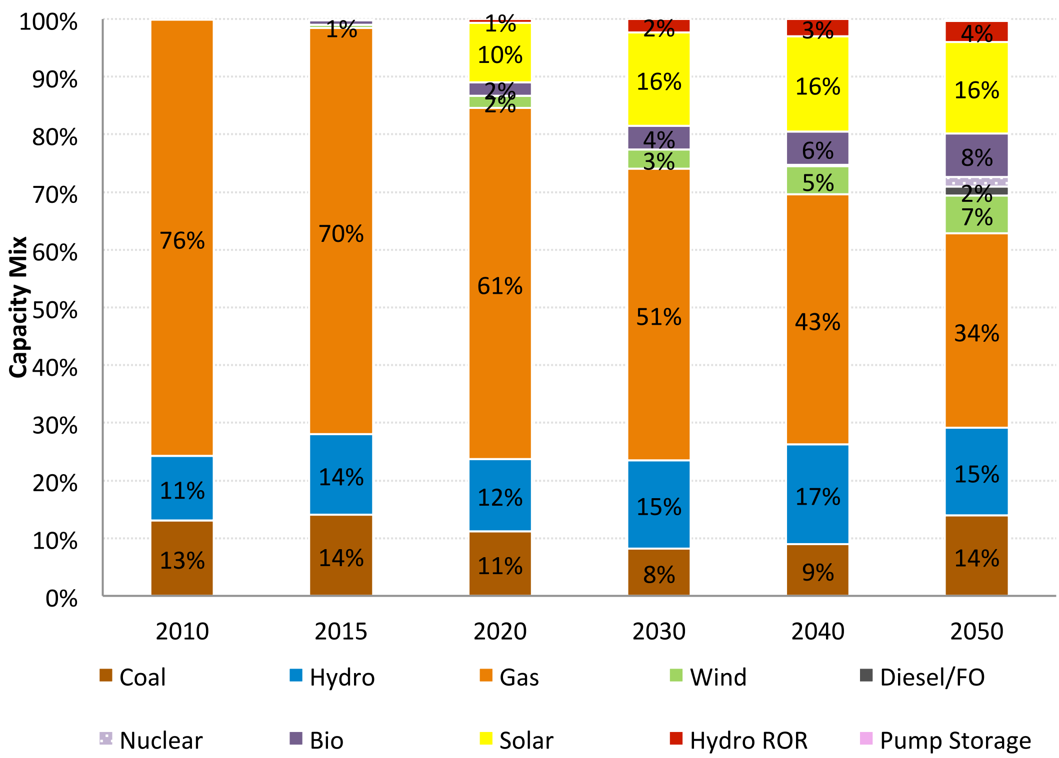



**Figure 39 Thailand Installed Capacity Mix Percentages (BAU, %)**



## Table 11 Thailand Capacity by Type (BAU, MW)

| Resource | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 4,428 | 5,758 | 5,640 | 5,276 | 8,080 | 16,080 |
| Diesel | 0 | 5 | 5 | 5 | 255 | 1,755 |
| Fuel Oil | 45 | 0 | 0 | 0 | 0 | 0 |
| Gas | 25,508 | 28,902 | 30,564 | 32,528 | 38,928 | 38,928 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 2,000 |
| Hydro | 3,747 | 5,743 | 6,265 | 9,858 | 15,465 | 17,565 |
| Onshore Wind | 0 | 223 | 1,052 | 2,088 | 4,109 | 6,572 |
| Offshore Wind | 0 | 0 | 0 | 10 | 239 | 1,026 |
| Biomass | 0 | 313 | 1,173 | 2,673 | 5,173 | 8,673 |
| Biogas | 0 | 0 | 0 | 0 | 0 | 0 |
| Solar | 0 | 100 | 5,178 | 10,378 | 14,778 | 18,378 |
| CSP | 0 | 0 | 0 | 0 | 0 | 0 |
| Battery | 0 | 0 | 0 | 0 | 0 | 0 |
| Hydro ROR | 0 | 0 | 300 | 1,500 | 2,700 | 4,200 |
| Geothermal | 0 | 0 | 0 | 0 | 0 | 0 |
| Pump Storage | 0 | 0 | 0 | 0 | 0 | 333 |
| Ocean | 0 | 0 | 0 | 0 | 0 | 0 |

## Table 12 Thailand Capacity Share by Type (BAU, %)

| Resource | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 13% | 14% | 11% | 8% | 9% | 14% |
| Diesel | 0% | 0% | 0% | 0% | 0% | 2% |
| Fuel Oil | 0% | 0% | 0% | 0% | 0% | 0% |
| Gas | 76% | 70% | 61% | 51% | 43% | 34% |
| Nuclear | 0% | 0% | 0% | 0% | 0% | 2% |
| Hydro | 11% | 14% | 12% | 15% | 17% | 15% |
| Onshore Wind | 0% | 1% | 2% | 3% | 5% | 6% |
| Offshore Wind | 0% | 0% | 0% | 0% | 0% | 1% |
| Biomass | 0% | 1% | 2% | 4% | 6% | 8% |
| Biogas | 0% | 0% | 0% | 0% | 0% | 0% |
| Solar | 0% | 0% | 10% | 16% | 16% | 16% |
| CSP | 0% | 0% | 0% | 0% | 0% | 0% |
| Battery | 0% | 0% | 0% | 0% | 0% | 0% |
| Hydro ROR | 0% | 0% | 1% | 2% | 3% | 4% |
| Geothermal | 0% | 0% | 0% | 0% | 0% | 0% |
| Pump Storage | 0% | 0% | 0% | 0% | 0% | 0% |
| Ocean | 0% | 0% | 0% | 0% | 0% | 0% |

## 5.4 Projected Generation Mix

Figure 40 plots the generation mix (on an as generated basis[45]) over time in the BAU case and Figure 41 plots the corresponding percentage shares. Coal-fired generation initially increases from 38 TWh to 46 TWh with the commissioning of the Hong Sa coal-fired power station in 2015/16 in Lao PDR Table 13 and Table 14 show the generation share by snapshot year to 2050.

Over time the generation share of coal declines towards 2025 then picks up with planned coal developments to meet baseload requirements accounting for 25% of supply by 2050. Large-scale hydro generation increases in line with growing installed capacities (mainly imports) but maintains its generation share around 10% of total production. The gas generation share decreases from 73% in 2010 to approximately 35% by 2050 as other technologies are brought into the system coinciding with gas supply limitations in Thailand. The two units of nuclear generation initially displace gas generation and account for 3% by 2050.

As renewable capacity increases, the generation share slowly picks up from approximately 1% in 2015 to around 24% by 2050, which was based on following the AEDP2015 to 2036 and allowing increases in renewable energy beyond 2036. Biomass accounts for 11%, solar PV 6% and wind 3% of the system total in 2050.

[45] Unless otherwise stated, all generation charts and statistics in this report are presented on an "as generated" basis, meaning that generation to cover generator's auxiliary consumption accounted for.

**Figure 40 Thailand Generation Mix (BAU, GWh)**

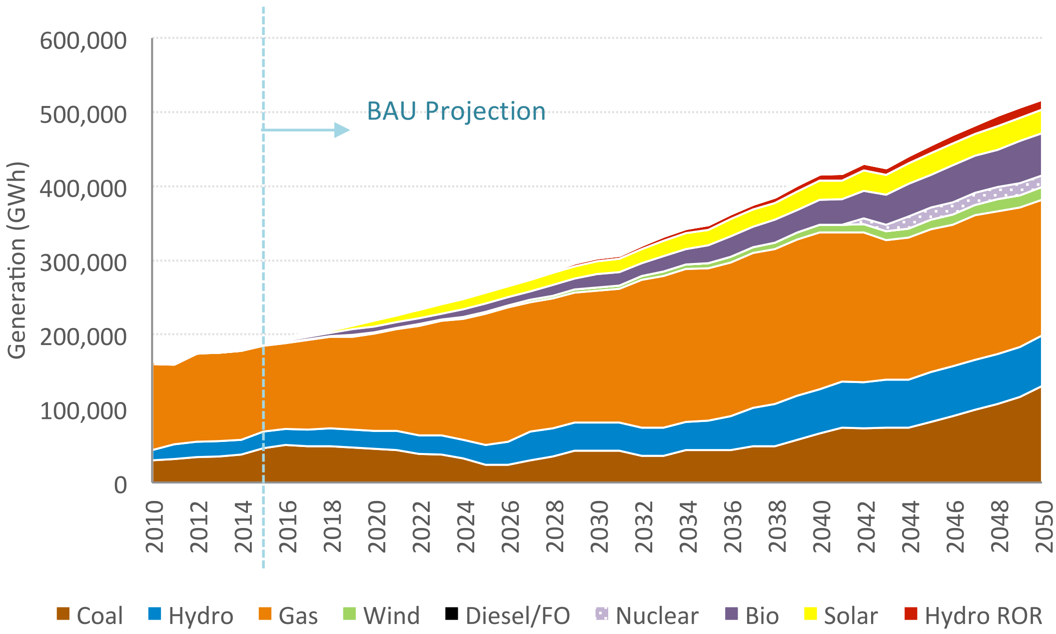
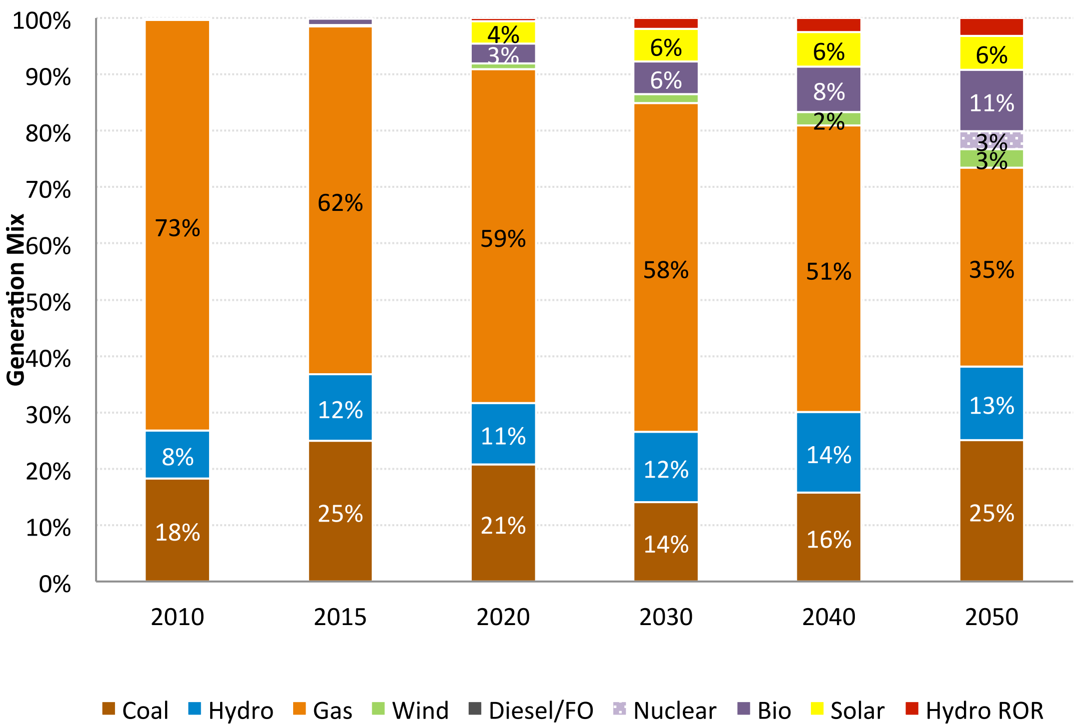



**Figure 41 Thailand Generation Mix Percentages (BAU, %)**



## Table 13 Thailand Generation by Type (BAU, GWh)

| Generation | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 29,764 | 46,807 | 45,864 | 42,836 | 65,884 | 130,554 |
| Diesel | 0 | 0 | 0 | 0 | 0 | 0 |
| Fuel Oil | 600 | 0 | 0 | 0 | 0 | 0 |
| Gas | 118,438 | 115,720 | 130,810 | 177,954 | 212,511 | 183,068 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 16,238 |
| Hydro | 13,684 | 22,137 | 24,146 | 37,997 | 59,608 | 67,702 |
| Onshore Wind | 0 | 500 | 2,364 | 4,731 | 9,338 | 14,984 |
| Offshore Wind | 0 | 0 | 0 | 24 | 543 | 2,338 |
| Biomass | 0 | 2,059 | 7,730 | 17,564 | 34,082 | 56,984 |
| Biogas | 0 | 0 | 0 | 0 | 0 | 0 |
| Solar | 0 | 170 | 8,855 | 17,723 | 25,334 | 31,384 |
| CSP | 0 | 0 | 0 | 0 | 0 | 0 |
| Hydro ROR | 0 | 0 | 0 | 0 | 0 | 0 |
| Geothermal | 0 | 0 | 1,164 | 5,782 | 10,472 | 16,189 |
| Pump Storage | 0 | 0 | 0 | 0 | 0 | 0 |
| Ocean | 0 | 0 | 0 | 0 | 0 | 329 |

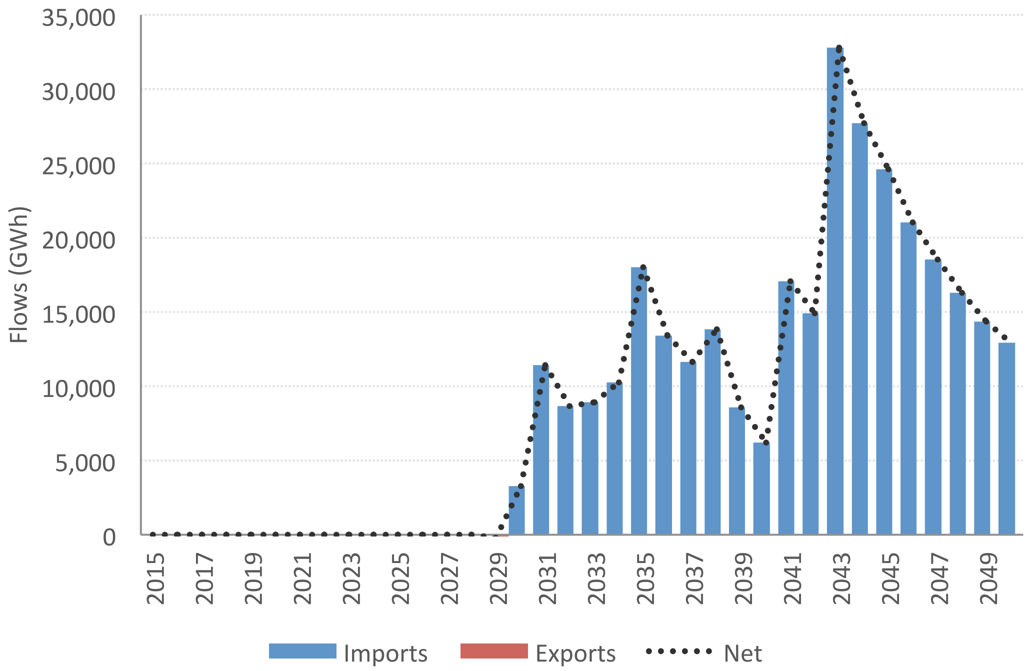
## Table 14 Thailand Generation share by Type (BAU, %)

| Generation | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 18% | 25% | 21% | 14% | 16% | 25% |
| Diesel | 0% | 0% | 0% | 0% | 0% | 0% |
| Fuel Oil | 0% | 0% | 0% | 0% | 0% | 0% |
| Gas | 73% | 62% | 59% | 58% | 51% | 35% |
| Nuclear | 0% | 0% | 0% | 0% | 0% | 3% |
| Hydro | 8% | 12% | 11% | 12% | 14% | 13% |
| Onshore Wind | 0% | 0% | 1% | 2% | 2% | 3% |
| Offshore Wind | 0% | 0% | 0% | 0% | 0% | 0% |
| Biomass | 0% | 1% | 3% | 6% | 8% | 11% |
| Biogas | 0% | 0% | 0% | 0% | 0% | 0% |
| Solar | 0% | 0% | 4% | 6% | 6% | 6% |
| CSP | 0% | 0% | 0% | 0% | 0% | 0% |
| Hydro ROR | 0% | 0% | 0% | 0% | 0% | 0% |
| Geothermal | 0% | 0% | 1% | 2% | 3% | 3% |
| Pump Storage | 0% | 0% | 0% | 0% | 0% | 0% |
| Ocean | 0% | 0% | 0% | 0% | 0% | 0% |

## 5.5 Grid to Grid Power Flows

Figure 42 plots the imports and exports in the BAU with the dotted line representing the net interchange. Overall flows in the BAU are relatively low up to 2029 when imports from Myanmar start to increase with its transmission capability augmented over time to 3,250 MW by 2050 driven by differences in the levelised cost of electricity. Outside of the dedicated Lao PDR hydro projects, a further 600 - 800 MW of power flows into Thailand from Lao PDR.

**Figure 42 Thailand Imports and Exports (BAU, GWh)**

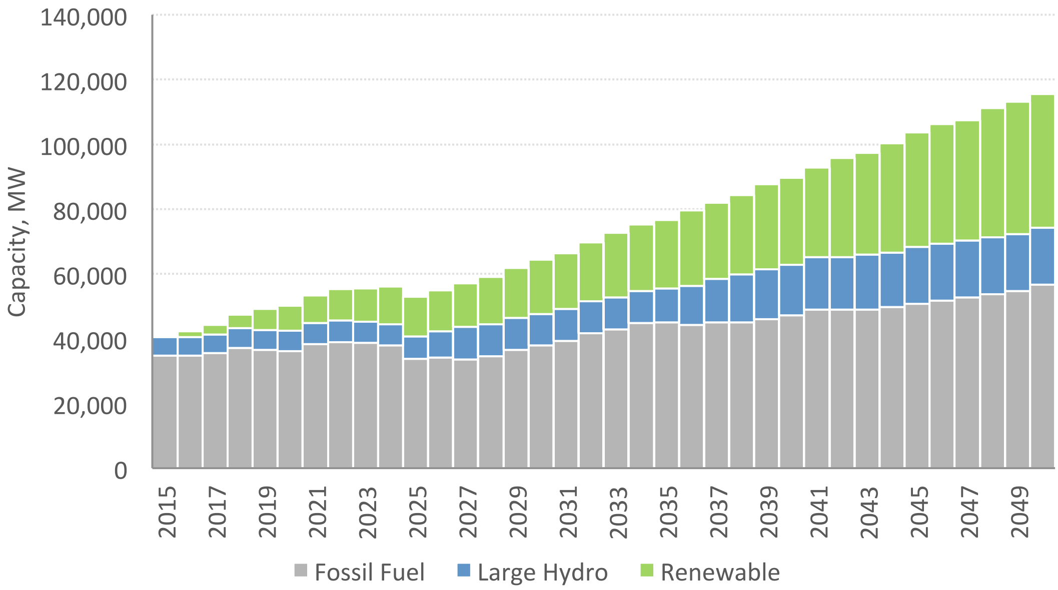



## 5.6 Projected Generation Fleet Structure

Figure 43 shows the installed generation capacity by the main categories of generation: thermal, renewable and large scale hydro, in order to provide greater insight into the basic structure of installed capacity under the BAU. This highlights that Thailand's BAU projection is as anticipated heavily dominated by fossil-fuel based generation. However, renewable capacity and generation increases over time to meet its renewable energy target. Figure 44 shows the on-grid composition of generation by major categories of generation: thermal, large hydro and renewable. As could be anticipated generation closely reflects the BAU's installed capacity mix.

To facilitate later comparison with the SES, Figure 45 plots installed capacity with capacity being distinguished between the following basic categories: (1) dispatchable capacity, (2) non-dispatchable capacity; and (3) semi-dispatchable capacity[46]. This provides some insight into the operational flexibility of the generation fleet to match demand uncertainty. The dispatchable category relates to generation that can be controlled and dispatched at short notice to ramp up or down, non-dispatchable means that the generation is not able to respond readily to dispatch instructions while the semi-dispatchable category means that the resource can respond within limits, and in particular is capable of being backed off should the need arise to for example, avoid overloading the network or “spill” energy in the event that an over generation situation emerges; solar photovoltaics and windfarms with appropriately installed control systems can be classified in this category. In the BAU, over time, as renewable generation trends towards 29% of the total installed capacity by 2050, the dispatchable percentage declines to 74% although still suggests a high level of dispatch control.

**Figure 43 Thailand Installed Capacity by Generation Type (BAU, MW)**




[46] Wind and solar is classified as semi-dispatchable, geothermal and hydro run-of-river is classified as non-dispatchable and all other technologies are classified as dispatchable.

**Figure 44 Thailand Generation Mix by Generation Type (BAU, GWh)**

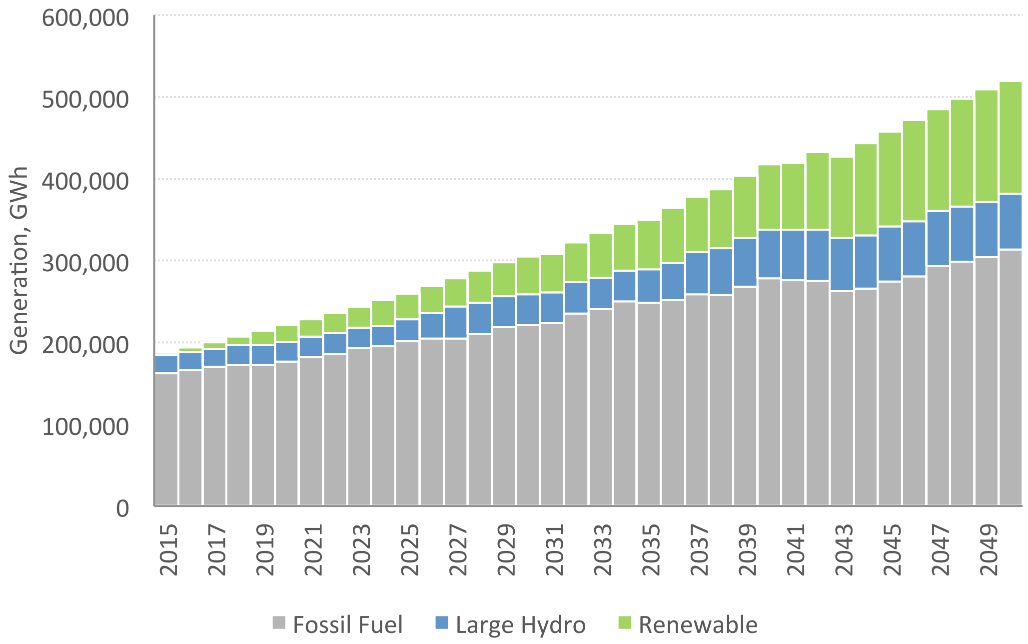
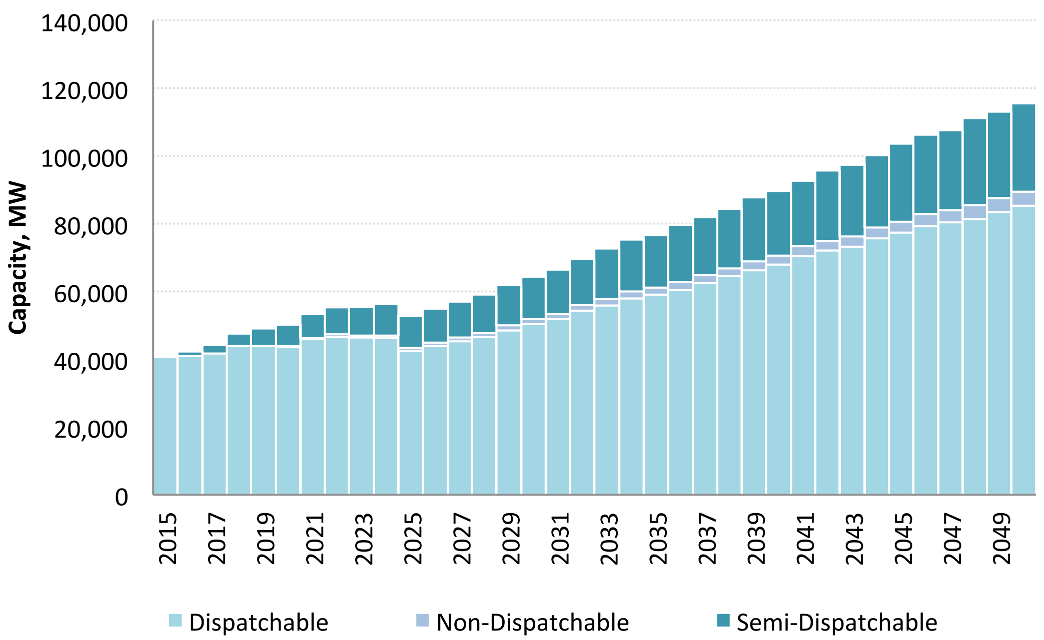


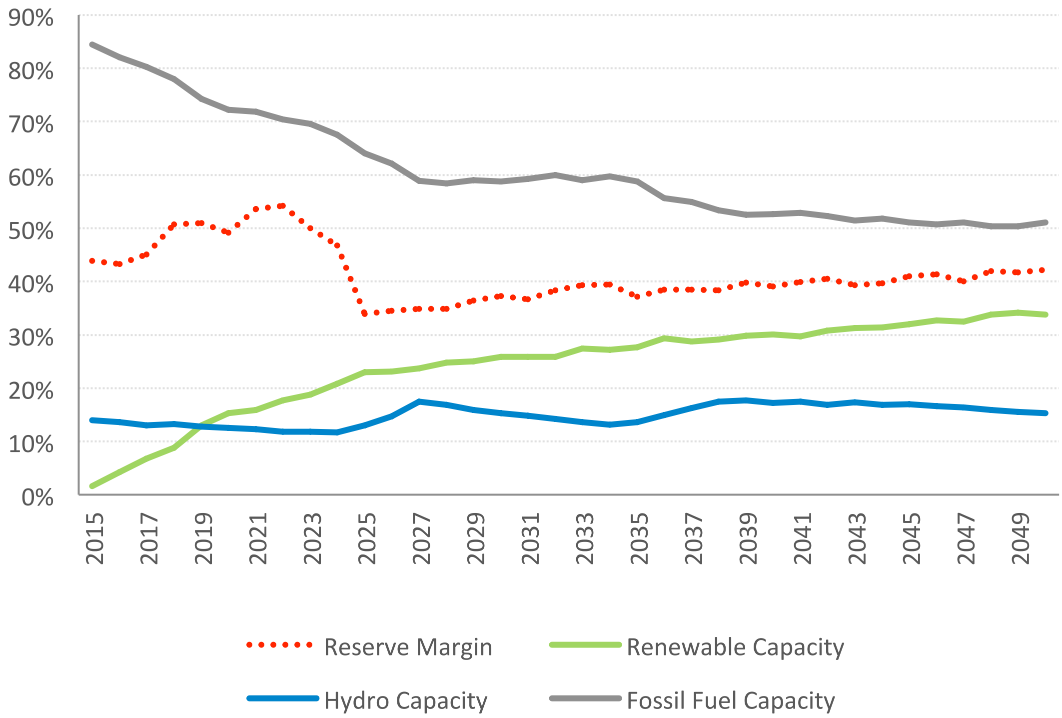

**Figure 45 Thailand Installed Capacity by Dispatch Status (BAU, MW)**



## 5.7 Reserve Margin and Generation Trends

Figure 46 plots the reserve margin based on nameplate capacity and annual peak demand. The Thailand reserve margin in the BAU increases past 50% by 2021 and then declines coinciding with 3,000 MW of gas plant retirements before trending back towards 45% by 2050. From 2025 to 2035, as renewable capacity starts to ramp up driving the reserve margin increases consistent with the lower capacity factors relative to conventional technologies. Thermal capacity drops to 51%% and hydro capacity remains around 14% across the horizon.

**Figure 46 Thailand Reserve Margin (BAU)**




To obtain a better understanding of the broad mix of generation capacity and generation mix, Figure 47 and Figure 48 show shares in installed capacity and in generation grouped by the main categories of generator: thermal, large hydro, renewable energy (RE) and large hydro plus renewable energy.

**Figure 47 Thailand Capacity Shares by Generation Type (BAU)**

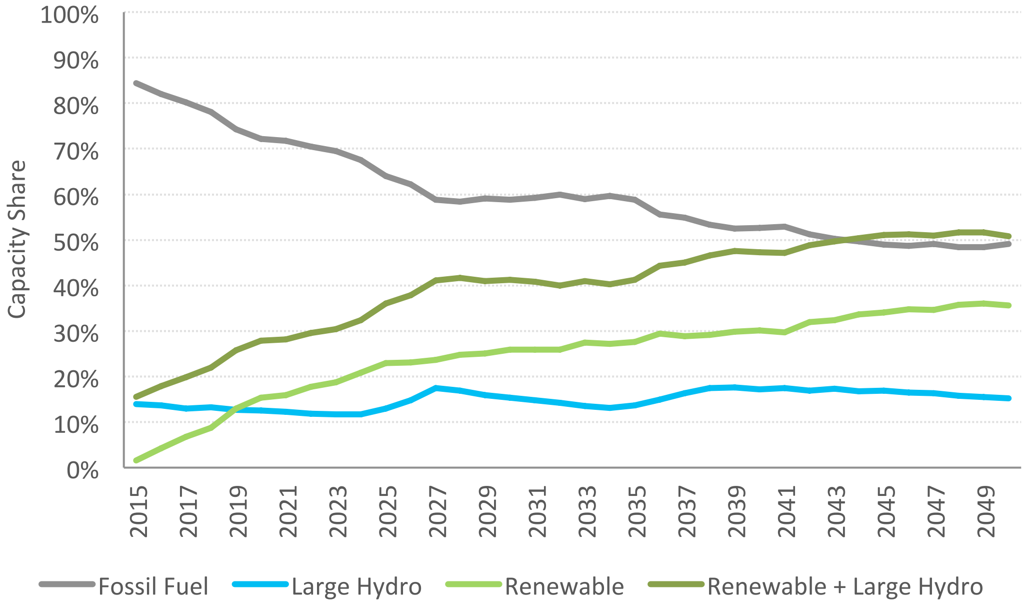
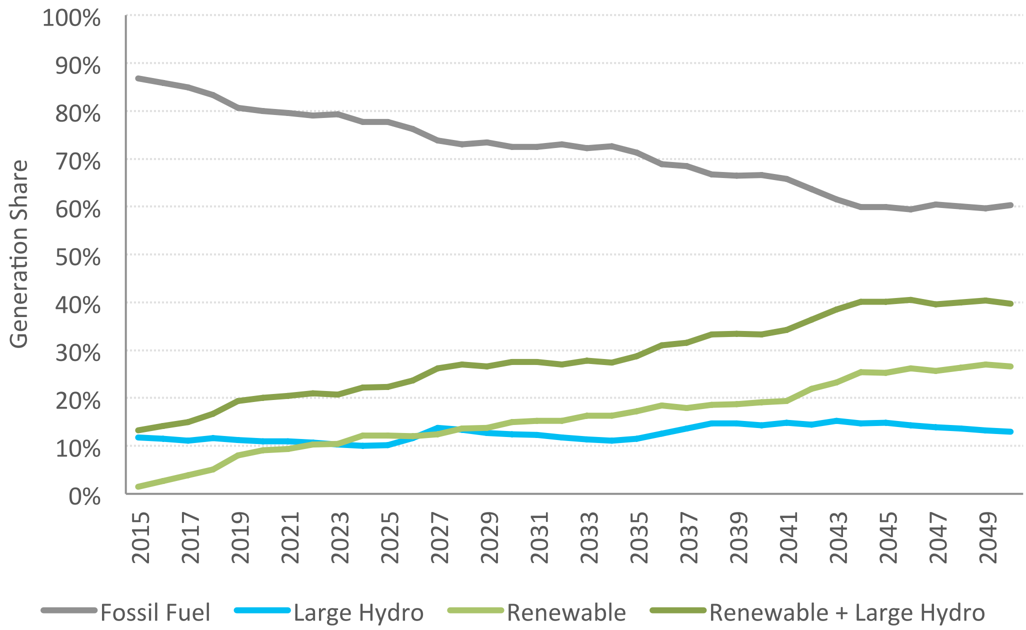



Figure 48 plots the generation shares by several different categories of generation. The thermal generation share declines from 87% in 2015 to 60% by 2050. Renewable energy including large-scale hydro gradually increases to 40% in 2050 as more renewable plants enter the system. The BAU has large-scale hydro being largely exploited and renewable energy deployment occurring in a way consistent with the Government's plans.

**Figure 48 Thailand Generation Shares by Generation Type (BAU)**




## 5.8 Electrification and Off-Grid

Thailand's grid-based electrification rate for its urban and rural population is assumed to reach close to 100% by 2030 in the BAU. Due to the limited impact of off-grid in this scenario it has been decided to only model the central grid-connected power system.

# 6 Sustainable Energy Sector Scenario

## 6.1 Sustainable Energy Sector Scenario

The SES seeks to transition electricity demand towards the best practice benchmarks of other developed countries in terms of energy efficiency, maximise the renewable energy development, cease the development of fossil fuel resources, and make sustainable and prudent use of undeveloped conventional hydro resources. The SES takes advantage of existing, technically proven and commercially viable renewable energy technologies.

## 6.2 Projected Demand Growth

Figure 49 plots Thailand's forecast energy consumption from 2015 to 2050 with the BAU energy trajectory charted as a comparison. The significant savings are due to additional energy efficiency assumptions relating to the various sectors achieving energy intensity benchmarks of comparable developed countries in Asia[47]. The SES demand grows at a slower rate of 2.1% pa over the period to 2050 with the commercial sector growing at 1.9% pa, industry growing at 2.4% pa and the residential sector growing at 0.8% pa. The agricultural sector grows at 1% and the uptake of electric transport options occur from 2025 onwards and grows to 28 TWh accounting for 5% of total demand by 2050 or 25% of all vehicles.

Figure 50 plots peak demand of Thailand. The firm blue line represents peak demand before any flexible demand side resources have been scheduled[48]. Flexible demand response is "dispatched" in the model in line with the least cost dispatch of all resources in the power system. The dashed line represents what peak demand became as a consequence of scheduling ("time-shifting") commercial, industrial and residential loads to minimise system costs. From 2020, the amount of flexible demand was assumed to grow to 10% of total demand across all sectors by 2050, or 15% if storage methods are included. The load factor associated with the SES was also assumed to reach 80% (compared to 75% under the BAU case) by 2030 as a further consequence of enhanced demand side management measures relative to the BAU.

Key drivers for demand growth and the demand projections are summarised in Table 12.

[47] Thailand's industrial intensity was trended towards levels commensurate with Hong Kong (2014) by 2050. Hong Kong had the lowest intensity based on a basket of comparable countries and the defined intensity metric.

[48] Flexible demand response is "dispatched" in the model in line with the least cost dispatch of all resources. The solid line represents peak demand as put in the model, while the dashed line represents what peak demand ended up being as a consequence of shifting demand from one period of time to another. This includes scheduling of loads associated with battery storage devices and rescheduling (time-shifting) commercial, industrial and residential loads.

**Figure 49 Thailand Projected Electricity Demand (2015-50, SES)**

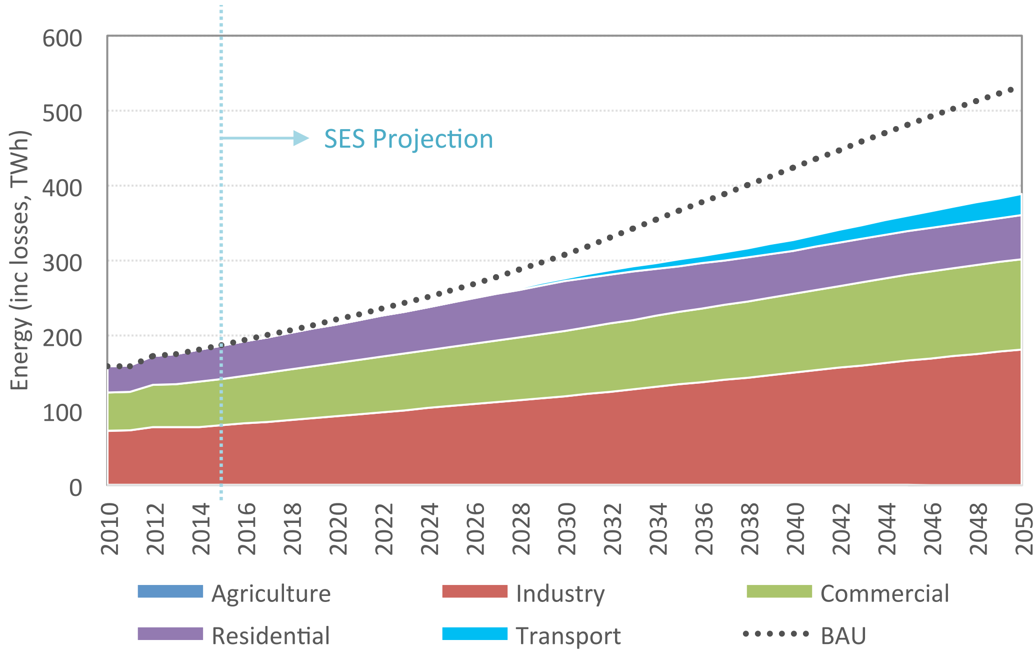



**Figure 50 Thailand Projected Electricity Demand (SES, MW)**

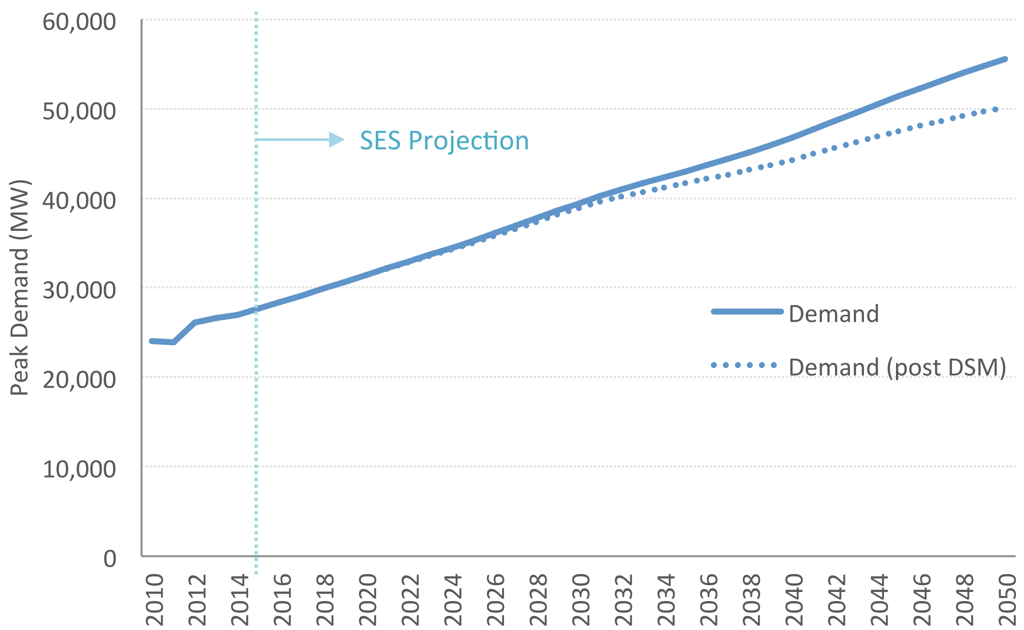


**Table 15 Thailand Demand and Demand Drivers (SES)**

| No. | Aspect | 2015-30 | 2030-40 | 2040-50 |
|---|---|---|---|---|
| 1 | Demand Growth (pa) | 2.4% | 1.7% | 1.7% |
| 2 | GDP Growth (Real, pa) | 4.0% | 4.0% | 2.9% |
| 3 | Electrification Rate (Population) | 100.0% | 100.0% | 100.0% |
| 4 | Population Growth | 0.60% | 0.23% | -0.04% |
| 5 | Per Capita Consumption (kWh) | 3,026 | 3,880 | 4,653 |
| 6 | Electricity Elasticity* | 1.56 | 1.28 | 1.20 |
| 7 | Electricity Intensity (kWh/USD) | 0.301 | 0.262 | 0.234 |

** Electricity elasticity is calculated as electricity demand growth divided by the population growth over the same period*

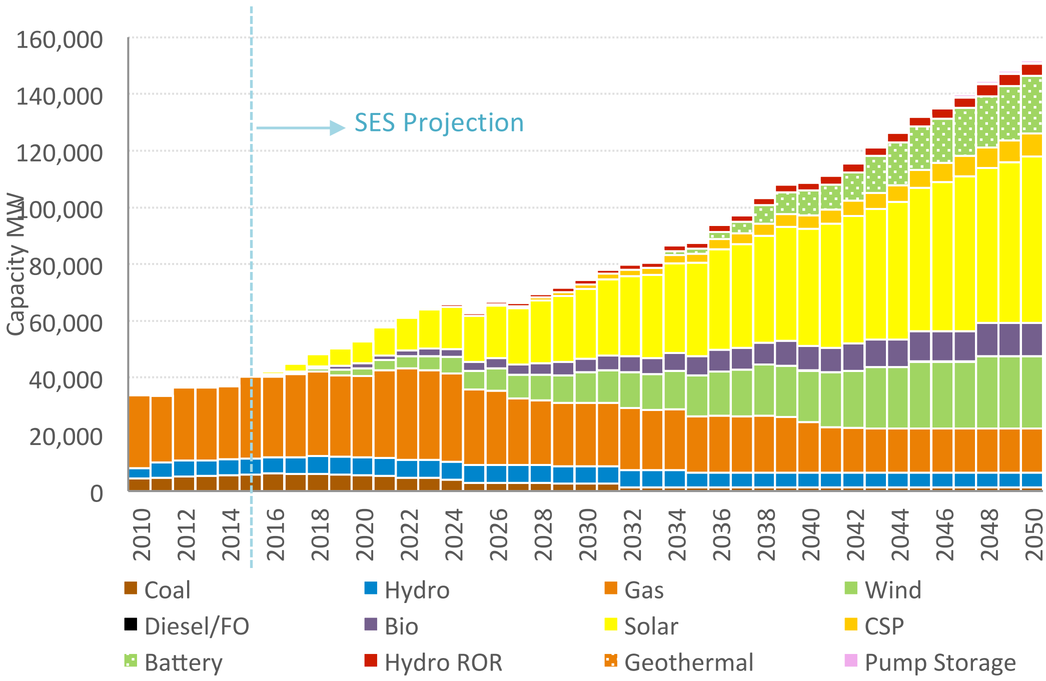
## 6.3 Projected Installed Capacity Development

Figure 51 plots the installed capacity developments under the SES and Figure 52 plots the corresponding percentage shares. Table 16 and Table 17 provide the statistical details of the installed capacity and capacity shares by type including the estimated 2010 levels.

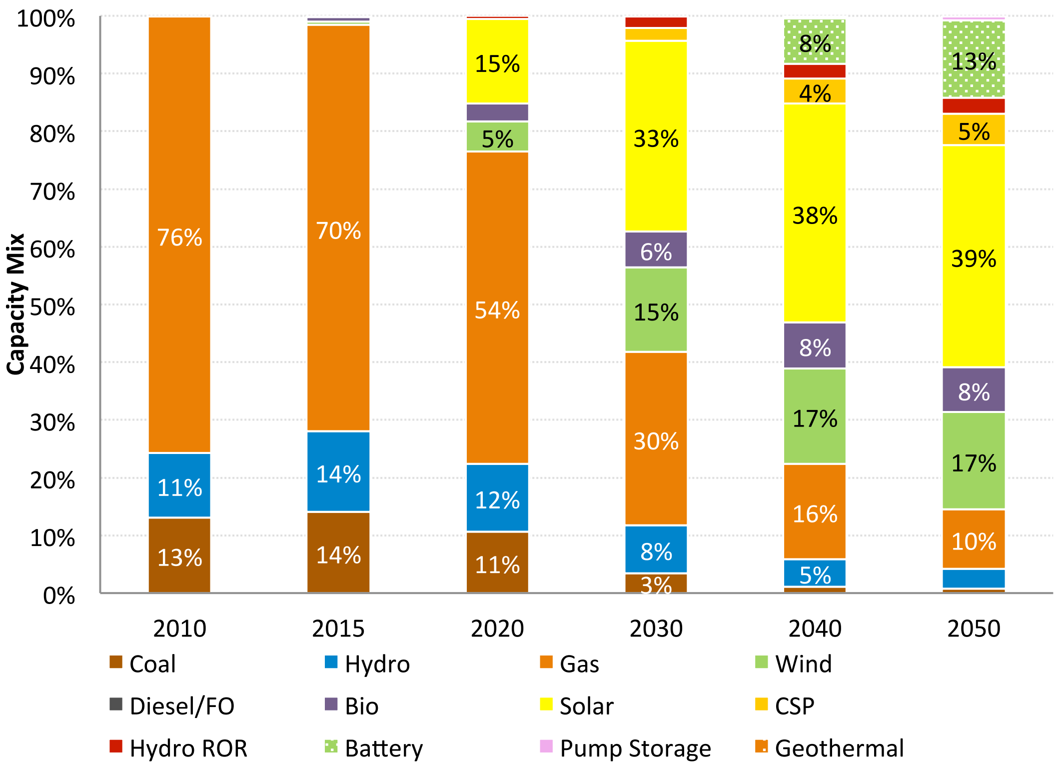
Committed and existing plants are assumed to come online as per the BAU but aren't replaced when retired. Planned and proposed thermal and large-scale hydro developments are assumed to not occur, with the exception of replacement gas plants, and all other generation requirements are instead met by renewable technologies. Coal and gas fired-generation in the earlier years is very similar to the BAU due to committed projects. Over time, these capacities drop off due to plant retirements and account for only 11% of total installed capacity by 2050 compared to 89% in 2015. Large-hydro penetration also decreases with planned large-scale hydro replaced with renewable energy.

Timing of renewable energy developments are based on the maturity of the technology and judgments of when it could be readily deployed in Thailand. Additional demand in the SES is predominantly met by renewables with 129 GW required to meet 2050 electricity demand from a current capacity base less than 1,000 MW (large-scale and grid connected). Solar PV is to account for 58 GW, biomass 12 GW, CSP 8 GW, and wind energy 25 GW of the total by 2050. Battery storage with an equivalent capability of 20 GW is developed to support the significant amount of solar PV and off-peak load.

**Figure 51 Thailand Installed Capacity by Type (SES, MW)**



## Figure 52 Thailand Capacity Shares (SES, %)




## Table 16 Thailand Capacity by Type (SES, MW)

| Resource | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 4,428 | 5,758 | 5,640 | 2,567 | 1,221 | 1,221 |
| Diesel | 0 | 5 | 5 | 5 | 5 | 5 |
| Fuel Oil | 45 | 0 | 0 | 0 | 0 | 0 |
| Gas | 25,508 | 28,902 | 28,700 | 22,367 | 18,000 | 15,558 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 0 |
| Hydro | 3,747 | 5,743 | 6,265 | 6,139 | 5,191 | 5,191 |
| Onshore Wind | 0 | 223 | 2,767 | 10,812 | 17,073 | 22,202 |
| Offshore Wind | 0 | 0 | 0 | 54 | 994 | 3,465 |
| Biomass | 0 | 313 | 1,673 | 4,673 | 8,673 | 11,246 |
| Biogas | 0 | 0 | 0 | 0 | 0 | 427 |
| Solar | 0 | 100 | 7,746 | 24,546 | 41,346 | 58,546 |
| CSP | 0 | 0 | 0 | 1,650 | 4,800 | 8,250 |
| Battery | 0 | 0 | 0 | 0 | 8,650 | 20,335 |
| Hydro ROR | 0 | 0 | 300 | 1,500 | 2,700 | 4,200 |
| Geothermal | 0 | 0 | 0 | 75 | 150 | 225 |
| Pump Storage | 0 | 0 | 0 | 0 | 300 | 900 |
| Ocean | 0 | 0 | 0 | 0 | 0 | 0 |

Table 17 Thailand Capacity Share by Type (SES, %)

| Resource | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 13% | 14% | 11% | 3% | 1% | 1% |
| Diesel | 0% | 0% | 0% | 0% | 0% | 0% |
| Fuel Oil | 0% | 0% | 0% | 0% | 0% | 0% |
| Gas | 76% | 70% | 54% | 30% | 16% | 10% |
| Nuclear | 0% | 0% | 0% | 0% | 0% | 0% |
| Hydro | 11% | 14% | 12% | 8% | 5% | 3% |
| Onshore Wind | 0% | 1% | 5% | 15% | 16% | 15% |
| Offshore Wind | 0% | 0% | 0% | 0% | 1% | 2% |
| Biomass | 0% | 1% | 3% | 6% | 8% | 7% |
| Biogas | 0% | 0% | 0% | 0% | 0% | 0% |
| Solar | 0% | 0% | 15% | 33% | 38% | 39% |
| CSP | 0% | 0% | 0% | 2% | 4% | 5% |
| Battery | 0% | 0% | 0% | 0% | 8% | 13% |
| Hydro ROR | 0% | 0% | 1% | 2% | 2% | 3% |
| Geothermal | 0% | 0% | 0% | 0% | 0% | 0% |
| Pump Storage | 0% | 0% | 0% | 0% | 0% | 1% |
| Ocean | 0% | 0% | 0% | 0% | 0% | 0% |

## 6.4 Projected Generation Mix

Grid generation is plotted in Figure 53 and Figure 54[49]. The corresponding statistics for snapshot years are provided in Table 19 and Table 20.

Thailand's generation mix in the earlier years to 2020 is similar to the BAU case as committed new entry are commissioned. Gas-fired generation is assumed to be developed replacing old plants keeping the system installed gas consistent with the capacity of the recently commissioned LNG facility. Thermal and large hydro projects outside what is deemed existing or committed is not developed and renewable technology is used to meet the remaining incremental demand. Biomass generation grows to 92 TWh by 2050 accounting for 23% of the country's generation, CSP contributes 10%, and wind accounts for 15%. By 2050, solar PV accounts for the highest generation share at 26% or almost 100 TWh of generation. By 2050 renewable technology (excluding large-scale hydro) generates 79% (or 84% including large-scale hydro) of total power requirements in the country coinciding with the retirements of older gas and coal plants.

[49] Battery storage is not included as storage technologies are generation neutral.

**Figure 53 Thailand Generation Mix (SES, GWh)**

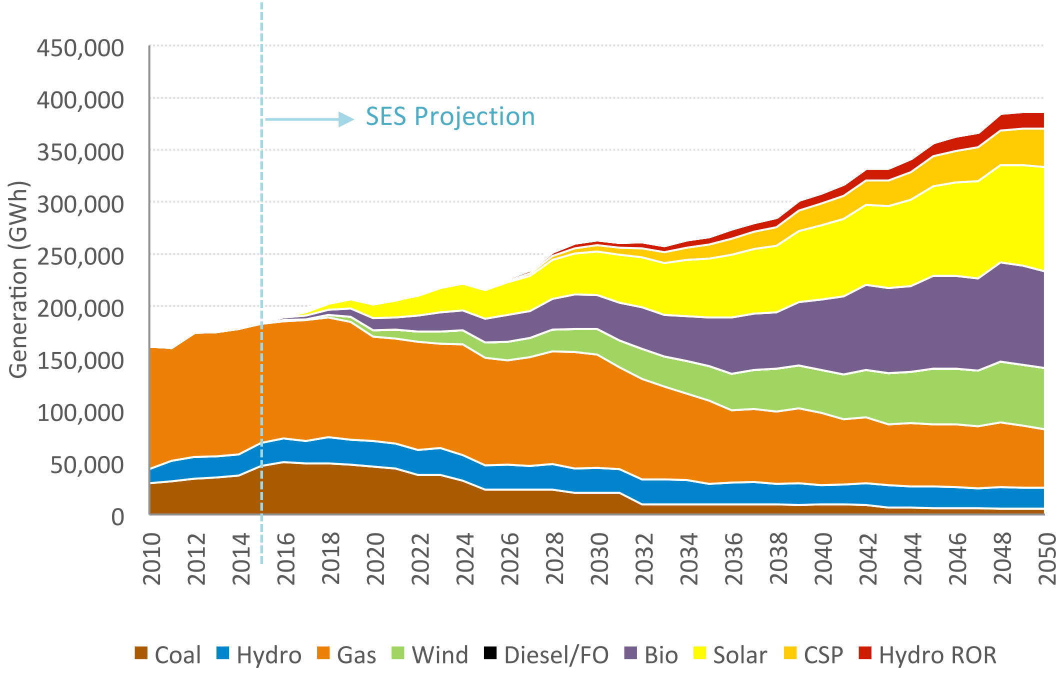
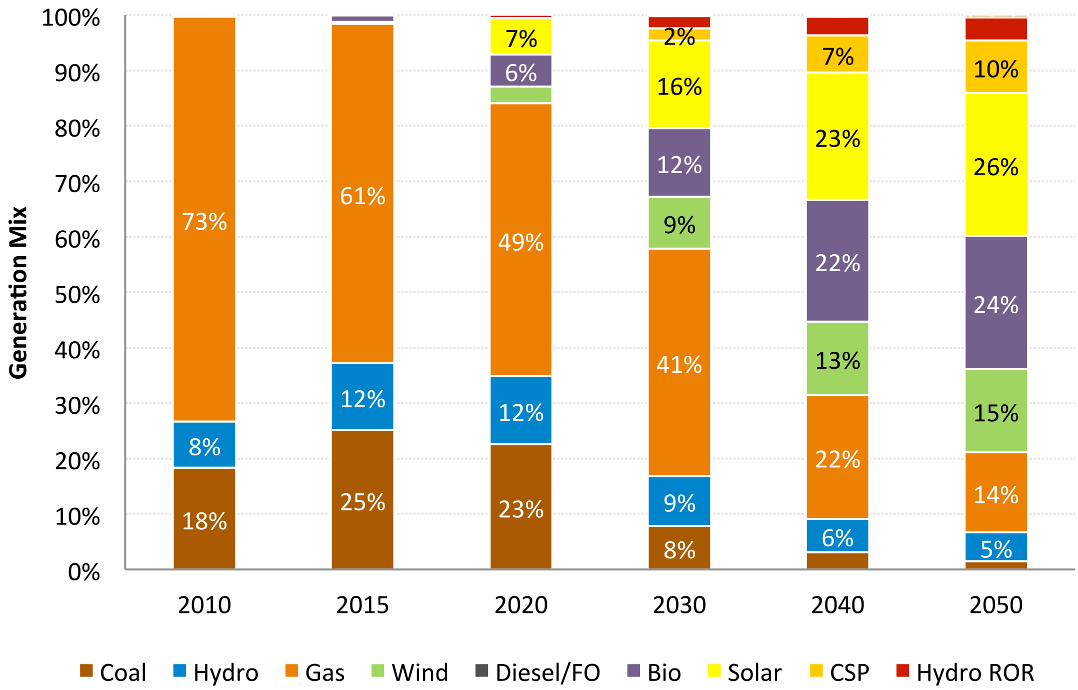



**Figure 54 Thailand Generation Share (SES, %)**



## Table 18 Thailand Generation by Fuel (SES, GWh)

| Generation | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 29,764 | 46,807 | 45,864 | 20,841 | 9,547 | 5,622 |
| Diesel | 0 | 0 | 0 | 0 | 10 | 0 |
| Fuel Oil | 600 | 0 | 0 | 0 | 0 | 0 |
| Gas | 118,438 | 113,791 | 99,824 | 108,582 | 69,103 | 55,910 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 0 |
| Hydro | 13,684 | 22,137 | 24,906 | 23,795 | 18,779 | 20,259 |
| Onshore Wind | 0 | 500 | 6,219 | 24,505 | 38,803 | 50,617 |
| Offshore Wind | 0 | 0 | 0 | 123 | 2,258 | 7,900 |
| Biomass | 0 | 2,190 | 11,753 | 32,745 | 67,951 | 89,522 |
| Biogas | 0 | 0 | 0 | 0 | 0 | 3,397 |
| Solar | 0 | 170 | 13,246 | 41,918 | 70,881 | 99,980 |
| CSP | 0 | 0 | 0 | 5,763 | 20,749 | 36,924 |
| Hydro ROR | 0 | 0 | 1,164 | 5,782 | 10,472 | 16,189 |
| Geothermal | 0 | 0 | 0 | 491 | 993 | 1,480 |
| Pump Storage | 0 | 0 | 0 | 0 | 252 | 835 |
| Ocean | 0 | 0 | 0 | 0 | 0 | 0 |

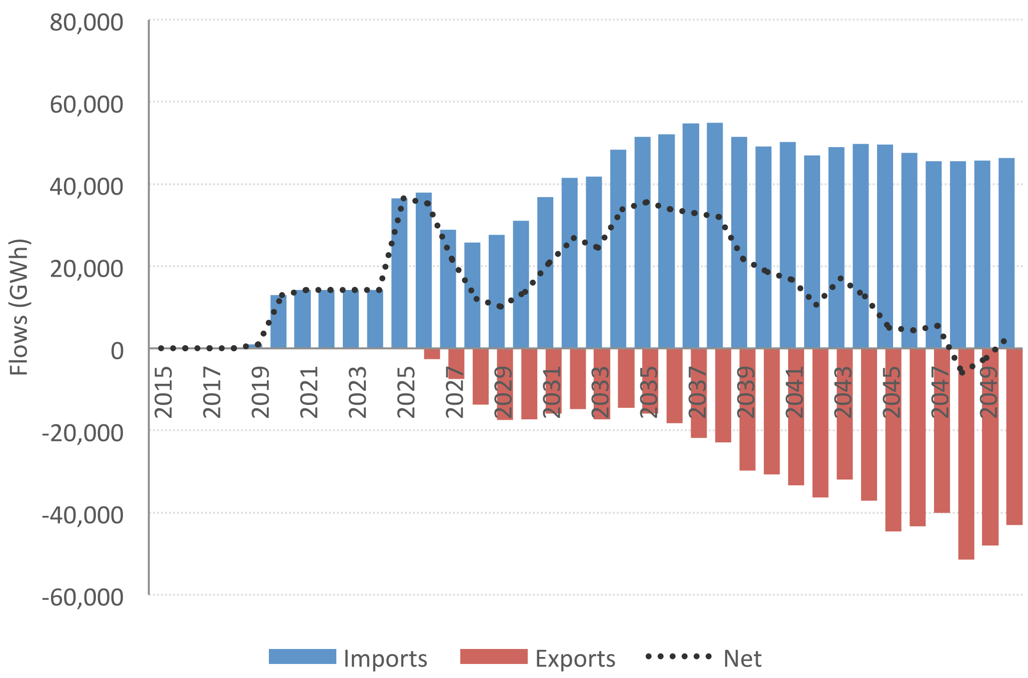
## Table 19 Thailand Generation Share by Fuel (SES, %)

| Generation | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 18% | 25% | 23% | 8% | 3% | 1% |
| Diesel | 0% | 0% | 0% | 0% | 0% | 0% |
| Fuel Oil | 0% | 0% | 0% | 0% | 0% | 0% |
| Gas | 73% | 61% | 49% | 41% | 22% | 14% |
| Nuclear | 0% | 0% | 0% | 0% | 0% | 0% |
| Hydro | 8% | 12% | 12% | 9% | 6% | 5% |
| Onshore Wind | 0% | 0% | 3% | 9% | 13% | 13% |
| Offshore Wind | 0% | 0% | 0% | 0% | 1% | 2% |
| Biomass | 0% | 1% | 6% | 12% | 22% | 23% |
| Biogas | 0% | 0% | 0% | 0% | 0% | 1% |
| Solar | 0% | 0% | 7% | 16% | 23% | 26% |
| CSP | 0% | 0% | 0% | 2% | 7% | 10% |
| Hydro ROR | 0% | 0% | 1% | 2% | 3% | 4% |
| Geothermal | 0% | 0% | 0% | 0% | 0% | 0% |
| Pump Storage | 0% | 0% | 0% | 0% | 0% | 0% |
| Ocean | 0% | 0% | 0% | 0% | 0% | 0% |

## 6.5 Grid to Grid Power Flows

Figure 55 plots the imports and exports in the SES with the dotted line representing the net interchange. Thailand imports and exports more in the SES than the BAU due to optimising generation across the region rather than on a country by country basis. Thailand imports are all from Myanmar with 7,000 MW of transmission developments. From 2025 Thailand starts to export energy into Cambodia (up to 3,300 MW) and into Lao PDR (up to 5,000 MW) – flows into Lao PDR augment power supply into Vietnam. Thailand on a net basis starts off as an importer then exports similar quantities towards 2050.

**Figure 55 Thailand Imports and Exports (SES)**




## 6.6 Projected Generation Fleet Structure

As for the BAU, to gain insight into the nature of the mix of generation technologies deployed in the SES, we present a number of additional charts. Figure 56 and Figure 57 show Thailand's installed capacity and generation by type for the SES – this is clearly heavily biased towards renewable generation forms and there is a gradual reduction in the thermal power plants. For Thailand, a considerable amount of non-renewable energy continues to feature in the generation mix and mainly relates to the investment in its LNG facility and gas generation plants.

**Figure 56 Thailand Installed Capacity by Generation Type (SES, MW)**

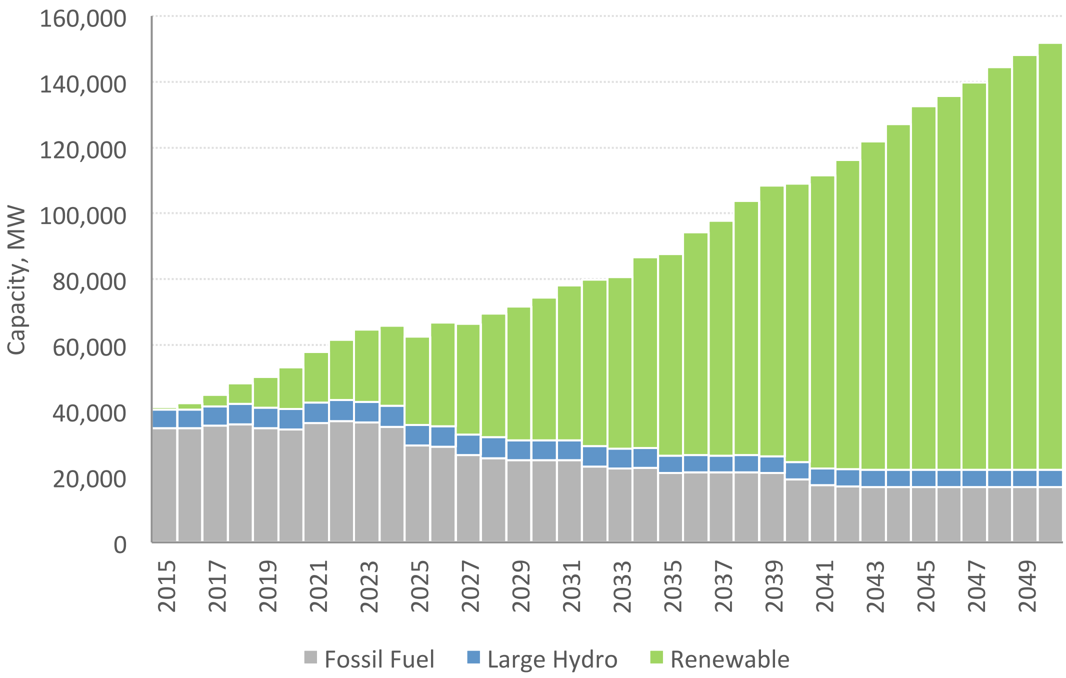



**Figure 57 Thailand Generation Mix by Generation Type (SES, GWh)**

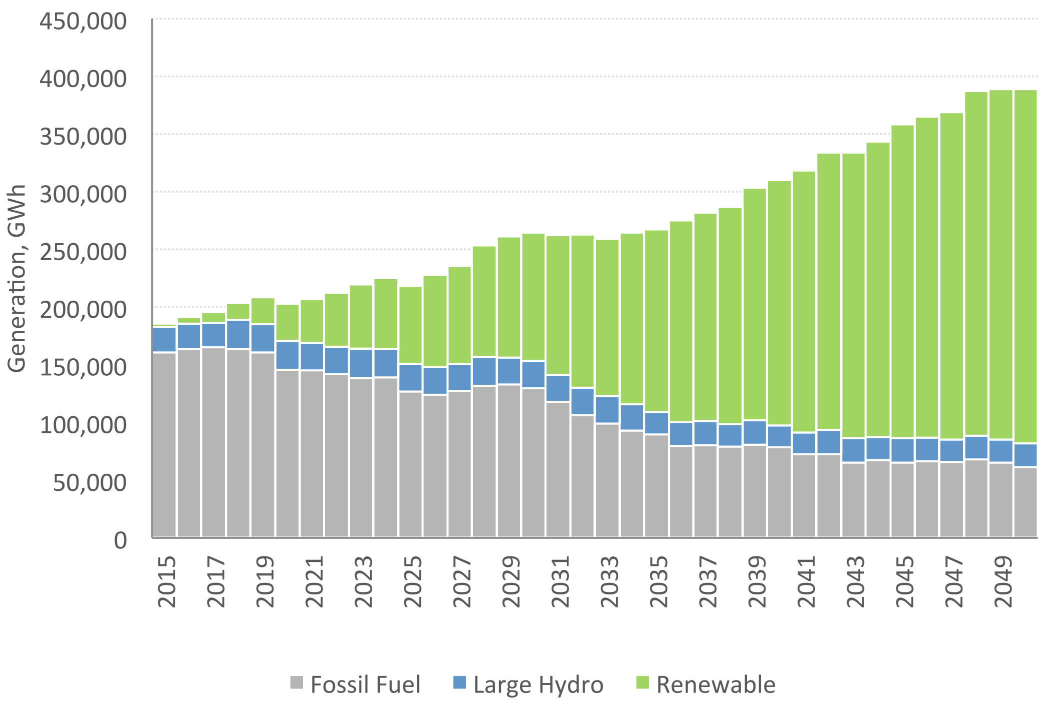
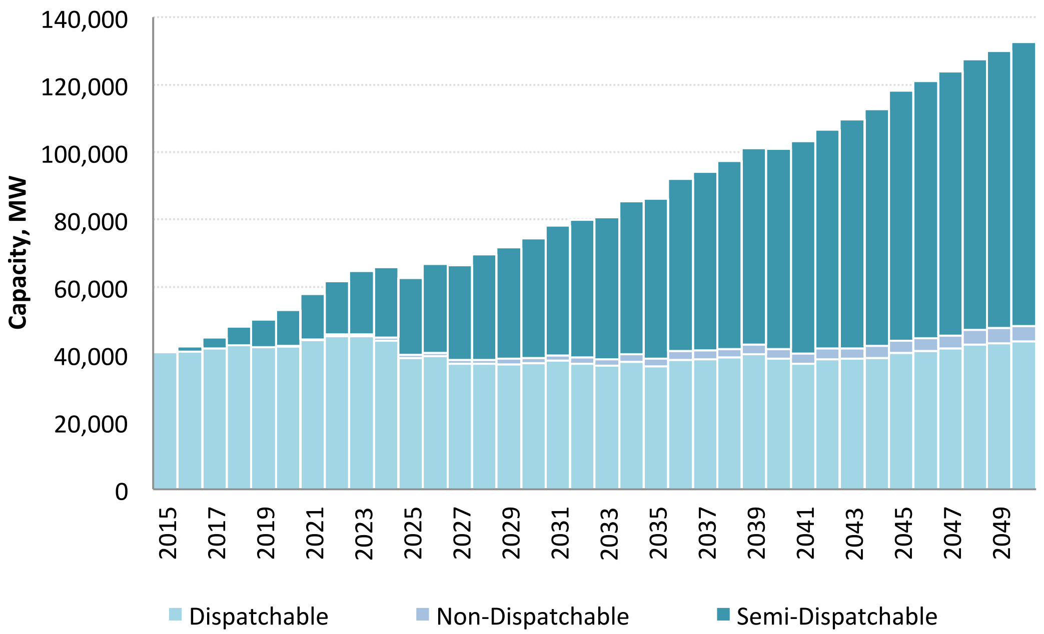


Figure 58, shows the dispatchable, semi-dispatchable and non-dispatchable components of installed capacity and it can be seen that semi-dispatchable increases to around 64% of the total system capacity compared to around 22% in the BAU by 2050. Based on operational simulations with this resource mix, it appears to be operationally feasible, although the reliance on generation forms that provide storage and having flexibility in the demand side play important roles. It is clear that short-term renewable energy solar and wind forecasting systems will be important, as will real-time updates on demand that can be controlled. Furthermore, control systems that can allow the dispatch of flexible resources on both supply and demand sides of the industry will be required.

**Figure 58 Thailand Installed Capacity by Dispatch Status (SES, MW)**




## 6.7 Reserve Margin and Generation Trends

Figure 59 plots the reserve margin under the SES. Figure 60 and Figure 61, respectively, show the installed capacity mix and generation mix for different categories of generation in the power system. The reserve margin in the SES increases to 140% by 2050 as installed renewable capacity increases to 83%. The high reserve margin is related to the low capacity factor technologies deployed in the SES. Conventional reserve margin measures are generally not suited to measuring high renewable energy systems in the same context used for thermal-based systems. Renewable technologies generally have much lower capacity factors and require more capacity to meet the same amount of energy produced from thermal-based technologies.

**Figure 59 Thailand Reserve Margin (SES)**

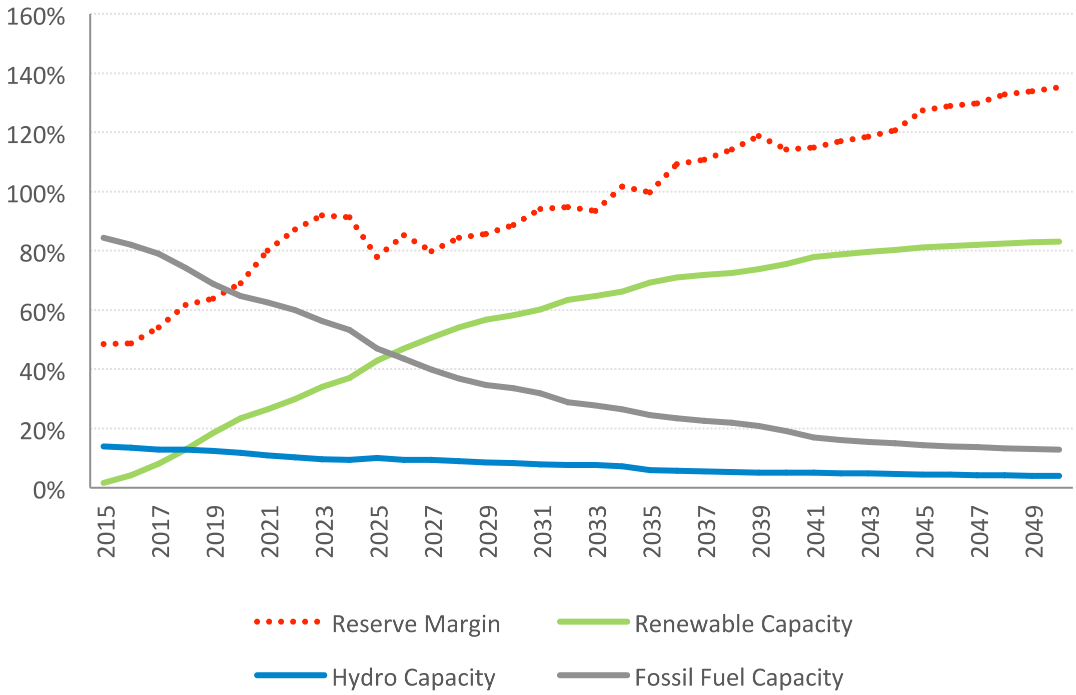



**Figure 60 Thailand Installed Capacity Shares for SES by Generation Type**

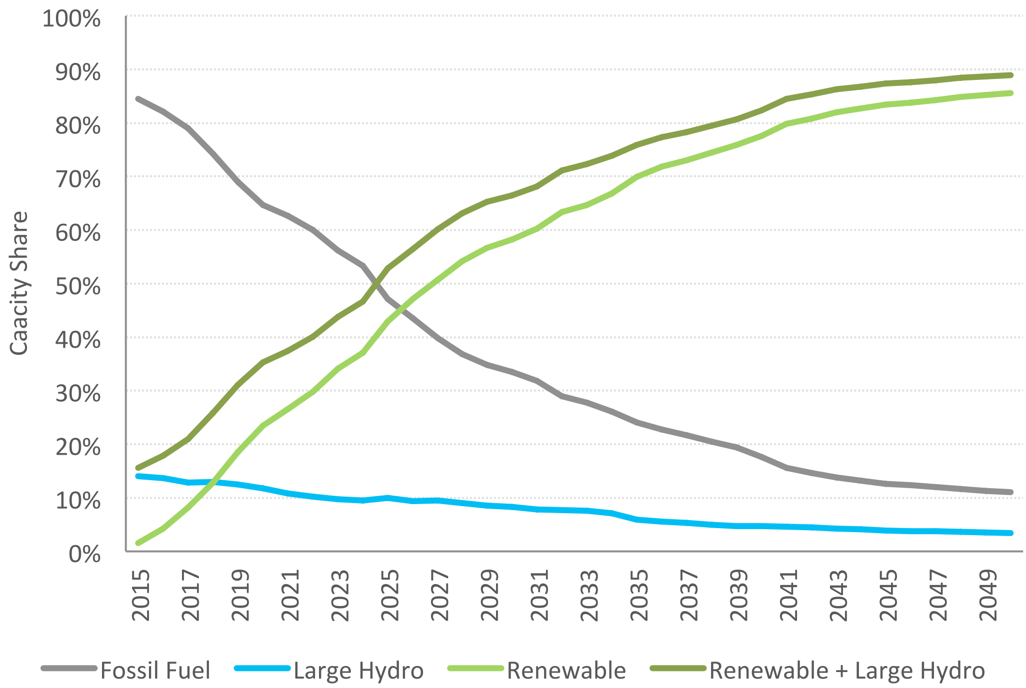
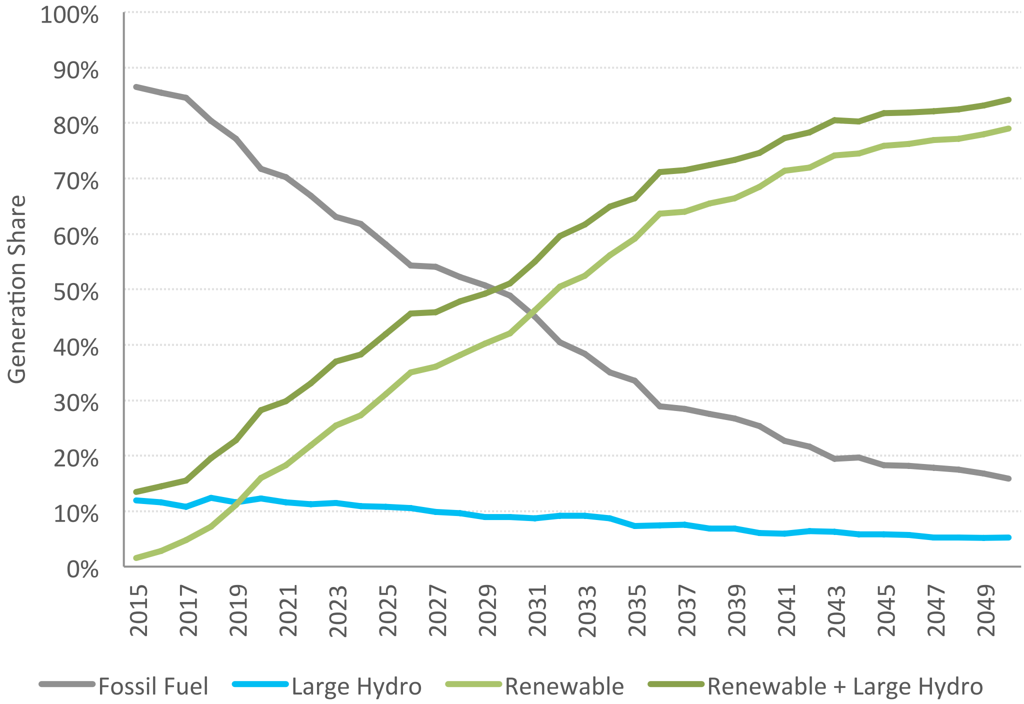


**Figure 61 Thaildand Generation Shares for SES by Generation Type**




## 6.8 Electrification and Off-Grid

Most of Thailand is already electrified and as per the BAU in the SES we have assumed that the grid remains a centrally interconnected into the future.

# 7 Advanced Sustainable Energy Sector Scenario

## 7.1 Advanced Sustainable Energy Sector Scenario

The ASES assumes that the power sector is able to more rapidly transition towards a 100% renewable energy technology mix under an assumption that renewable energy is deployed more than in the SES scenario with renewable energy technology costs declining more rapidly compared to BAU and SES scenarios.

## 7.2 Projected Demand Growth

Figure 62 plots Thailand's forecast energy consumption from 2015 to 2050 with the BAU and SES energy trajectory charted with a dashed line for comparison. The SES energy savings against the BAU are due to allowing Thailand's energy demand to transition towards energy intensity benchmarks of comparable developed countries in Asia. The ASES applies an additional 10% energy efficiency against the SES demands which is partially offset with additional transport demands associated with higher uptake rates. Electric vehicle uptake is assumed to double to 50% in the ASES.

The SES demand grows at a slower rate of 2.2% pa over the period from 2015 to 2050 with the commercial sector at 1.8% pa, industry growing at 2.2% pa and residential sector growing at 0.8% pa. Demand from the transport sector in the ASES is doubled and grows to 57 TWh or 14% of total demand by 2050.

Figure 63 plots the peak demand of Thailand. The firm blue line represents peak demand without any demand side management impacts. Demand side management reflects demand responses to tight supply and network conditions. This is assumed to grow to as much as 17.5% of demand across all sectors by 2050, representing the portion of flexible demand that is not met through technology means (i.e. battery storage). The load factor associated with the ASES is also assumed to reach 80% (compared to 75% under the BAU case) by 2030 as a further consequence of enhanced demand side management measures relative to the BAU.

Key drivers for demand growth and the demand projections are summarised in Table 17.

**Figure 62 Thailand Projected Electricity Demand (2015-50, ASES)**

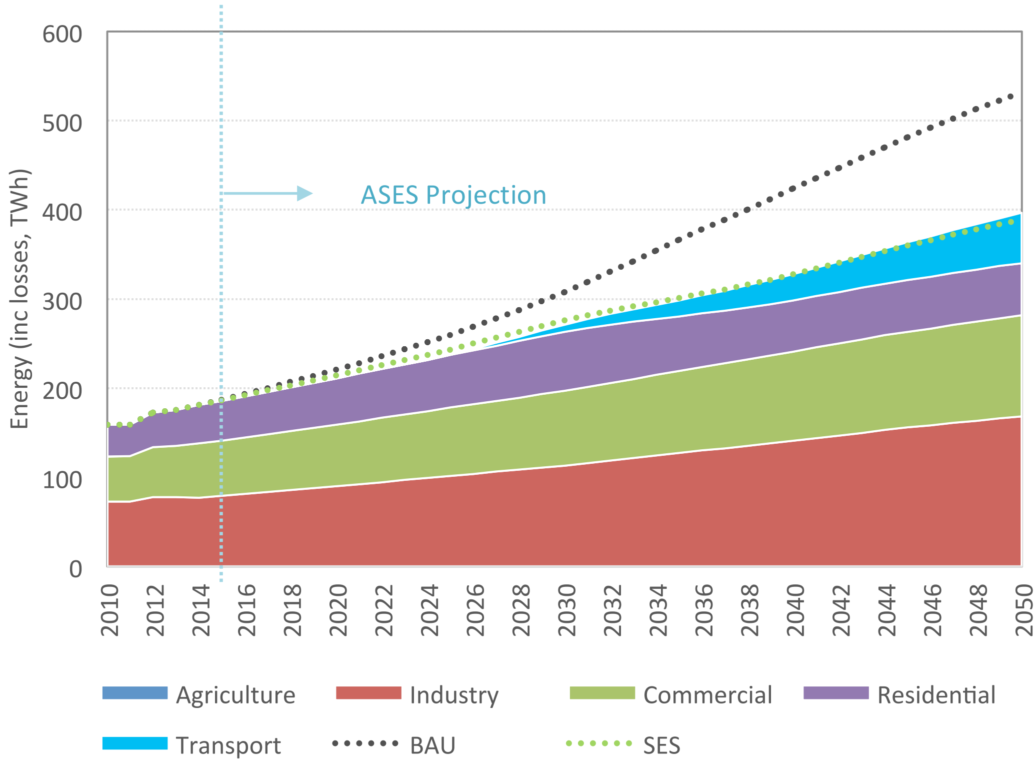



**Figure 63 Thailand Projected Electricity Demand (ASES, MW)**

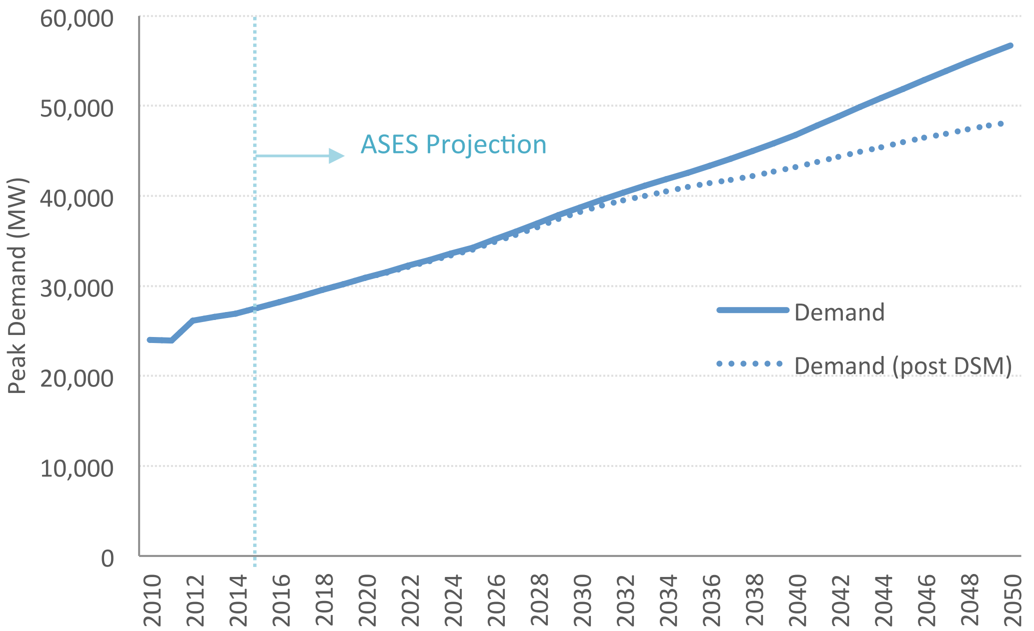


**Table 20 Thailand Demand and Demand Drivers (ASES)**

| No. | Aspect | 2015-30 | 2030-40 | 2040-50 |
|---|---|---|---|---|
| 1 | Demand Growth (pa) | 2.3% | 1.9% | 1.9% |
| 2 | GDP Growth (Real, pa) | 4.0% | 4.0% | 2.9% |
| 3 | Electrification Rate (Population) | 100.0% | 100.0% | 100.0% |
| 4 | Population Growth | 0.60% | 0.23% | -0.04% |
| 5 | Per Capita Consumption (kWh) | 2,976 | 3,812 | 4,656 |
| 6 | Electricity Elasticity* | 1.54 | 1.28 | 1.22 |
| 7 | Electricity Intensity (Demand/GDP) | 0.296 | 0.257 | 0.234 |

** Electricity elasticity is calculated as electricity demand growth divided by the population growth over the same period*

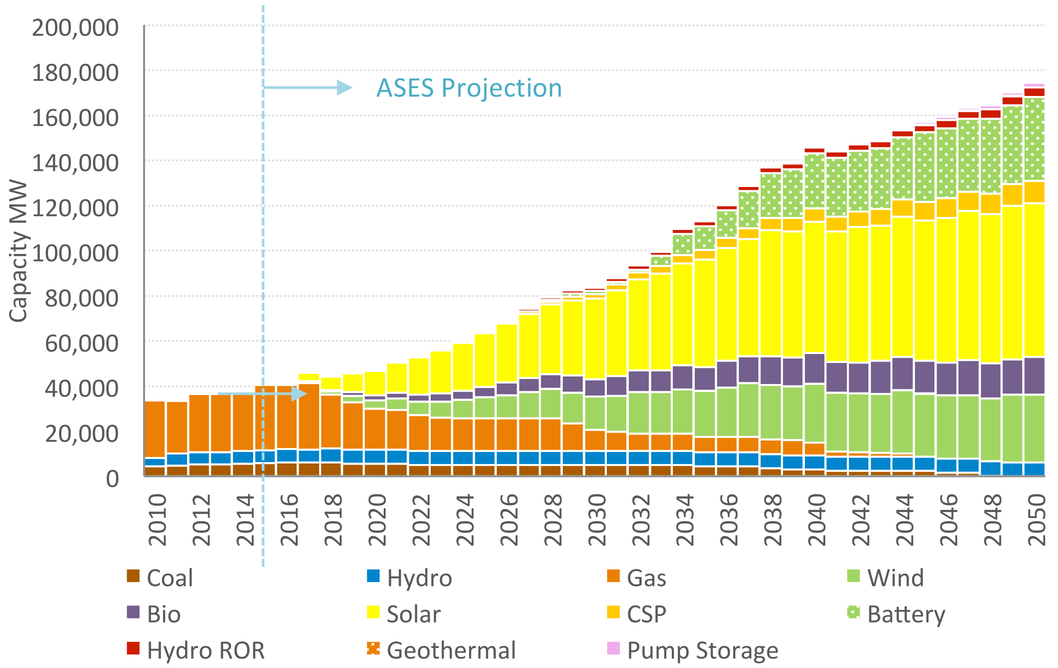
## 7.3 Projected Installed Capacity Development

Figure 64 plots the installed capacity developments under the SES and Figure 65 plots the corresponding percentage shares. Table 21 and Table 22 provide the statistical details of the installed capacity and capacity shares by type including the 2010 levels.

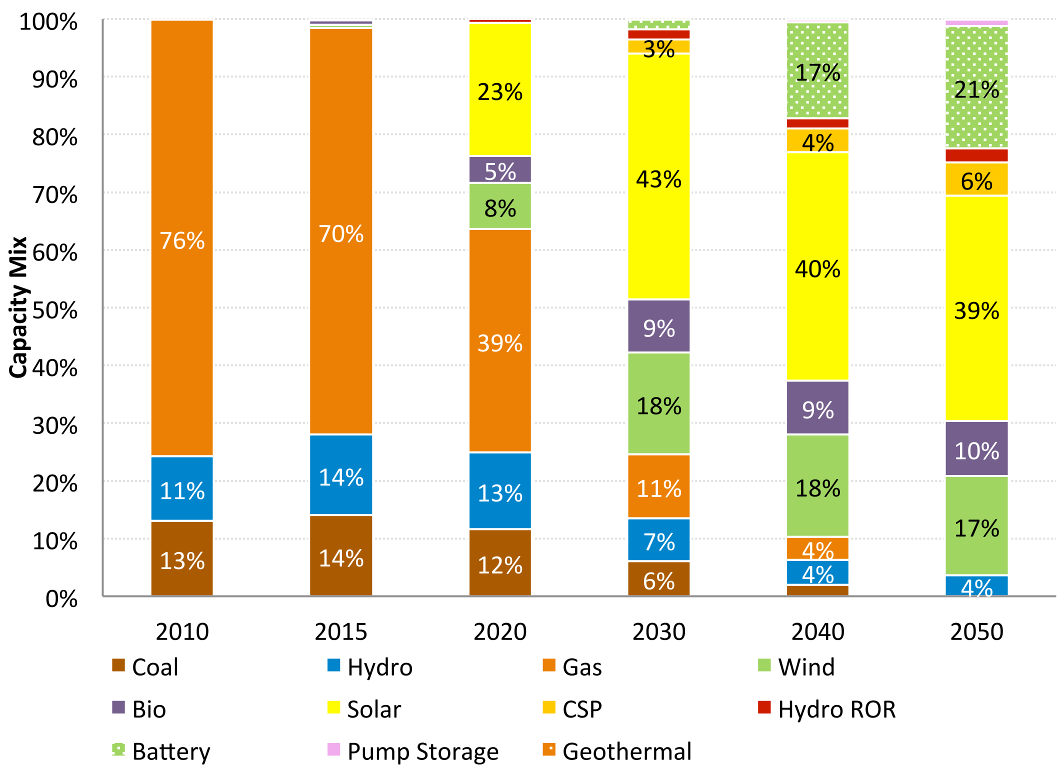
Committed and existing plants are assumed to come online as per the BAU but aren't replaced when retired. Existing thermal plant are retired early to meet the imposed renewable generation targets across the region. Renewable technologies ramp up much faster than in the SES to replace retirements of conventional generation technologies. By 2030 less than 20% of the installed capacity is based on fossil fuels and is entirely phased out by 2050.

By 2050 there is 68 GW (or 39%) of installed solar PV supported by 37 GW of battery storage capability mainly to defer generation for off-peak periods. Significant investment in wind, biomass and CSP technologies occur to meet the rising demands, accounting for 15%, 10%, and 6%, respectively, of total installed capacity by 2050.

## Figure 64 Thailand Installed Capacity by Type (ASES, MW)




## Figure 65 Thailand Capacity Shares (ASES, %)



## Table 21 Thailand Capacity by Type (ASES, MW)

| Resource | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 4,428 | 5,758 | 5,458 | 5,098 | 2,965 | 0 |
| Diesel | 0 | 5 | 5 | 0 | 0 | 0 |
| Fuel Oil | 45 | 0 | 0 | 0 | 0 | 0 |
| Gas | 25,508 | 28,902 | 18,171 | 9,194 | 5,826 | 0 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 0 |
| Hydro | 3,747 | 5,743 | 6,265 | 6,265 | 6,265 | 6,265 |
| Onshore Wind | 0 | 223 | 3,796 | 14,722 | 24,566 | 25,946 |
| Offshore Wind | 0 | 0 | 0 | 74 | 1,430 | 4,049 |
| Biomass | 0 | 313 | 2,173 | 7,673 | 13,673 | 16,673 |
| Biogas | 0 | 0 | 0 | 0 | 0 | 0 |
| Solar | 0 | 100 | 10,843 | 35,643 | 58,043 | 68,043 |
| CSP | 0 | 0 | 0 | 2,100 | 6,000 | 10,050 |
| Battery | 0 | 0 | 0 | 1,360 | 24,360 | 37,013 |
| Hydro ROR | 0 | 0 | 300 | 1,500 | 2,700 | 4,200 |
| Geothermal | 0 | 0 | 0 | 75 | 150 | 225 |
| Pump Storage | 0 | 0 | 0 | 0 | 600 | 1,800 |
| Ocean | 0 | 0 | 0 | 0 | 0 | 0 |

## Table 22 Thailand Capacity Share by Fuel (ASES)

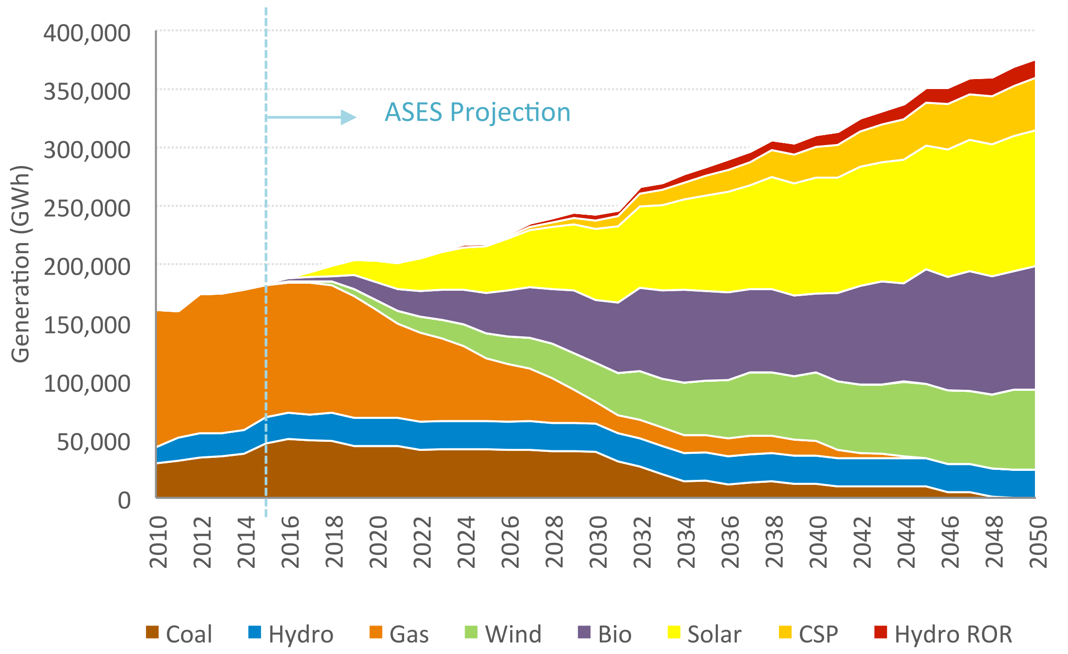
| Resource | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 13% | 14% | 12% | 6% | 2% | 0% |
| Diesel | 0% | 0% | 0% | 0% | 0% | 0% |
| Fuel Oil | 0% | 0% | 0% | 0% | 0% | 0% |
| Gas | 76% | 70% | 39% | 11% | 4% | 0% |
| Nuclear | 0% | 0% | 0% | 0% | 0% | 0% |
| Hydro | 11% | 14% | 13% | 7% | 4% | 4% |
| Onshore Wind | 0% | 1% | 8% | 18% | 17% | 15% |
| Offshore Wind | 0% | 0% | 0% | 0% | 1% | 2% |
| Biomass | 0% | 1% | 5% | 9% | 9% | 10% |
| Biogas | 0% | 0% | 0% | 0% | 0% | 0% |
| Solar | 0% | 0% | 23% | 43% | 40% | 39% |
| CSP | 0% | 0% | 0% | 3% | 4% | 6% |
| Battery | 0% | 0% | 0% | 2% | 17% | 21% |
| Hydro ROR | 0% | 0% | 1% | 2% | 2% | 2% |
| Geothermal | 0% | 0% | 0% | 0% | 0% | 0% |
| Pump Storage | 0% | 0% | 0% | 0% | 0% | 1% |
| Ocean | 0% | 0% | 0% | 0% | 0% | 0% |

## 7.4 Projected Generation Mix

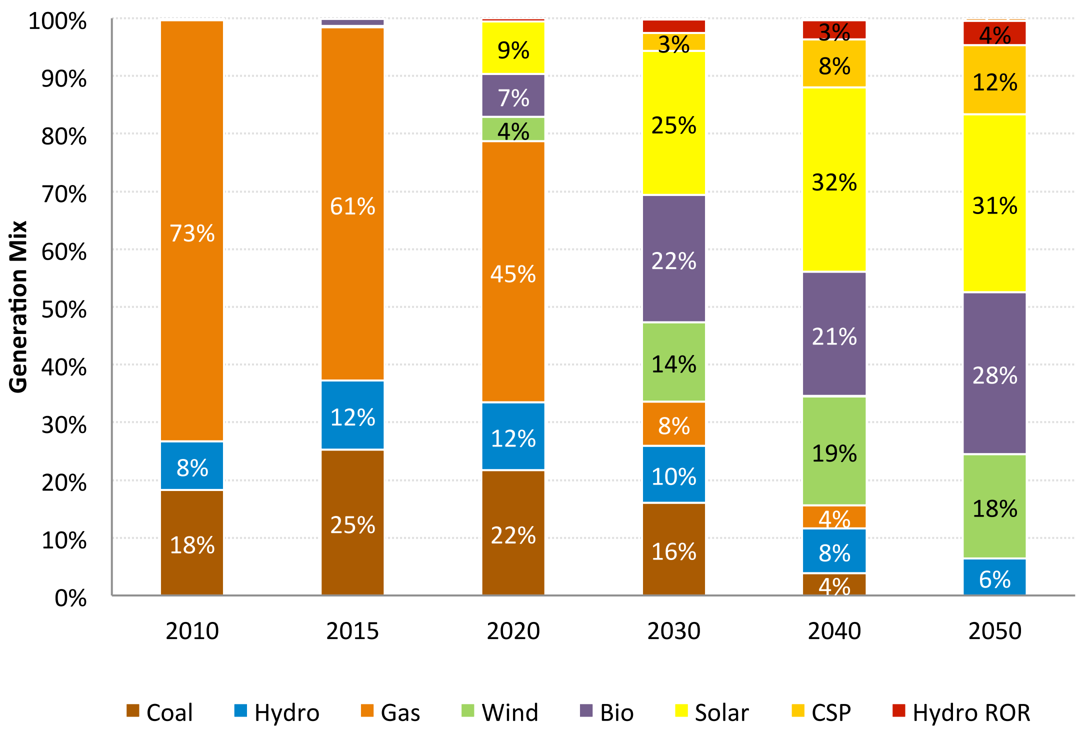
ASES grid generation is plotted in Figure 66 and generation shares in Figure 67[50]. The corresponding statistics for snapshot years are provided Table 24 and Table 25. Thailand's generation mix in the earlier years to 2020 is similar to the BAU case as committed new generation projects are commissioned and this has largely been kept the same.

Of the renewable technologies, by 2050, solar PV contributes the highest generation share of 11 TWh or 31% followed by biomass at 28%. Wind comprised mainly of onshore projects contribute 18% of the total generation share by 2050. Biomass fills the baseload role in the power system as gas and coal plants technologies retire earlier than in the SES. By 2030, 76% of all generation is from renewable sources (includes large-scale hydro) and moves towards 100% by 2050.

## Figure 66 Thailand Generation Mix (ASES, GWh)




## Figure 67 Thailand Generation Mix (ASES, %)



## Table 23 Thailand Generation by Type (ASES, GWh)

| Generation | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 29,764 | 46,807 | 44,384 | 39,189 | 12,109 | 0 |
| Diesel | 0 | 0 | 0 | 0 | 0 | 0 |
| Fuel Oil | 600 | 0 | 0 | 0 | 0 | 0 |
| Gas | 118,438 | 113,139 | 92,356 | 18,682 | 12,266 | 0 |
| Nuclear | 0 | 0 | 0 | 0 | 0 | 0 |
| Hydro | 13,684 | 22,137 | 24,146 | 24,146 | 24,146 | 24,146 |
| Onshore Wind | 0 | 500 | 8,532 | 33,365 | 55,832 | 59,154 |
| Offshore Wind | 0 | 0 | 0 | 168 | 3,249 | 9,232 |
| Biomass | 0 | 2,190 | 15,267 | 53,769 | 67,080 | 105,652 |
| Biogas | 0 | 0 | 0 | 0 | 0 | 0 |
| Solar | 0 | 170 | 18,542 | 60,868 | 99,505 | 116,198 |
| CSP | 0 | 0 | 0 | 7,440 | 25,996 | 44,974 |
| Hydro ROR | 0 | 0 | 1,164 | 5,782 | 10,472 | 16,189 |
| Geothermal | 0 | 0 | 0 | 491 | 993 | 1,480 |
| Pump Storage | 0 | 0 | 0 | 0 | 712 | 2,130 |
| Ocean | 0 | 0 | 0 | 0 | 0 | 0 |

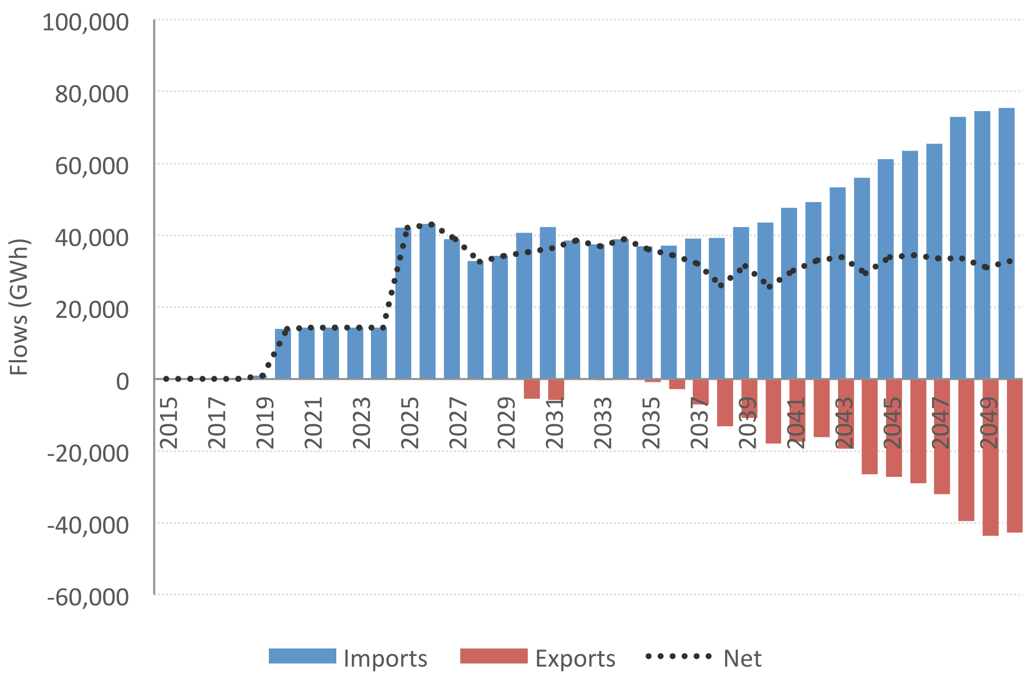
## Table 24 Thailand Generation Share by Type (ASES, %)

| Generation | 2010 | 2015 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Coal | 18% | 25% | 22% | 16% | 4% | 0% |
| Diesel | 0% | 0% | 0% | 0% | 0% | 0% |
| Fuel Oil | 0% | 0% | 0% | 0% | 0% | 0% |
| Gas | 73% | 61% | 45% | 8% | 4% | 0% |
| Nuclear | 0% | 0% | 0% | 0% | 0% | 0% |
| Hydro | 8% | 12% | 12% | 10% | 8% | 6% |
| Onshore Wind | 0% | 0% | 4% | 14% | 18% | 16% |
| Offshore Wind | 0% | 0% | 0% | 0% | 1% | 2% |
| Biomass | 0% | 1% | 7% | 22% | 21% | 28% |
| Biogas | 0% | 0% | 0% | 0% | 0% | 0% |
| Solar | 0% | 0% | 9% | 25% | 32% | 31% |
| CSP | 0% | 0% | 0% | 3% | 8% | 12% |
| Hydro ROR | 0% | 0% | 1% | 2% | 3% | 4% |
| Geothermal | 0% | 0% | 0% | 0% | 0% | 0% |
| Pump Storage | 0% | 0% | 0% | 0% | 0% | 1% |
| Ocean | 0% | 0% | 0% | 0% | 0% | 0% |

## 7.5 Grid to Grid Power Flows

Figure 68 plots the imports and exports in the BAU with the dotted line representing the net interchange. The power flows in the ASES is similar in magnitude to the SES with most of the power imported from Myanmar due to its vast renewable resources and smaller energy requirement. Across the horizon, Thailand is a net importer with comparatively smaller exports of energy into Cambodia and Lao PDR.

**Figure 68 Thailand Imports and Exports (ASES)**




## 7.6 Projected Generation Fleet Structure

To gain insight into the nature of the mix of generation technologies deployed in the ASES, we present a number of additional charts. Figure 69 and Figure 70 show Thailand's installed capacity by generation type for the SES – this is clearly heavily biased towards renewable generation forms and there is a steady reduction in the thermal power plants. For Thailand, a considerable amount of non-renewable energy continues to feature in the generation mix in the earlier years before declining to 0 by 2050.

**Figure 69 Thailand Installed Capacity by Type (ASES)**

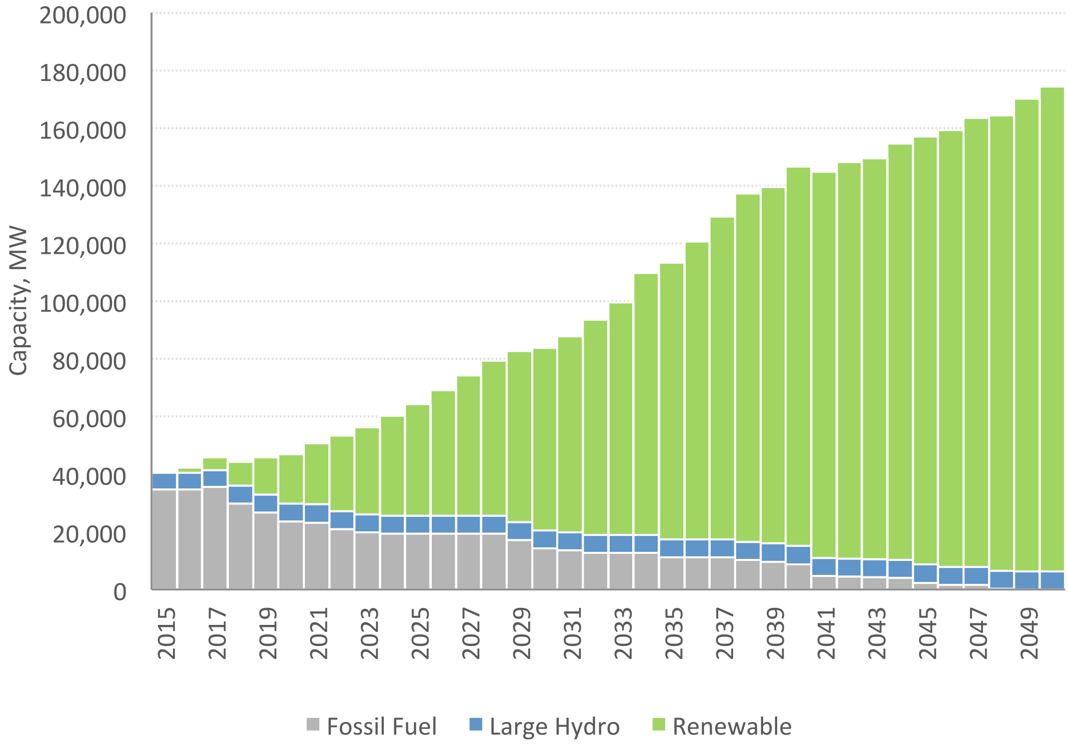



**Figure 70 Thailand Generation Mix by Type (ASES)**

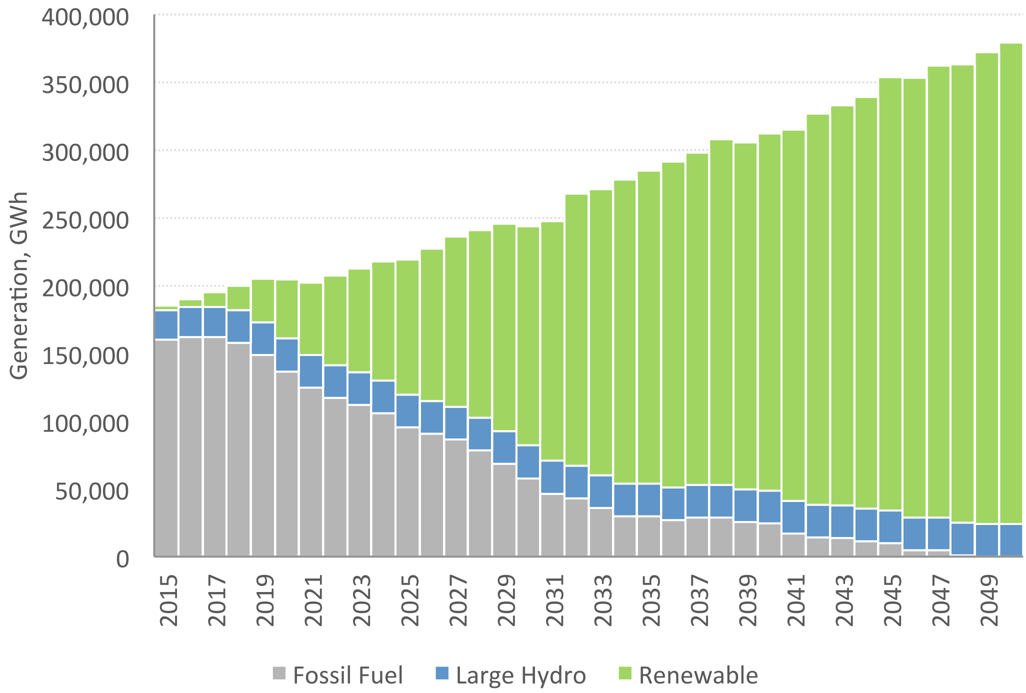
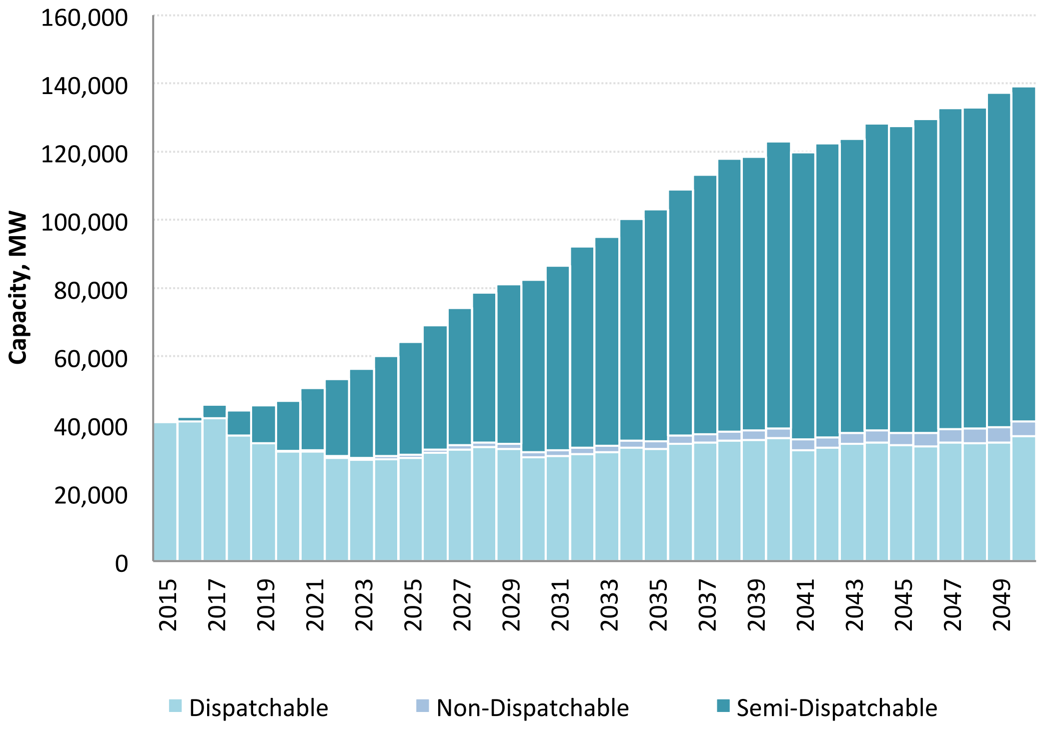


Figure 71, shows the dispatchable, semi-dispatchable and non-dispatchable components of installed capacity and it can be seen that semi-dispatchable increases to around 71% of the total system capacity compared to around 22% in the BAU by 2050. Based on operational simulations with this resource mix, it appears to be operationally feasible, although the reliance on generation forms that provide storage and having flexibility in the demand side play important roles. It is clear that short-term renewable energy solar and wind forecasting systems will be important, as will real-time updates on demand that can be controlled. Furthermore, control systems that can allow the dispatch of flexible resources on both supply and demand sides of the industry will be required.

**Figure 71 Thailand Installed Capacity by Dispatch Status (ASES)**




## 7.7 Reserve Margin and Generation Trends

Figure 72 plots the reserve margin under the ASES. Figure 73 and Figure 74, respectively, show the installed capacity mix and generation mix for different categories of generation in the power system. The ASES reserve margin trends past 100% as conventional baseload technologies are retired early to meet the renewable energy policy target of 100% by 2050.

It is worth noting conventional reserve margin measures are generally not suited to measuring high renewable energy systems in the same context used for thermal-based systems. Renewable technologies generally have much lower capacity factors and require more capacity to meet the same amount of energy produced from thermal-based technologies.

**Figure 72 Thailand Reserve Margin (ASES)**

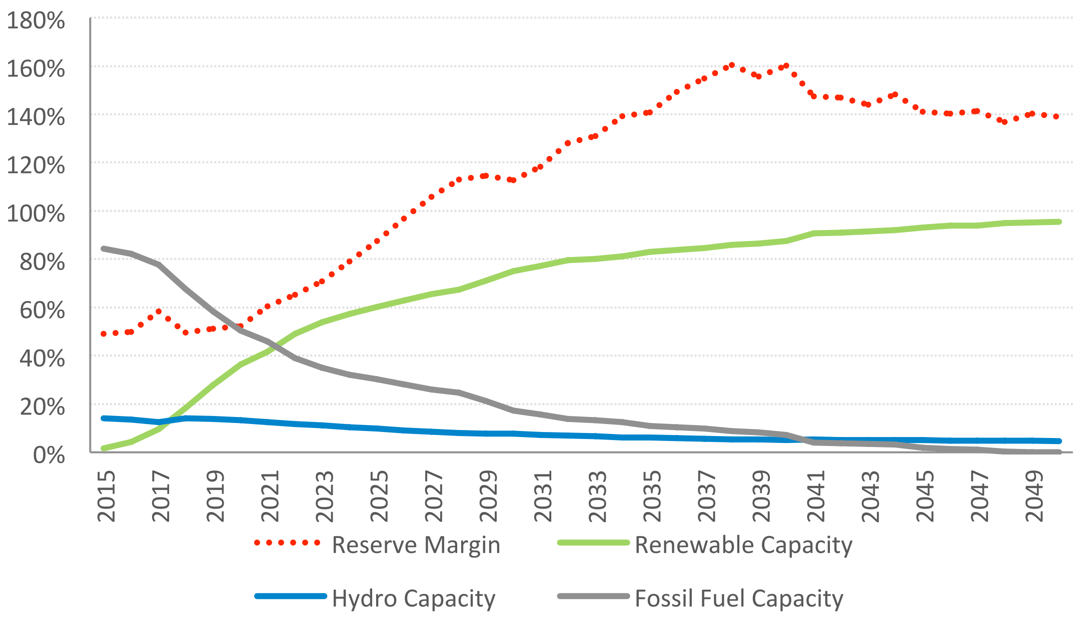



**Figure 73 Thailand Installed Capacity Shares for ASES by Generation Type**

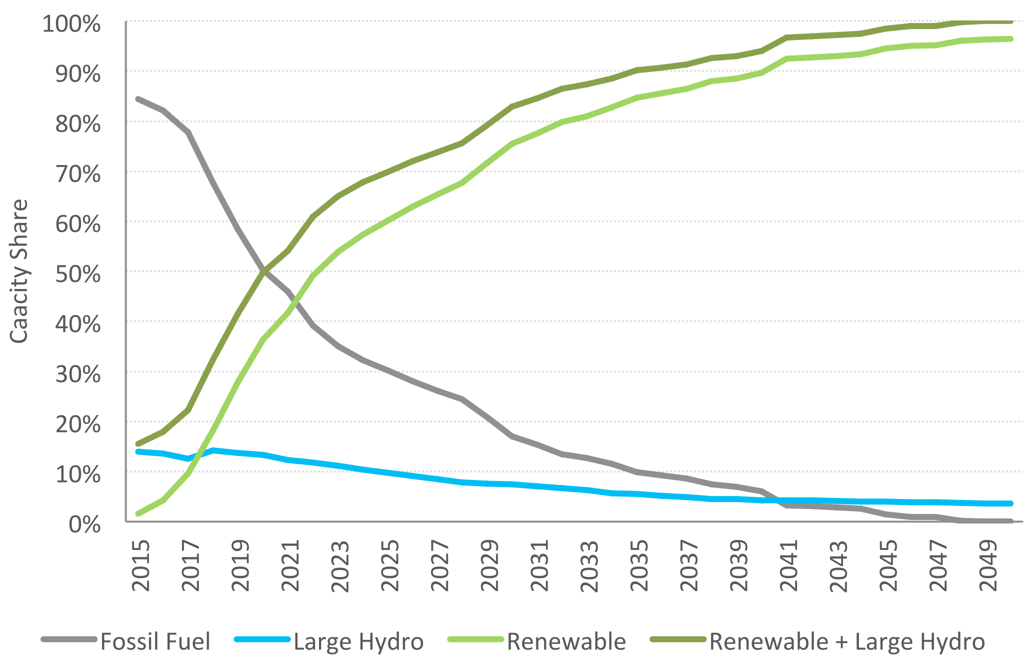
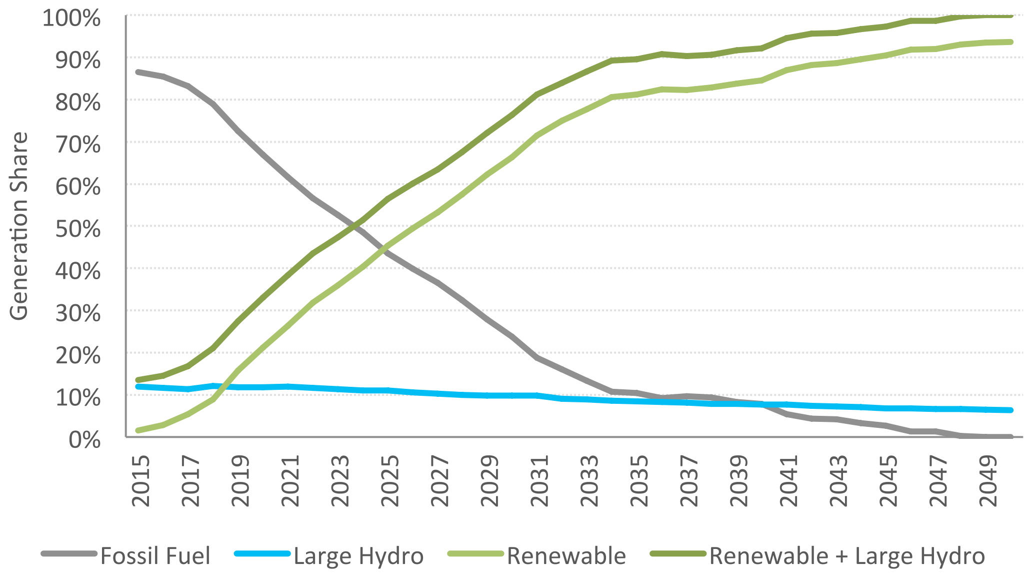


**Figure 74 Thailand Generation Shares for ASES by Generation Type**




## 7.8 Electrification and Off-Grid

Most of Thailand is already electrified and as per the BAU in the SES we have assumed that the grid remains a centrally interconnected into the future.

# 8 Analysis of Scenarios

Section 5, section 6 and section 7 presented projections of capacity and generation mix for the BAU, SES and ASES scenarios respectively. In order to understand the implications of the SES and ASES over the BAU, we have formulated a set of metrics to assist in their comparison.

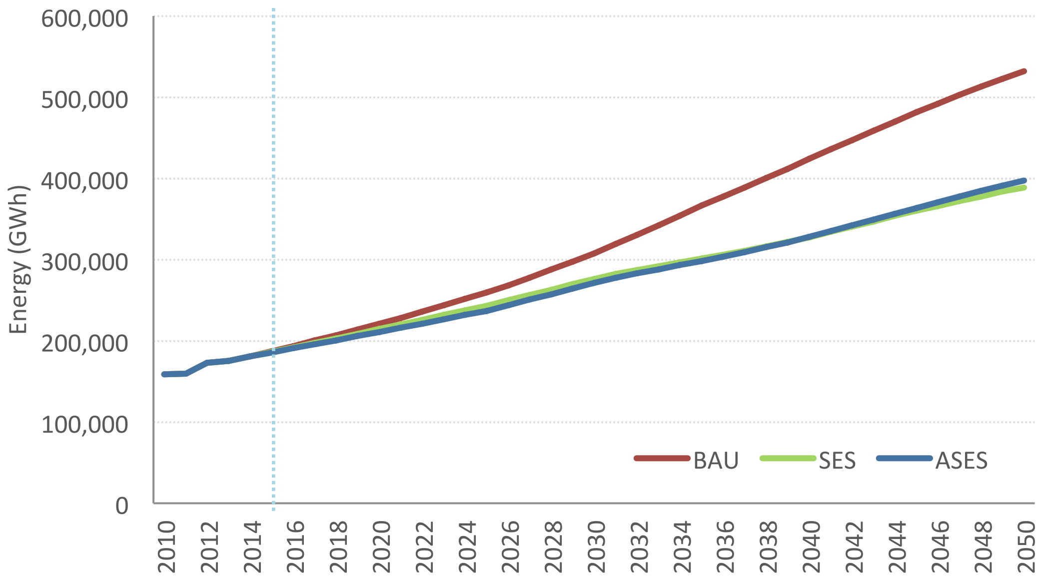
These are as follows:

- Overall energy consumption per year;
- Peak electricity demand per year;
- Renewable energy percentage comparisons;
- Carbon emissions measures;
- Hydro power developments;
- Analysis of bioenergy situation;
- A number of simple security of supply measures; and
- Interregional power flows.

## 8.1 Energy and Peak Demand

Figure 75 compares the total electricity consumption of the BAU, SES and ASES with Figure 76 plotting the percentage reduction in electricity consumption of the SES relative to the BAU and ASES relative to the BAU. As can be seen the energy consumption, the SES is lower than the BAU with the main driver being enhancements in energy efficiency in the SES. The reduction in energy in the ASES is offset by the doubling of transport demand.

## Figure 75 Thailand Energy Demand Comparison




## Figure 76 Thailand Percentage Reduction in Electricity Demand

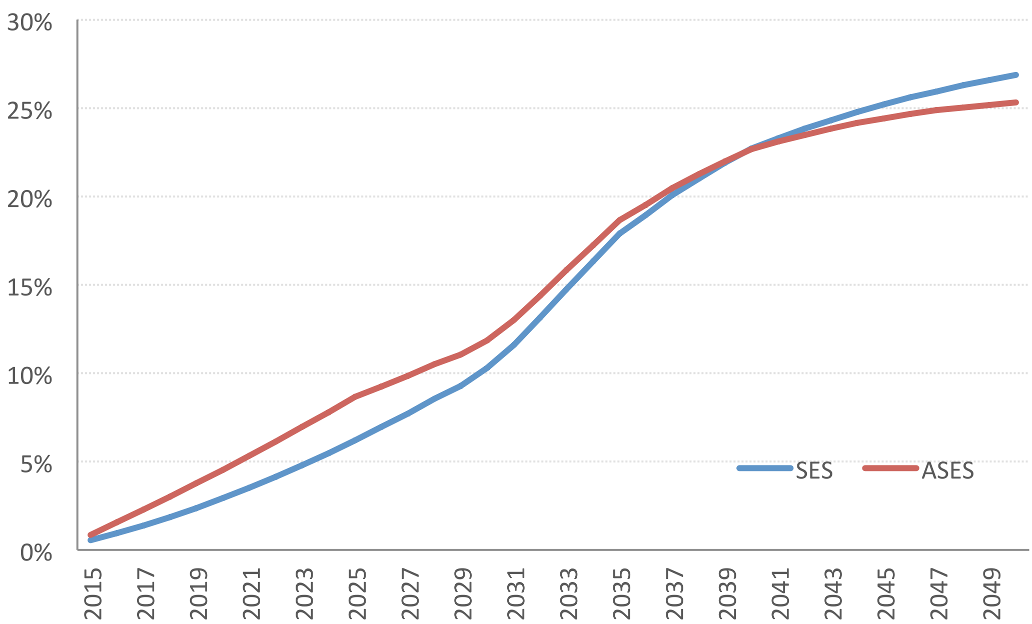
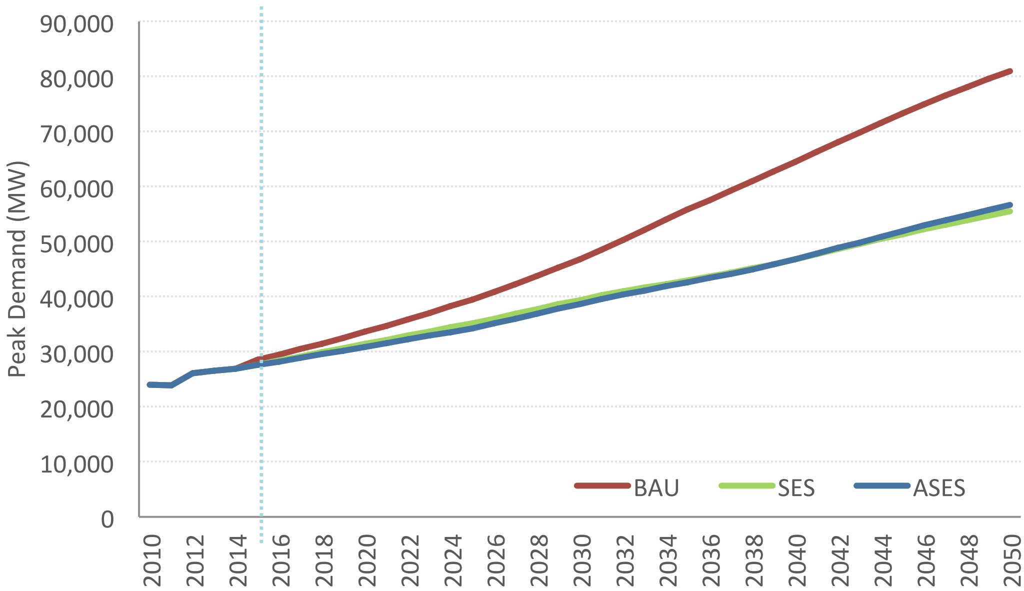



Figure 77 compares peak load and shows the same relativities. This is attributable to improvements in load factor (80% in SES and ASES). On top of this the SES and ASES has contributions from flexible and controllable demand that allows reductions in peak demand consumption (not shown here).

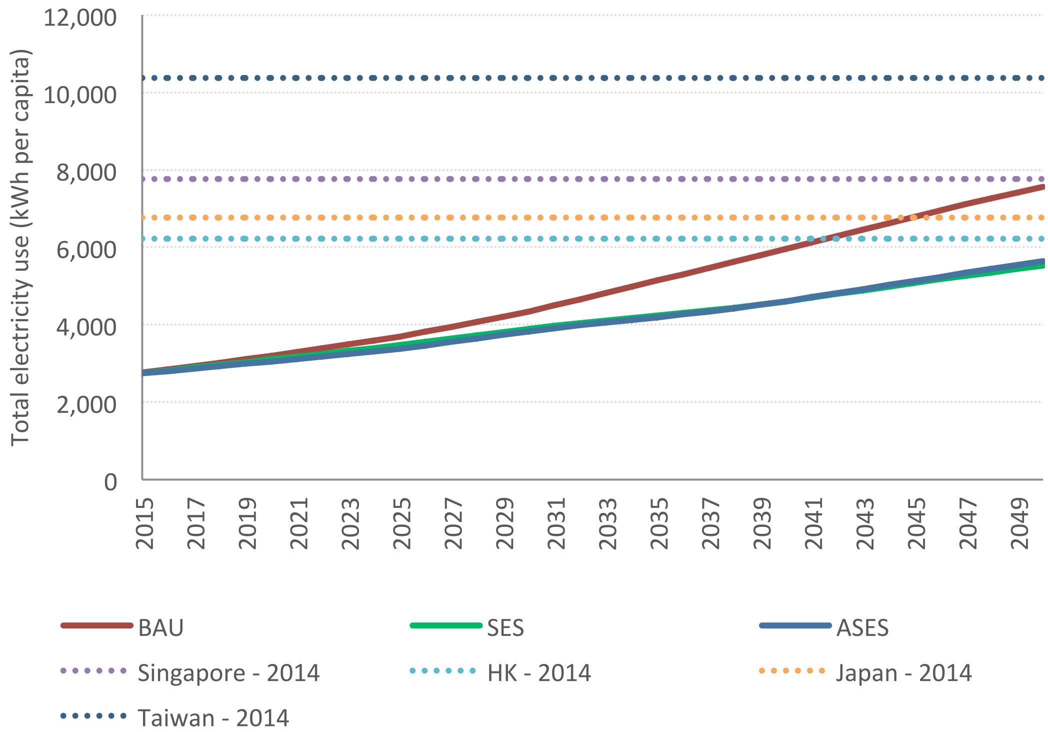
**Figure 77 Thailand Peak Demand Comparison**




## 8.2 Energy intensity

Figure 78 plots the per capita electricity consumption per annum across the scenarios. Electricity consumption includes all electricity consumption across the country. In the BAU, per capita consumption levels increase at a rate of 2.9% to reach 7,500 kWh pa around Singapore's current levels. In the ASES and SES, it increases more slowly at 2.0% pa to approxiamtely 5,600 kWh pa - the SES and ASES assumes higher energy efficiency savings keeping it below Hong Kong's current levels. It should be noted that GDP growth assumptions remain constant across all scenarios with the difference in the ASES and SES being measures taken to improve energy efficiency.

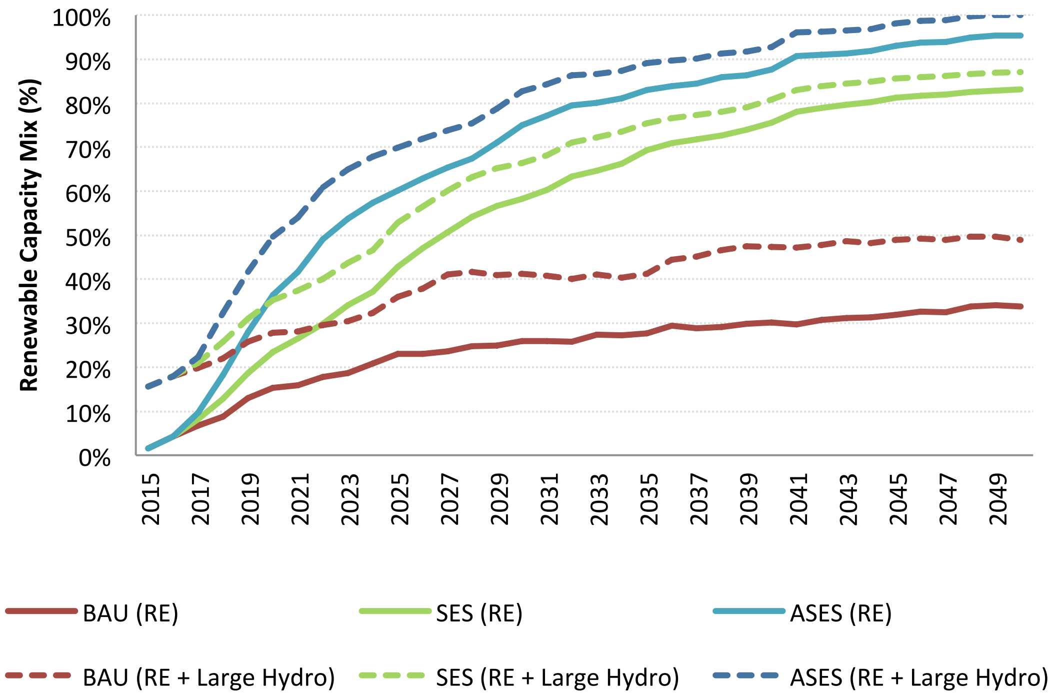
**Figure 78 Thailand Per Capita Consumption Comparison (kWh pa)**



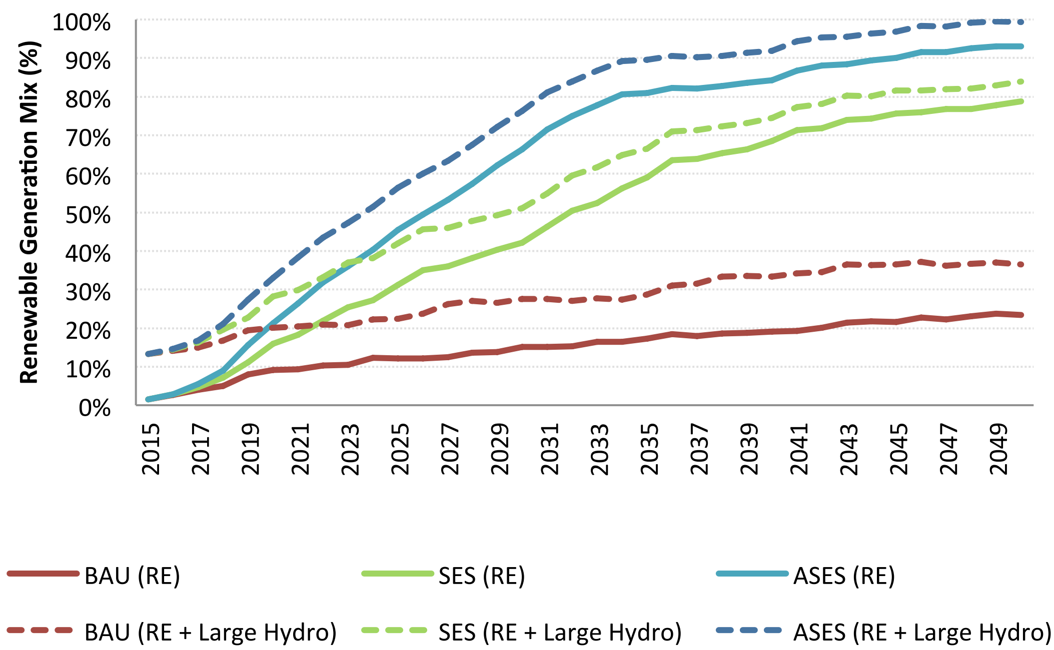

## 8.3 Generation Mix Comparison

Figure 79 and Figure 80 below shows the renewable capacity and generation mix between the two scenarios. Renewable capacity (including large-scale hydro) reaches 49% in the BAU which is equivalent to a 36% generation share compared to the capacity reaching 87% in the SES contributing 83%. The ASES has renewables (including large-scale hydro) accounting for 100% of total capacity and generation by 2050.

## Figure 79 Thailand Renewable Installed Capacity Mix




## Figure 80 Thailand Renewable Generation Mix Comparison



## 8.4 Carbon Emissions

Figure 81 and Figure 82 show the carbon intensity of Thailand's power system and the total per annum carbon emissions respectively. The BAU trajectory intensity declines initially to 2040 as additional gas and renewable generation enter the mix below before reversing the trend as additional coal generation is developed. The intensity trajectory in the SES reaches 0.07t-CO2e/MWh by 2050. In terms of total carbon emissions, the shift towards the SES and ASES saves up to 157 and 184 mt-CO2e, respectively, or the equivalent to a 85% and 100% saving from the BAU.

**Figure 81 Thailand Carbon Intensity Comparison**

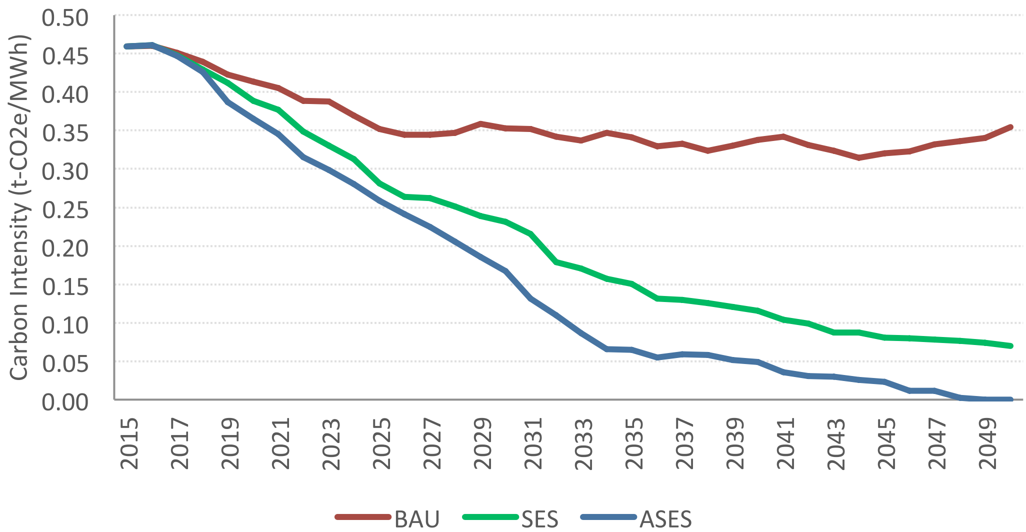
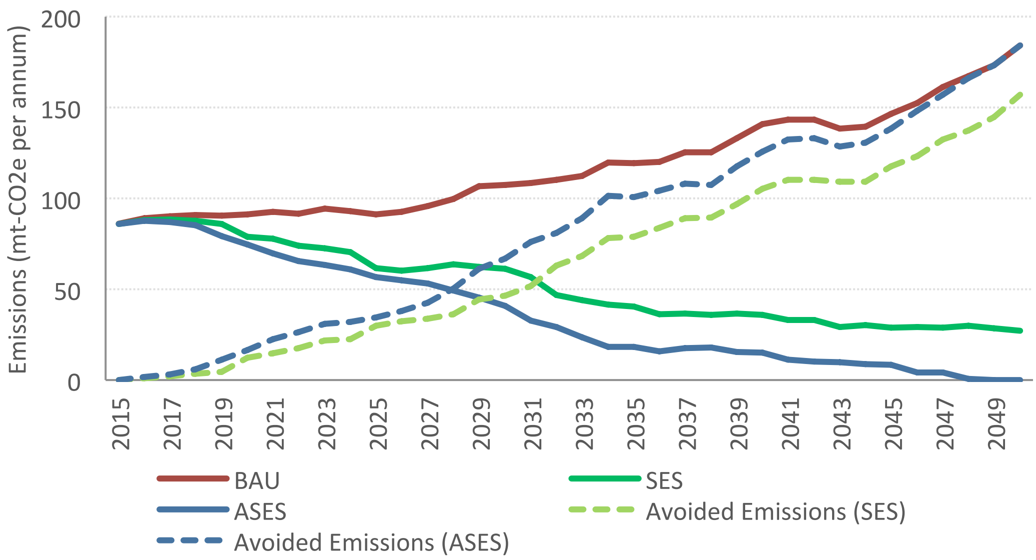



**Figure 82 Thailand Carbon Emissions Comparison**



## 8.5 Hydro Power Developments

Table 22 lists the hydro generation projects and commissioning year under the 3 scenarios. Hydro projects are assumed to be refurbish as required to maintain operations throughout the modelling horizon. As discussed earlier, projects such as Nam Ngiep 1 located in other countries but dedicated to exports are included as projects in the export markets (with capacities adjusted accordingly).

**Table 25 Hydro Power Developments (BAU, SES and ASES)**

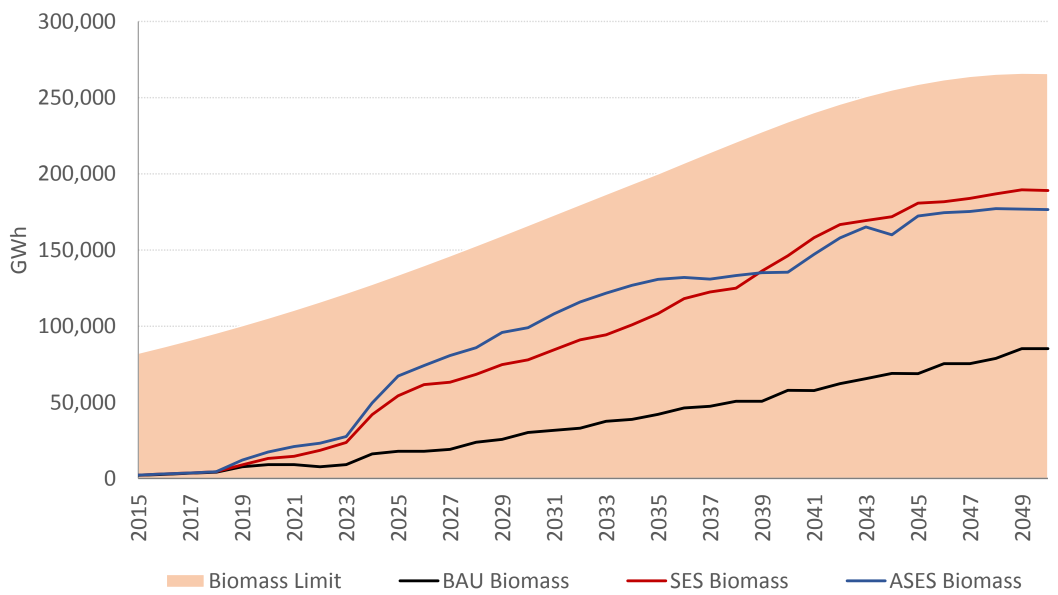
| Hydro Project | Installed Capacity (MW) | Year Commissioned | | |
|---|---|---|---|---|
| | | BAU | SES | ASES |
| Kwae Noi Dam #1-2 | 30 | 2015 | 2015 | 2015 |
| Prakarnchon Dam | 10 | 2015 | 2015 | 2015 |
| Chulabhorn Hydropower | 10 | 2015 | 2015 | 2015 |
| Mae Hydro | 12 | 2015 | 2015 | 2015 |
| Bang Lang Dam (upgrade) | 12 | 2016 | 2016 | 2016 |
| Lamtakong Pump Storage #3-4 | 500 | 2018 | 2018 | 2018 |
| Tron Dam Hydropower | 2.5 | 2018 | 2018 | 2018 |
| Xe-Pian Xe-Namoi | 354 | 2025 | Projects not developed in the SES and ASES | |
| Nam Ngiep 1 | 269 | 2021 | | |
| Xayaburi | 1220 | 2026 | | |
| Pha Dam | 14 | 2028 | | |
| Lamtakong Dam | 1.5 | 2029 | | |
| Lam Pao Dam | 1 | 2032 | | |
| Yasothon Hydropower | 4 | 2032 | | |
| Pranburi Dam | 1.5 | 2033 | | |
| Maha Sarakham Hydropower | 3 | 2033 | | |
| Man Phaya Hydropower | 2 | 2034 | | |
| Noida Hydropower | 2 | 2034 | | |
| Lamtapearn Hydropower | 1.2 | 2034 | | |
| Village Hydropower | 1.5 | 2035 | | |
| Chulabhorn Pump Storage | 800 | 2035 | | |
| Thap Salao Dam | 1.5 | 2035 | | |
| Sri Nakarin Pump Storage | 801 | 2036 | | |
| Fai Lam Dome Yai Hydropower | 2 | 2037 | | |
| Kamalasai Hydropower | 1 | 2037 | | |
| Samong Dam | 1 | 2037 | | |
| Dam Hydropower | 16 | 2037 | | |
| Luang Dam Hydropower | 1 | 2038 | | |

## 8.6 Analysis of Bioenergy

Figure 83 shows a projection of the biomass available for the GMS (converted to GWh) and the total biomass generation for each scenario for the GMS. The shaded pink area represents the projected total technical biomass resource availability[51] while the solid lines show the biomass consumption used by each scenario. The projected available biomass was based on forecast growth rates in the agricultural sectors of each country. It was assumed that no more than 75% of the total projected available biomass resource was used. The remainder of the bioenergy requirements for each scenario was then assumed to be satisfied by biogas technologies.

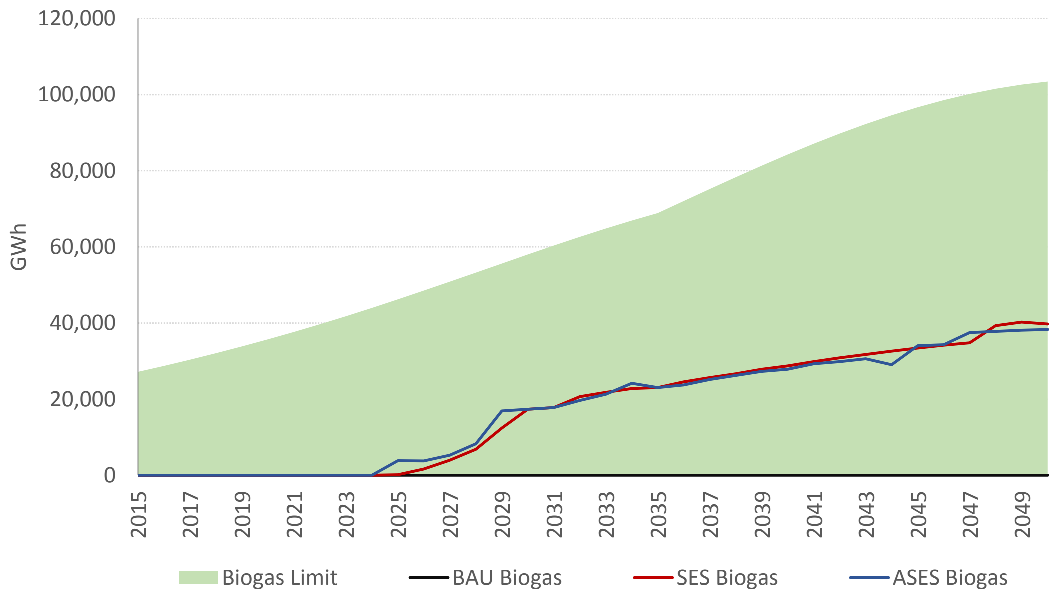
Figure 84 shows a similar chart to for the GMS except for biogas. The green shaded area in this chart represents the amount of biogas available (again in units of GWh) and the corresponding generation from biogas in each scenario. This shows that the SES and ASES are dependent on biogas while the BAU is assumed to not deploy this technology. Based on the projections the biomass and biogas resources available to the region can be seen to be sufficient to support the amount of biomass and biogas generation to 2050.

**Figure 83 Projected Biomass Availability and Consumption in the BAU, SES and ASES scenarios for the GMS as a whole**




[51] Projections of biomass availability developed by IES based on baselines established from information on biomass and biogas potential reported in 'Renewable Energy Developments and Potential in the Greater Mekong Subregion', ADB (2015) report.

**Figure 84 Projected GMS Biogas Requirements**




## 8.7 Security of Supply Indicators

Figure 85 plots the energy reserve margin calculated as the difference between the maximum annual production from all plants accounting for energy limits and the annual electricity demands. For importing countries like Thailand, gross import limits have also been included. The figure below shows similar energy reserve margins with the ASES having lower margins in the earlier years due to the retirement of gas plants.

**Figure 85 Thailand Security of Supply Measure: Energy Reserve**

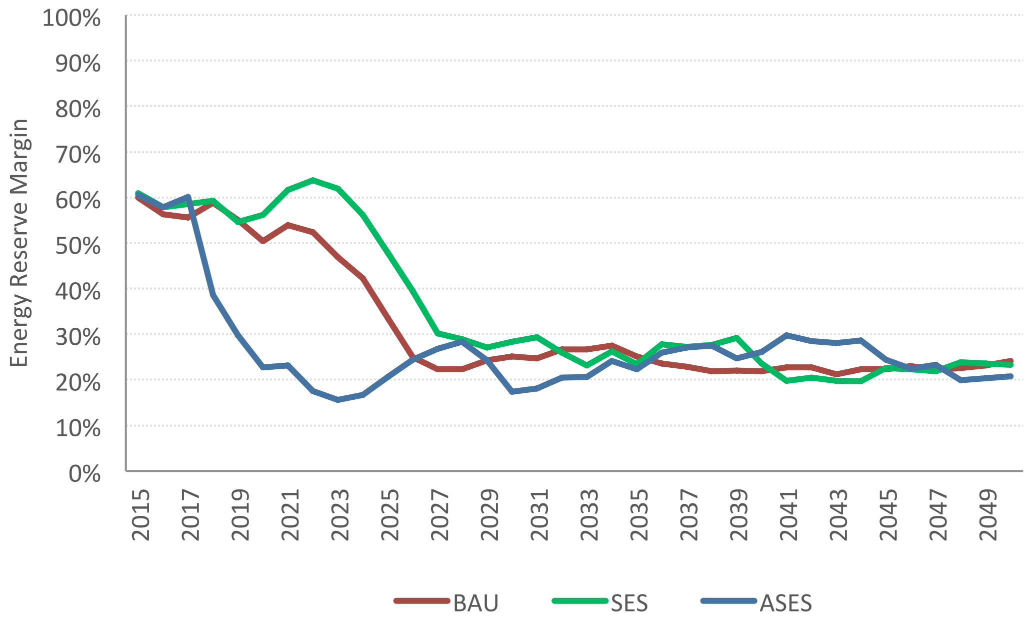



Figure 86 charts the percentage of electricity generated using domestic resources. The percentage generated using domestic fuel sources start above 75% and decline over time to around 36% by 2050 in the BAU as more gas and coal is imported. The security level in the SES and ASES case remains relatively high. The ASES has the highest security of supply from 2030 but does not reach 100% due to power imports from Myanmar. The SES security index is lower than the ASES due to gas plants still in the generation mix to 2050 and imports also.

**Figure 86 Thailand Security of Supply Measure: Percentage of Electricity Generated by Domestic Resources**

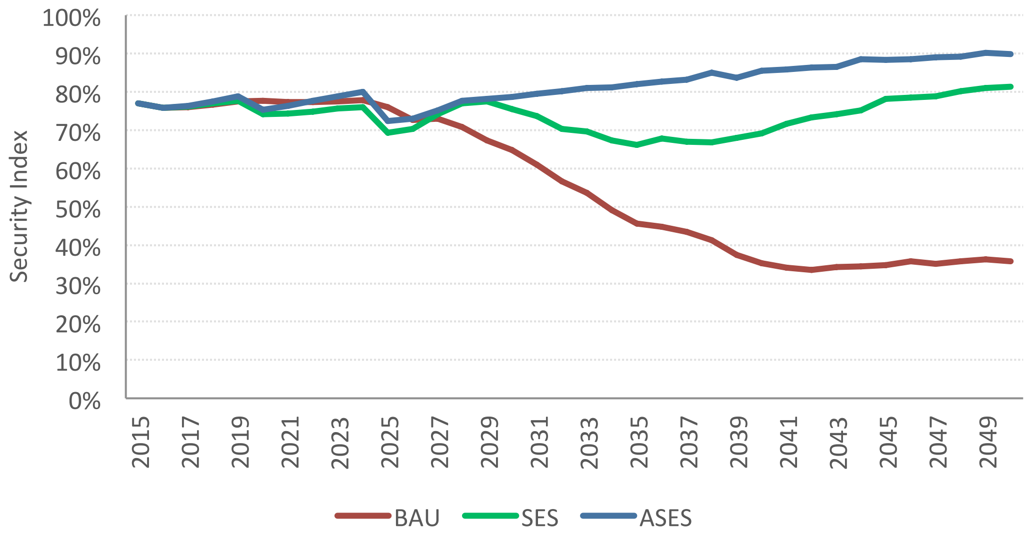



Figure 87 below plots the highest share of generation from a particular fuel source. In the BAU, the dominance is held by gas fired generation throughout the horizon. The SES is dominated by gas up until 2040 before solar PV captures 23% and 26% in 2040 and 2050. The ASES follows the same trend as the SES except solar PV dominates the generation mix from 2030. Across all scenarios it is clear that the SES and ASES generation mixes are a lot more diversified than in the BAU.

**Figure 87 Thailand Security of Supply Measure: Maximum Dominance of a Technology in Generation Mix**

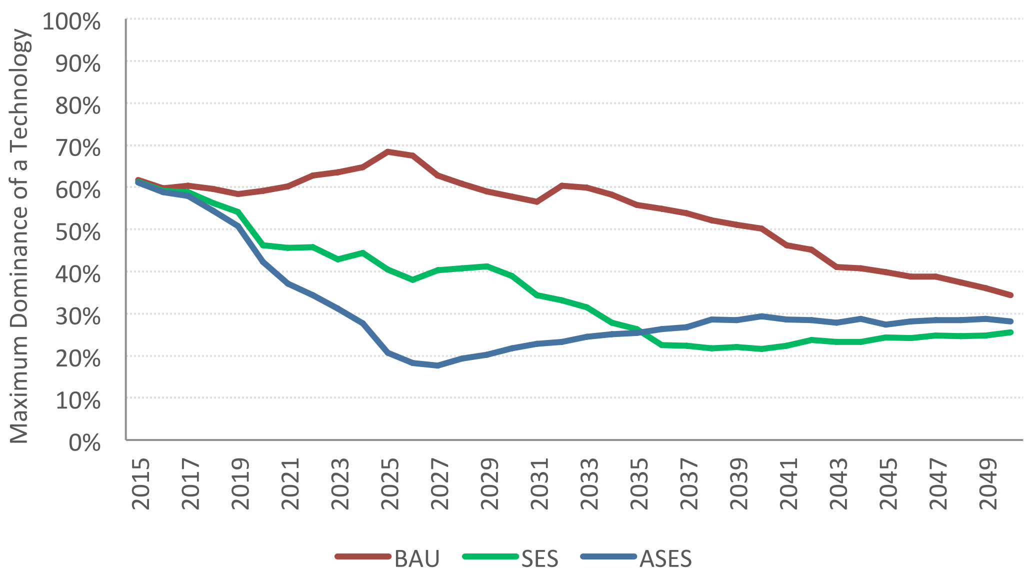
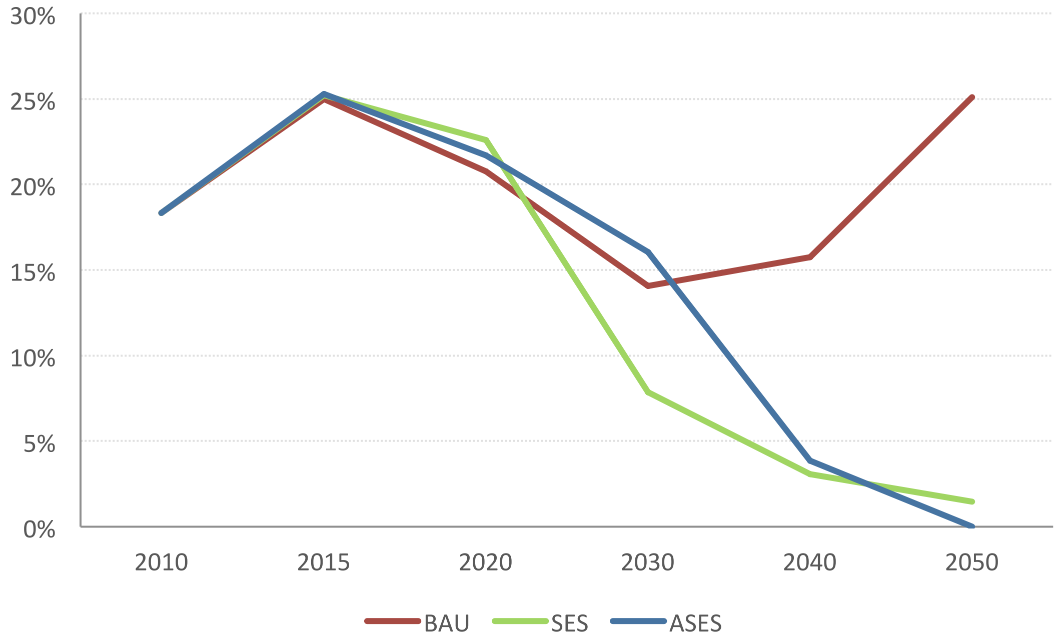


Figure 88 plots the dependence on coal in all scenarios. The AES and SES trajectories decline as expected whereas the BAU drops to 15% in 2030 but increases to 25% by 2050 as 14,000 MW of additional coal is brought into the mix to meet increasing demands.

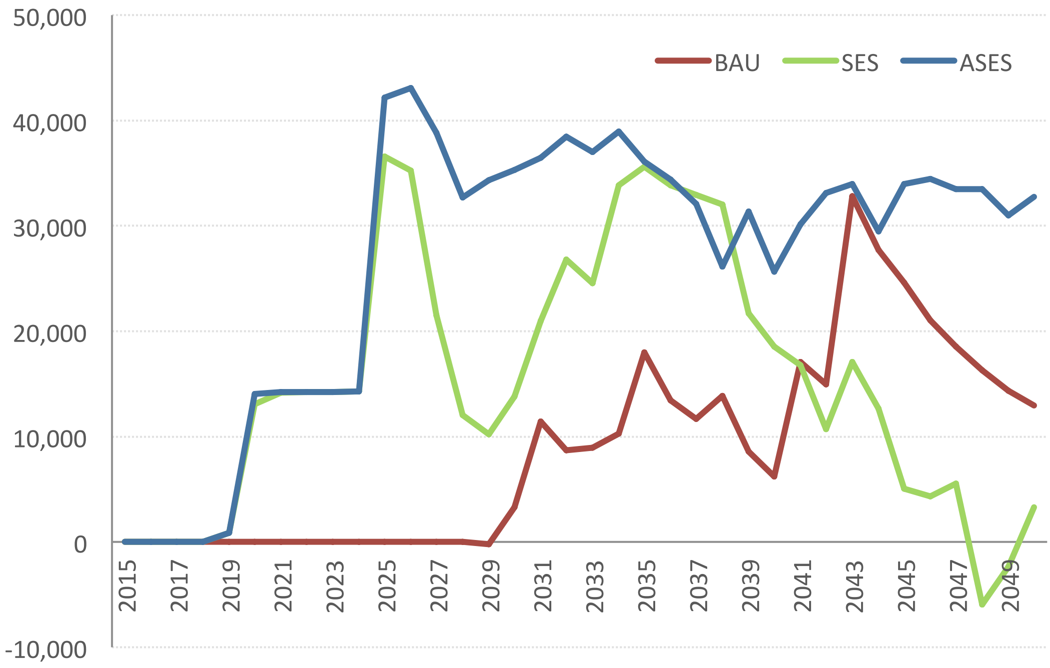
**Figure 88 Thailand Security of Supply Measure: Coal Share**




## 8.8 Interregional Power Flows

Figure 89 compares the net flows in and out of Thailand. The BAU has the lowest amount of imports due to the way BAU generation developments occur and Thailand is a net importer initially in the SES before exporting into Lao PDR and Cambodia towards 2050. In the ASES, Thailand is a net exporter throughout the horizon, importing up to 10% of its power requirements.

**Figure 89 Thailand Imports (positive) and Exports (negative) (GWh)**



# 9 Economic Implications

In this section we consider the economic implications of the three scenarios and examine in particular: (1) the levelised cost of electricity (LCOE) generation for the entire system, (2) investment costs, (3) total operating and capital expenditure including the cost of energy efficiency and (4) implications for job creation. It should be noted that the analysis presented in this section is done for the purpose of comparison, and that the prices and costs provided are dependent on the fuel price projections and technology cost assumptions that were used in the scenarios and have been listed in Appendix A and Appendix B. The analysis in this section is also supported by sensitivity analysis to examine how changes in fuel prices impact the LCOE and to examine how a carbon price would affect electricity costs.

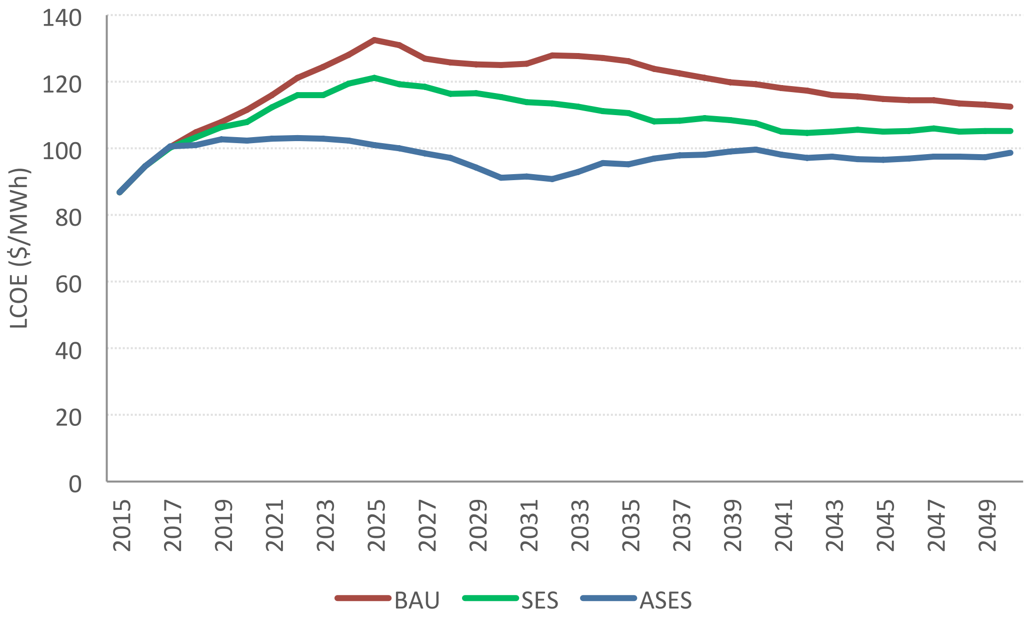
## 9.1 Overall Levelised Cost of Electricity (LCOE)

The comparison of the LCOE (only includes generation costs) is shown in Figure 90. The LCOE for the BAU starts to increase initially as a result of increasing fuel costs returning to long-term averages then steadily declines to $112/MWh as coal and gas costs stay flat and lower cost renewable generation is added into the capacity mix.

The ASES and SES initially decline then rise from around 2030 onwards driven by more investment in higher cost renewable technologies and battery storage which increases the overall LCOE. The ASES LCOE is significantly lower than the other scenarios due to the accelerated cost reductions assumed. By 2050 the SES and ASES reaches $105/MWh and $99/MWh respectively. This LCOE analysis does not include the cost of externalities[52].

[52] A detailed study on the cost of externalities is presented in the following reference: Mark Z. Jacobson et al., "100% Clean and Renewable Wind, Water, and Sunlight (WWS) All Sector Energy Roadmaps for 139 Countries of the World", 13 December 2015, available: https://web.stanford.edu/group/efmh/jacobson/Articles/I/CountriesWWS.pdf.

**Figure 90 Thailand LCOE for Generation**




## 9.2 LCOE Composition

High integration levels of renewable energy allow for the avoidance of fuel costs. In order to understand the structure of the LCOE from the previous section we provide decomposed versions of the LCOE in Figure 90 for the BAU, Figure 91 for the SES and Figure 92 for the ASES. This reveals an important trend in the structure of the cost of electricity: a thermal-dominated system has a high portion of its costs as fuel costs while a renewable energy dominated power system is more heavily biased towards capital costs. As is shown in the SES case, the fuel cost component steadily decreases from early in the modelling[53].

The SES and ASES capital costs on a $/MWh basis increases gradually due to greater investments in battery storage, offshore wind and CSP.

[53] It does not go to zero due to bio generation.

**Figure 91 Thailand LCOE Composition in BAU**

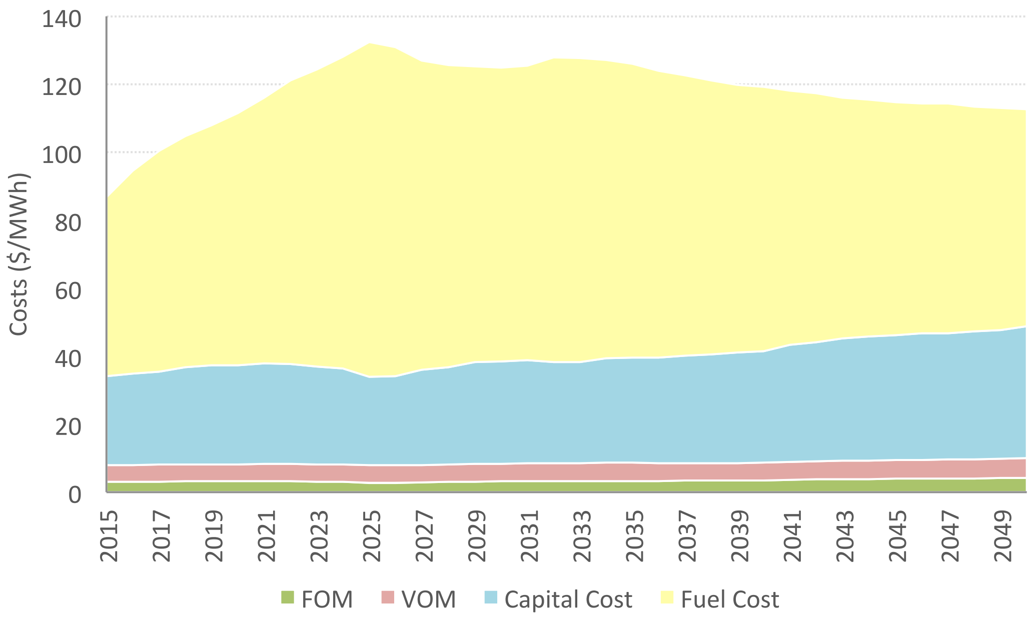



**Figure 92 Thailand LCOE Composition in SES**

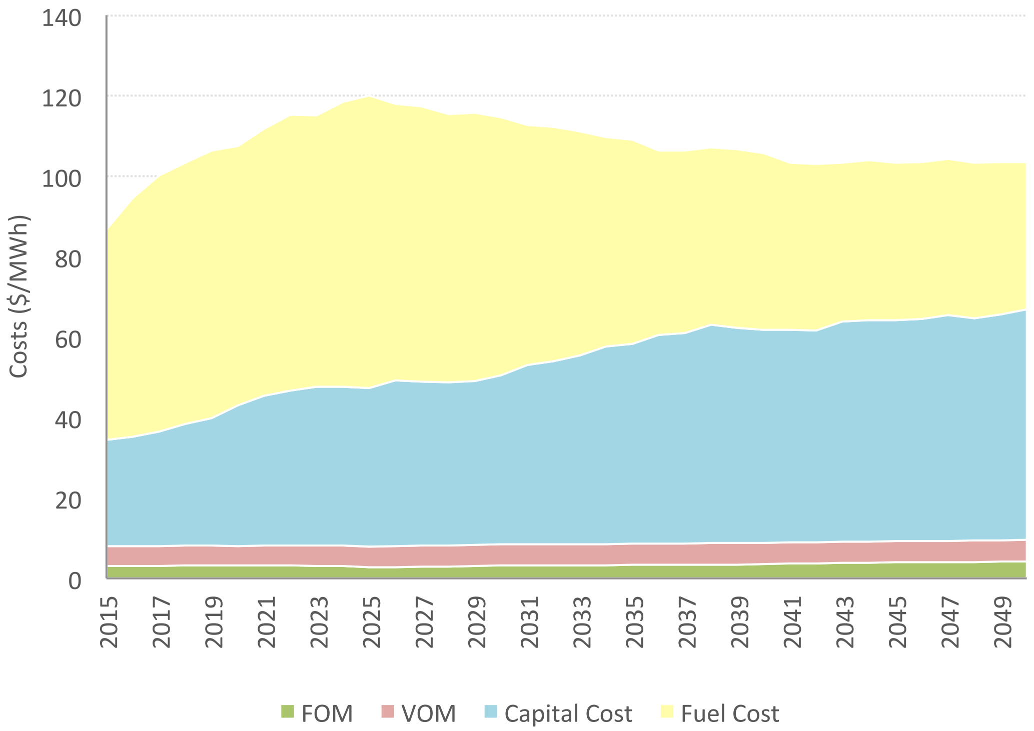
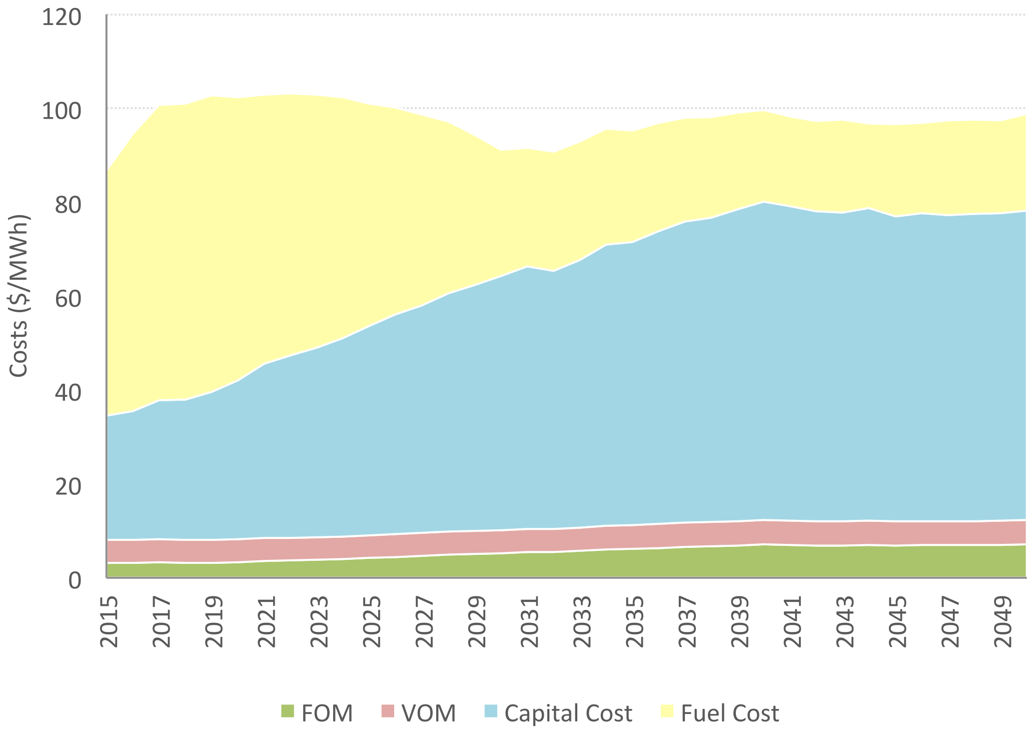


**Figure 93 Thailand LCOE Composition in ASES**




## 9.3 Cumulative Capital Investment

The following section details the investment costs of meeting demand in Thailand and also takes into account import costs (at the LCOE of neighbouring countries). Conversely, the investment costs of net exporting countries will be reduced according to the percentage of power that is exported.

Figure 94 shows the cumulative investment in generation CAPEX and energy efficiency in millions of Real 2014 USD. Although the earlier observation of the SES and ASES having lower demand owing to energy efficiency gains should be recognised. Figure 94 shows the BAU requiring less capital investment across the modelling horizon primarily driven by investment in gas plants to meet increasing demands. The SES and ASES includes investment in energy efficiency measures and greater investments in CSP, offshore wind and battery storage to defer solar PV generation which ramps up post-2035.

The breakdown of costs by generation type are presented in Figure 95, Figure 96 and Figure 97.

**Figure 94 Thailand Cumulative Investment (Real 2014 USD)**

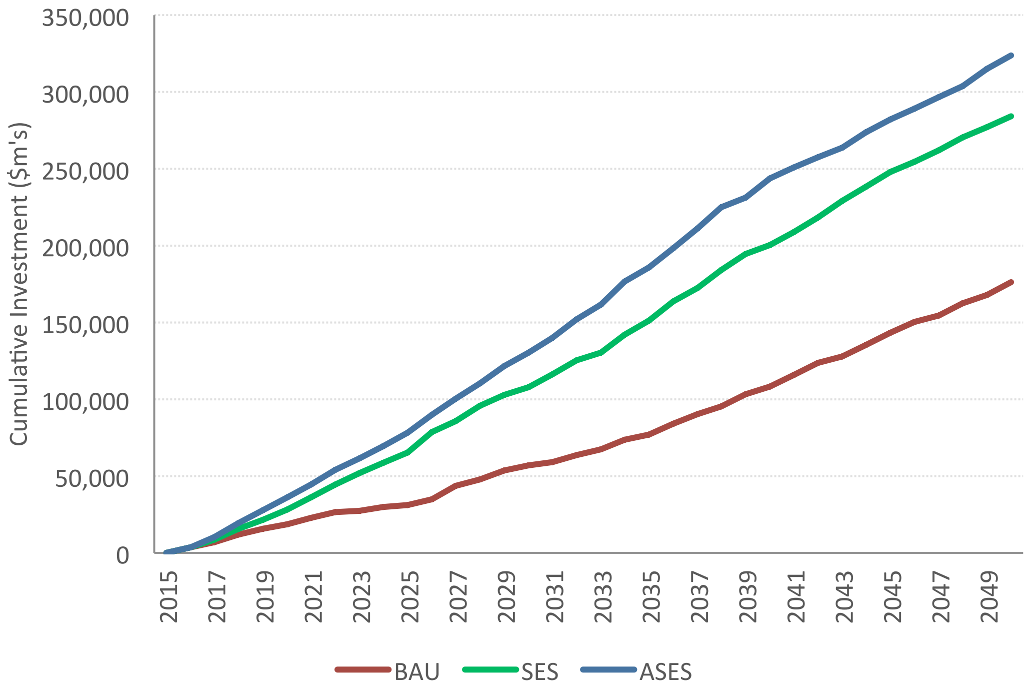



**Figure 95 Thailand Cumulative Investment by Type (BAU, Real 2014 USD)**

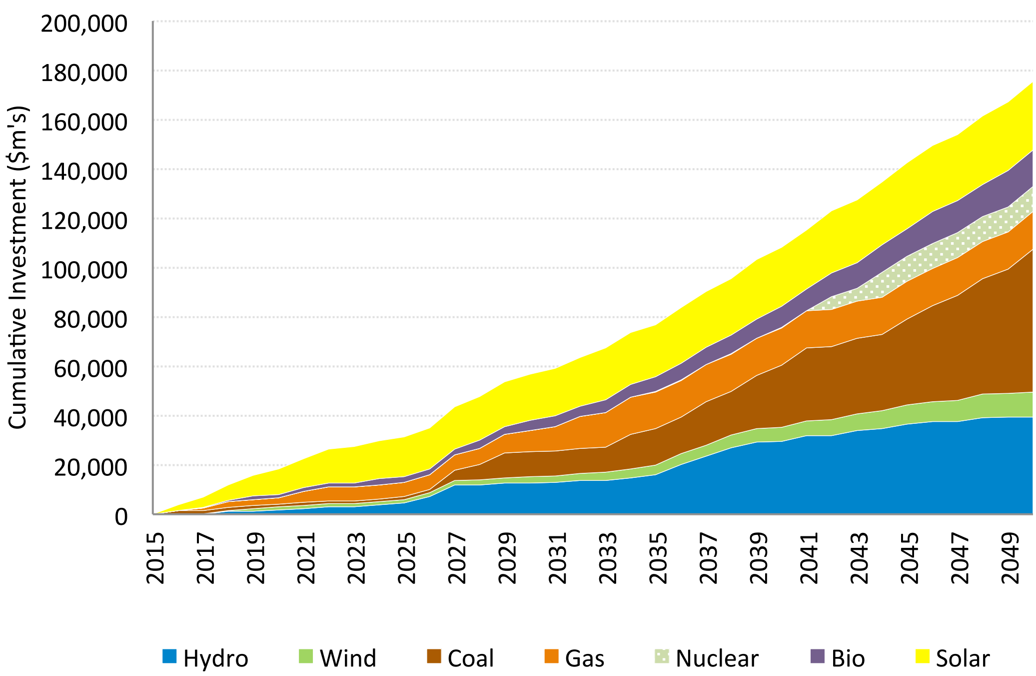


**Figure 96 Thailand Cumulative Investment by Type (SES, Real 2014 USD)**

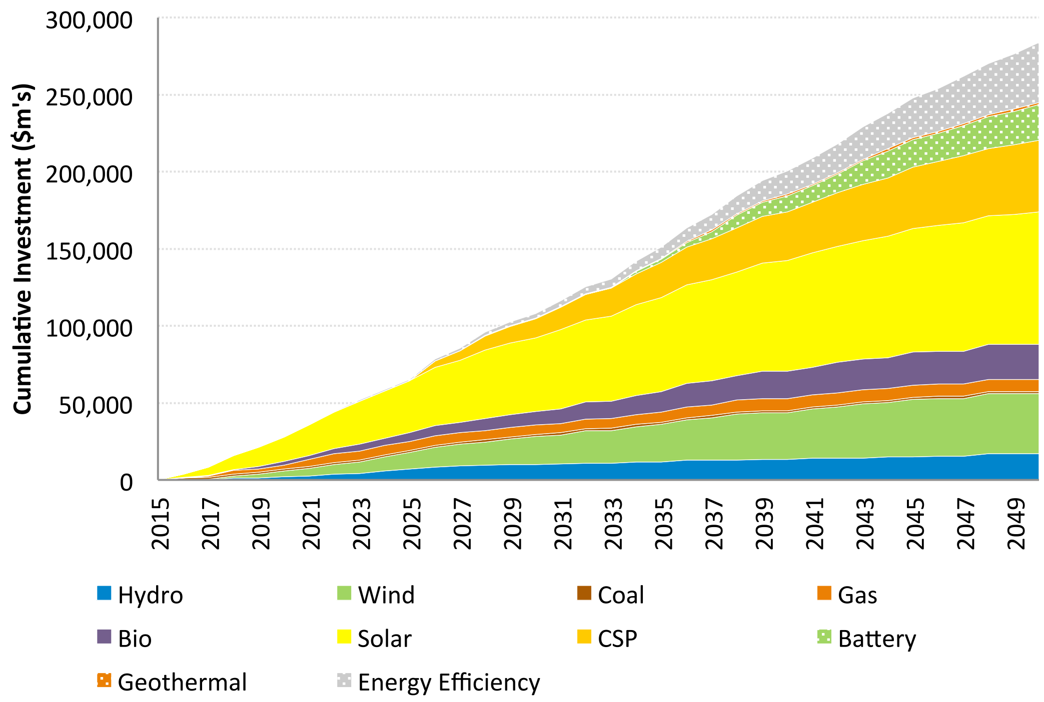



**Figure 97 Thailand Cumulative Investment by Type (ASES, Real 2014 USD)**

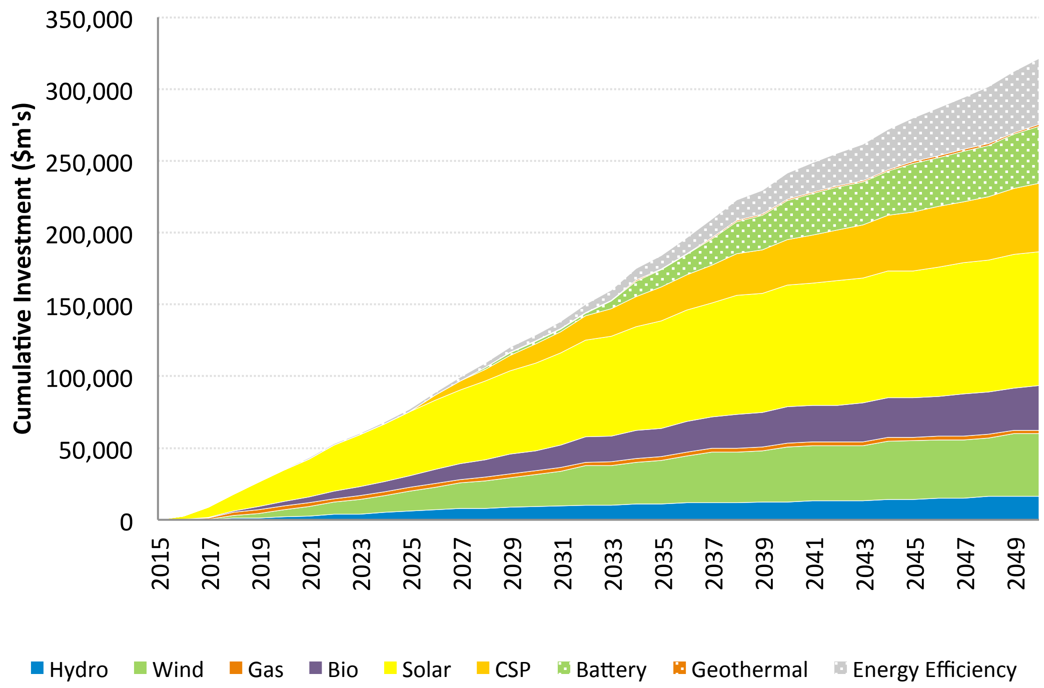


Figure 98, Figure 99 and Figure 100 plot the cumulative investment split for imports and exports. The BAU investment cost is primarily for its own electricity demand with only small amounts of power imported from Myanmar. By 2050, $176 billion is required to develop the BAU generation requirements. In the SES, $250 billion is required to develop generation projects (and energy efficiency) in Thailand, with a further $34 billion on projects outside Thailand, or $108 billion more than the BAU by 2050. The ASES adds an additional $39 billion bringing the total investment to $323 billion by 2050, or $147 billion more than the BAU at 2050.

**Figure 98 Thailand Cumulative Investment of BAU (Real 2014 USD)**

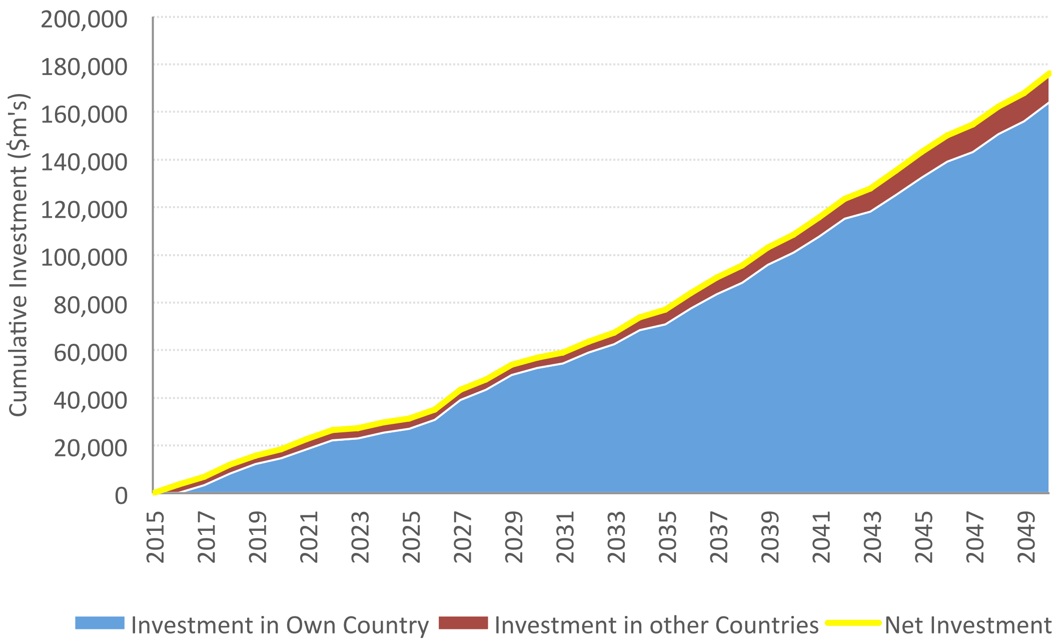


**Figure 99 Thailand Cumulative Investment of SES (Real 2014 USD)**

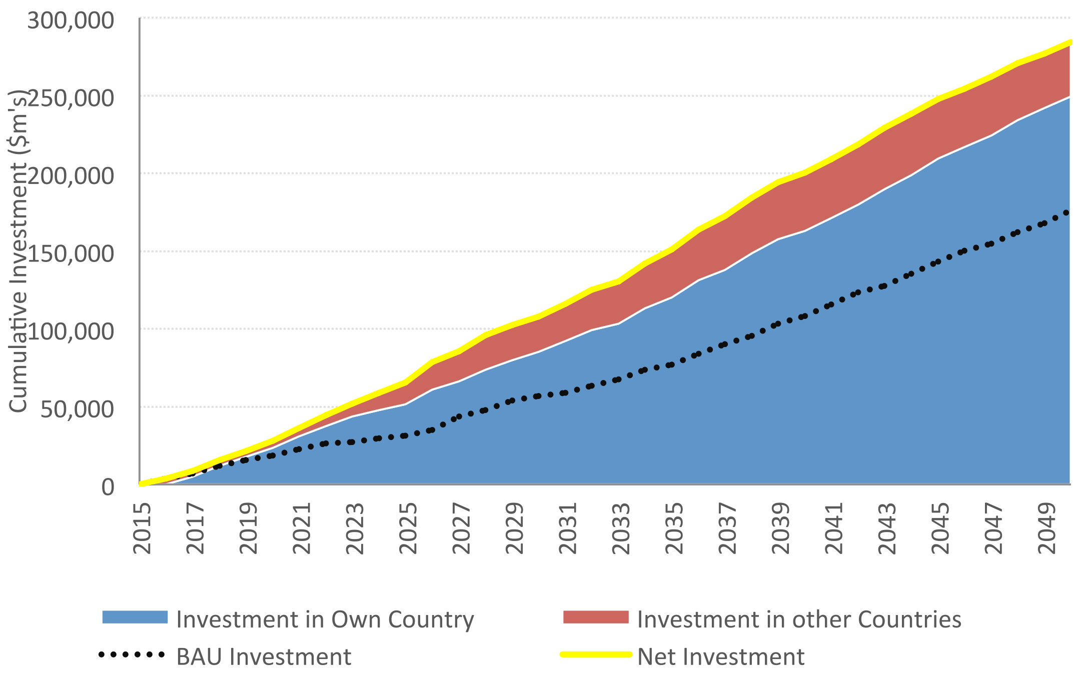
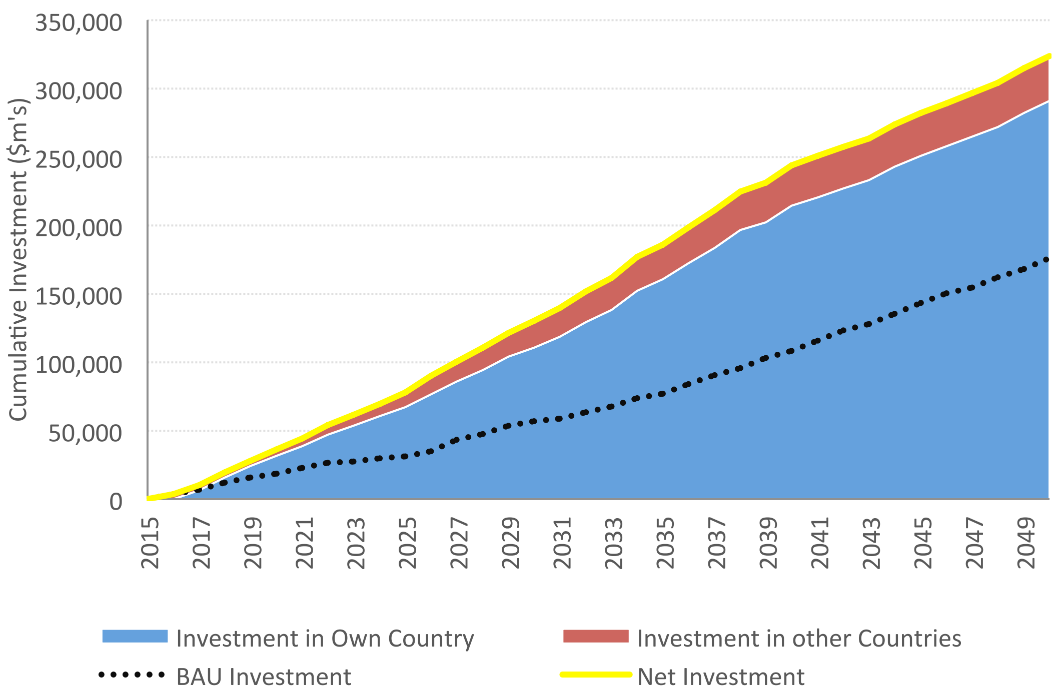



**Figure 100 Thailand Cumulative Investment of ASES (Real 2014 USD)**



## 9.4 Operating Costs, Amortised Capital Costs and Energy Efficiency Costs

Figure 101 plots the total CAPEX, OPEX and energy efficiency costs as a proportion of total forecast GDP. Capital expenditure has been amortised over the life of the project to derive annual capex figures. The BAU rises to almost 6% of GDP mainly driven by the ramp up in fuel costs before declining as the LCOE drops and GDP continues to increase. The SES and ASES costs are very similar with the ASES requiring less investment than the SES due to lower dependence on fossil fuels in the medium to long term. Figure 102, Figure 103 and Figure 104 plots the total annual system cost for each of the scenarios.

**Figure 101 Total CAPEX, OPEX and Energy Efficiency over GDP**

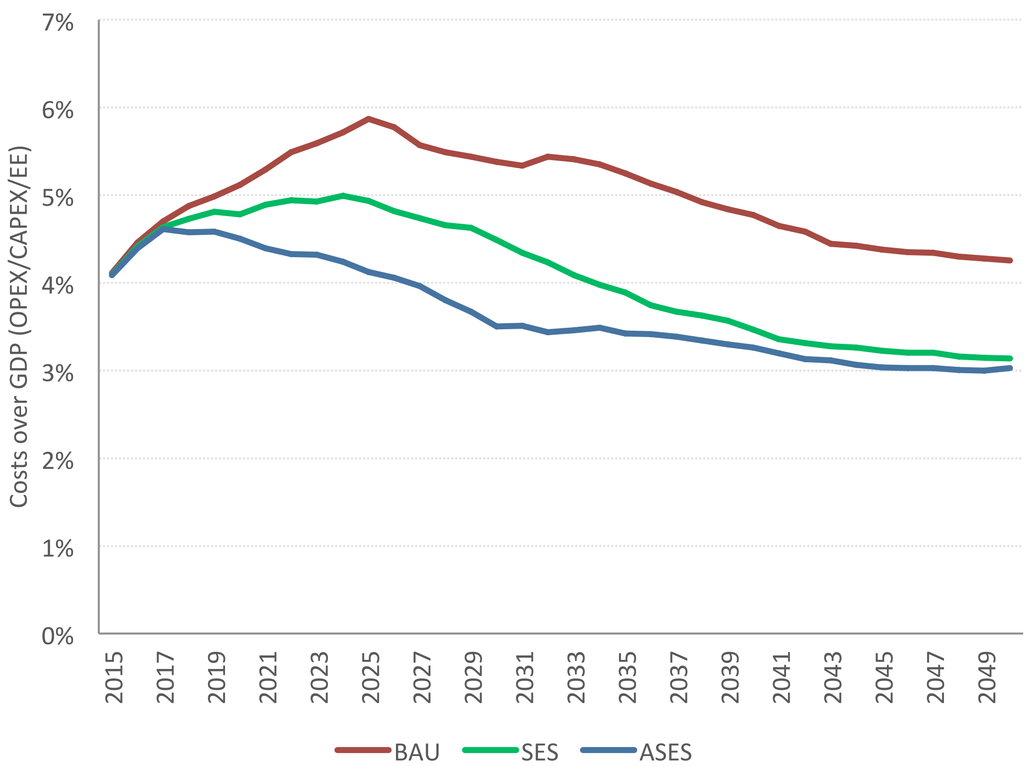


**Figure 102 Total System Cost by Type (BAU)**

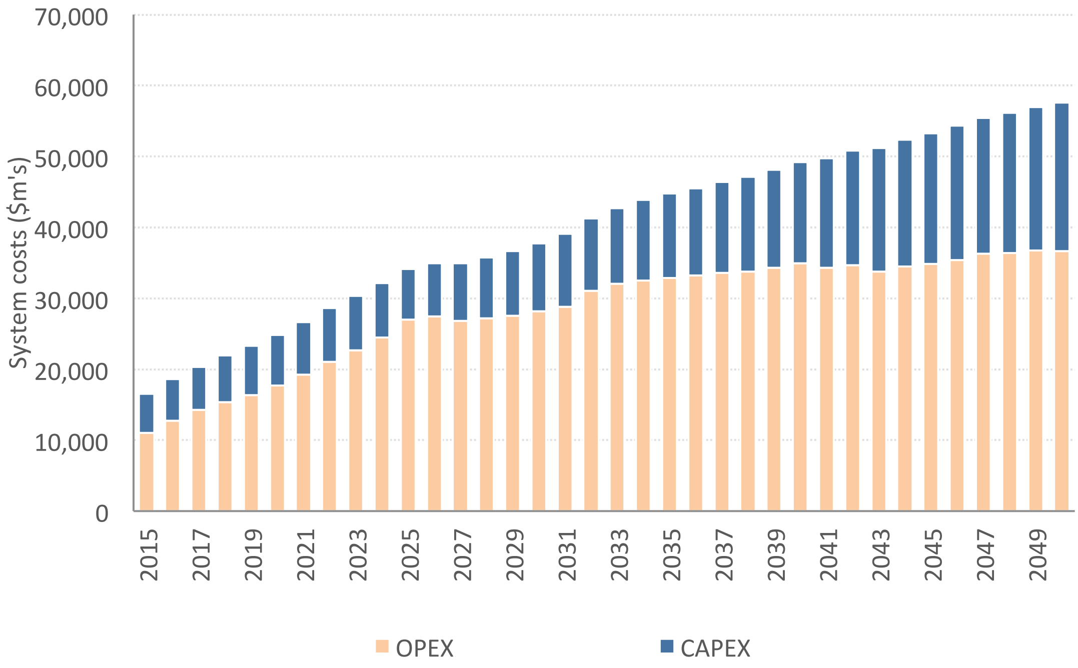



**Figure 103 Total System Cost by Type (SES)**

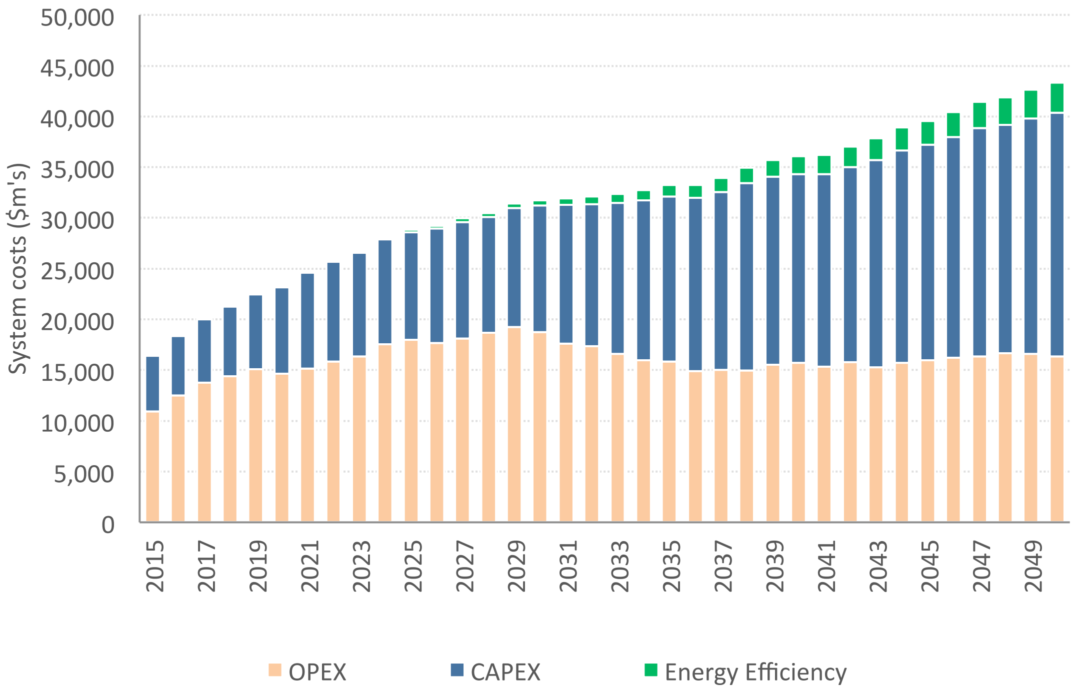


**Figure 104 Total System Cost by Type (ASES)**

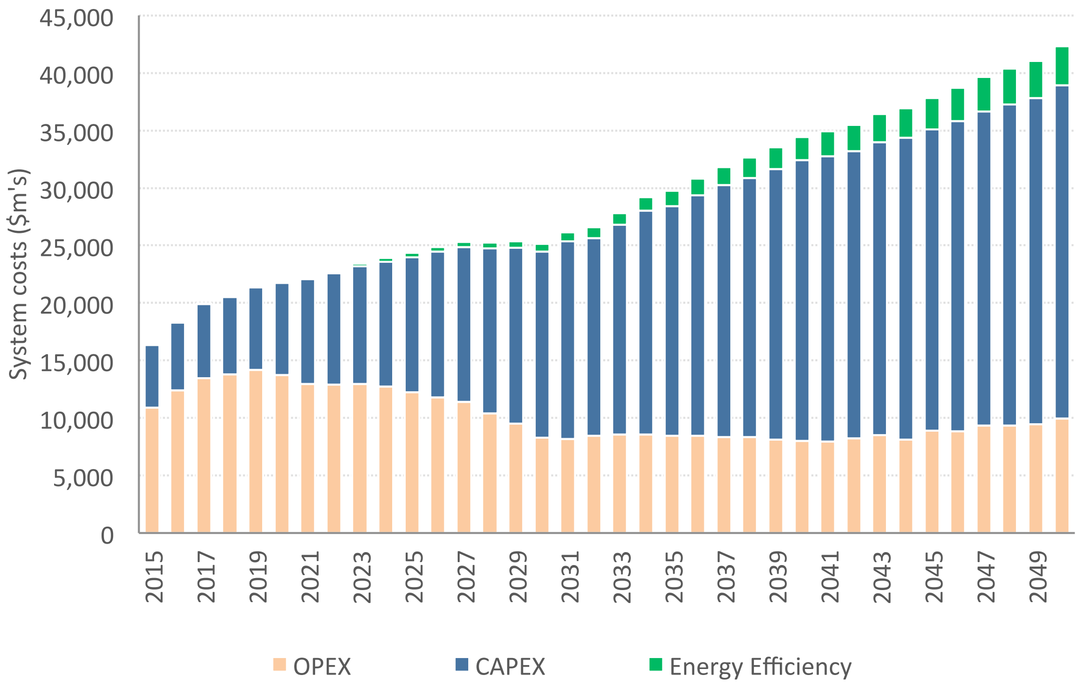



Figure 105 and Figure 106 plots the difference in amortised CAPEX, OPEX and energy efficiency costs between the SES and BAU, and ASES and BAU respectively. The costs have also been adjusted for exports and imports. Positive amounts represent an additional investment required in either the SES or ASES and negative amounts correspond to cost savings.

For the SES against BAU case, the fuel savings are immediate as renewable developments displace traditional fossil fuels increasing towards $20 billion a year in fuel savings by 2050 (noting demand differences between the two scenarios). Capex remains more expensive in the SES despite nuclear investment in the BAU. Energy efficiency is assumed to cost up to $3 billion a year by 2050. Across all three categories, the net result is a cost saving of up to $15 billion a year by 2050.

The ASES follows similar trends with a higher capex investment than in the SES despite cost reductions in CAPEX. This is driven by the added renewable capacity required to replace conventional gas and coal from 2020 onwards. The higher CAPEX also produces higher OPEX savings of up to $26 billion a year by 2050. The ASES has net savings of up to $17 billion a year by 2050.

Figure 105 Difference in CAPEX, OPEX and Energy Efficiency Costs (SES and BAU)

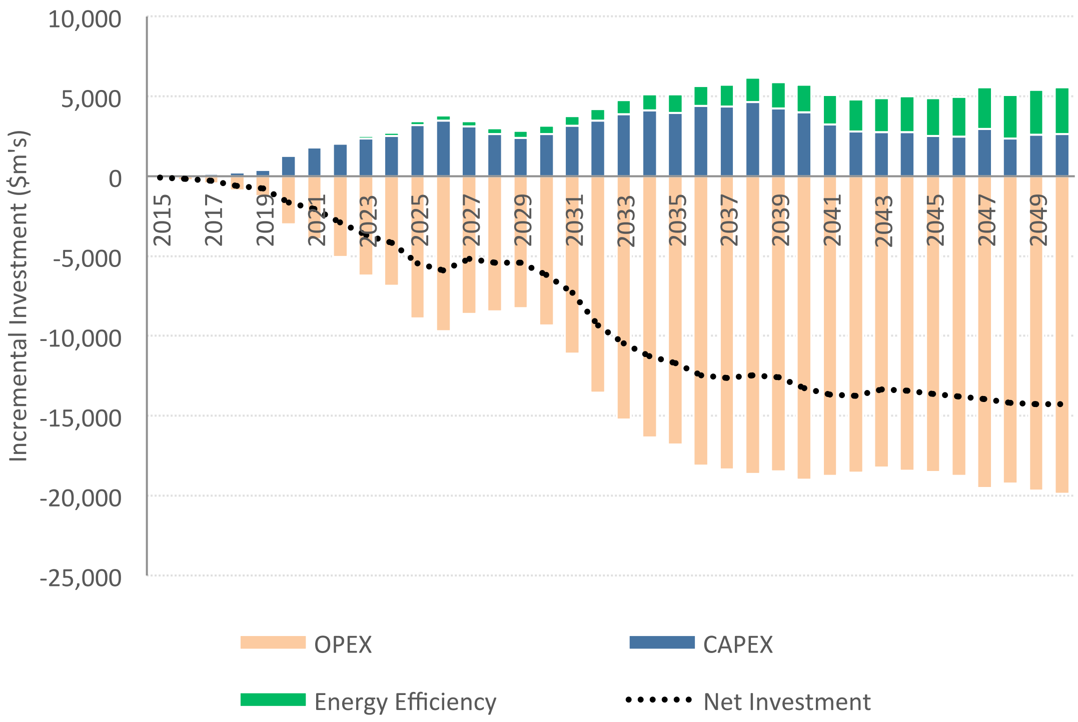


**Figure 106 Difference in CAPEX, OPEX and Energy Efficiency Costs (ASES and BAU)**

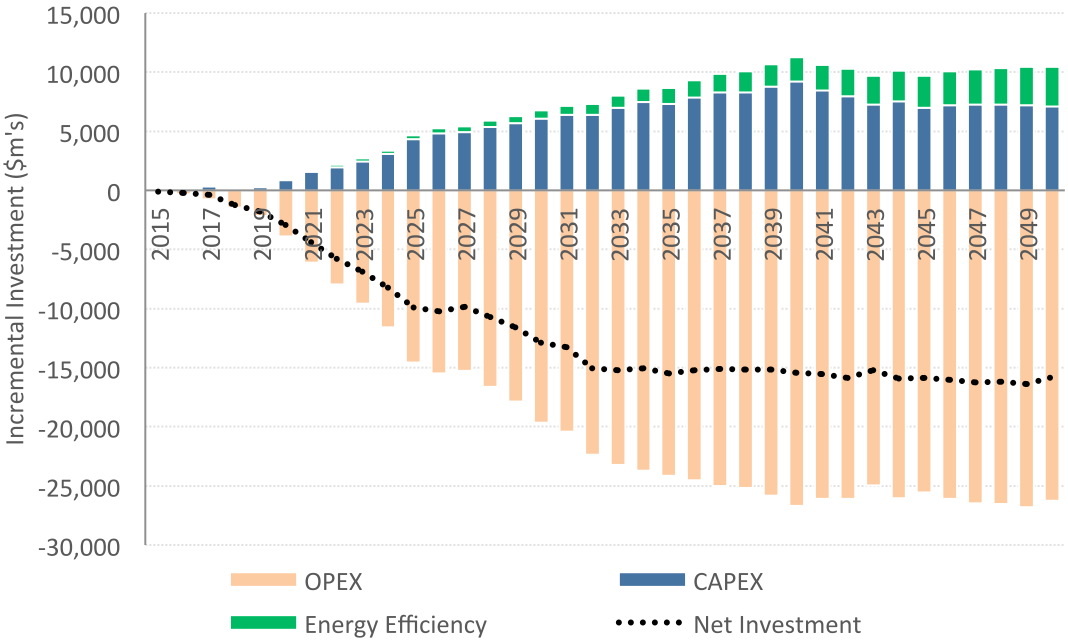



**Figure 107 NPV of System Costs over 2015-2050 period**

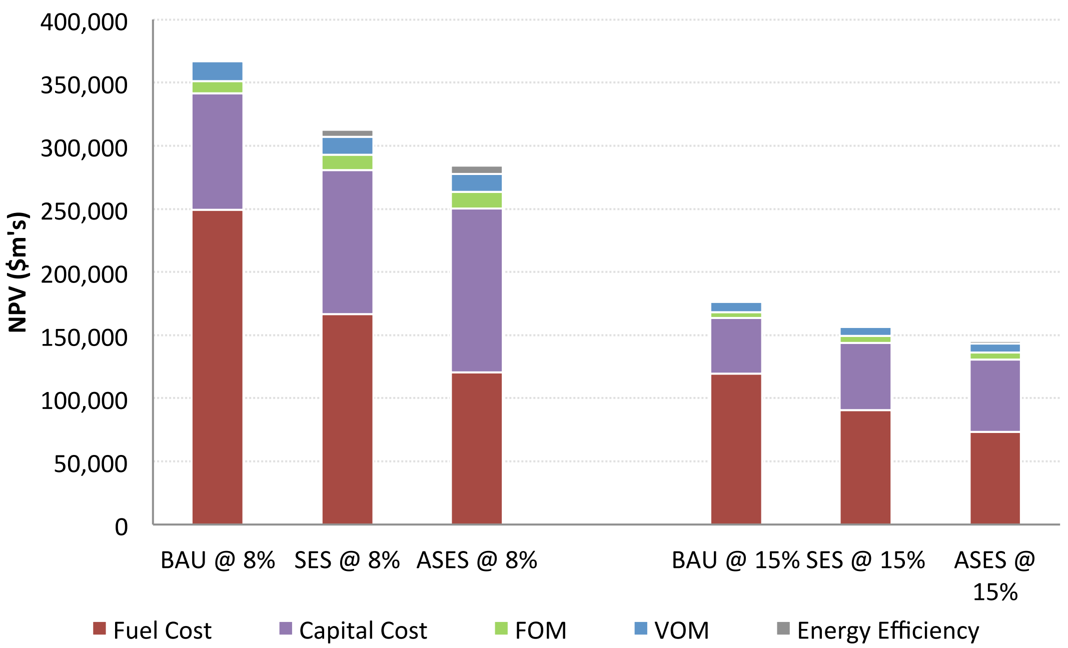



Figure 107 charts the net present value of the power system costs by component using an 8% and 15% discount rate. Figures are tabulated in Table 26. The BAU is comprised of a higher percentage of fuel costs, whereas the ASES has the highest percentage relating to capital costs. The total NPV difference between the BAU and ASES is approximately $83 billion under an 8% discount rate

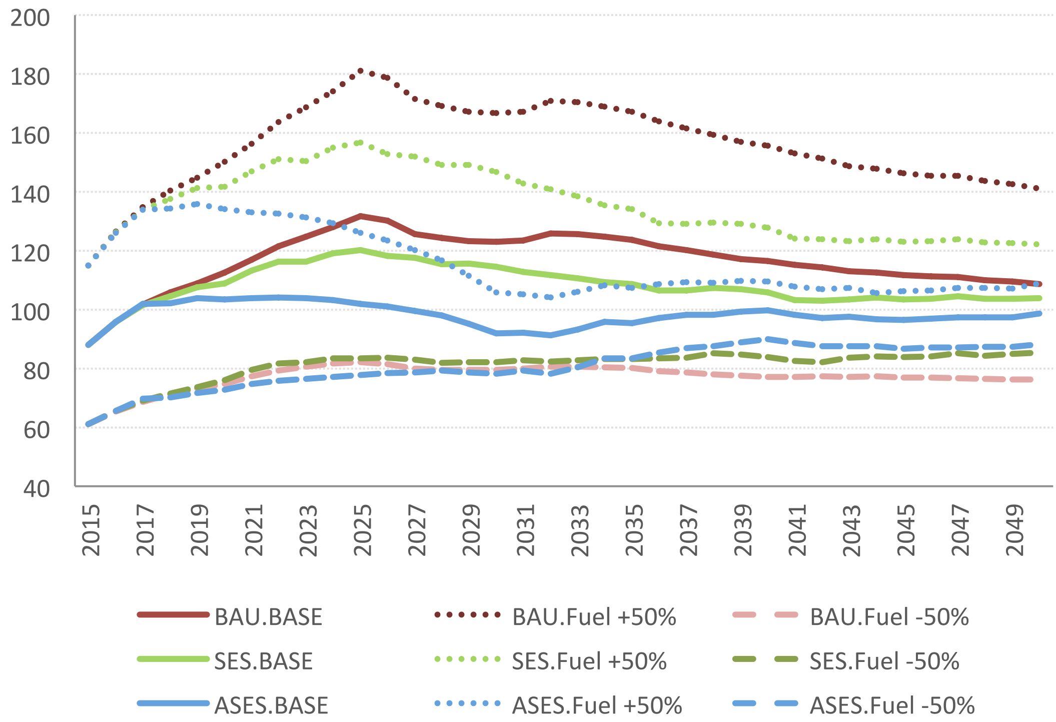
**Table 26 NPV of System Costs (Real USD 2014)**

| NPV ($m's) | BAU @ 8% | SES @ 8% | ASES @ 8% | BAU @ 15% | SES @ 15% | ASES @ 15% |
|---|---|---|---|---|---|---|
| Fuel Cost | 249,456 | 166,564 | 120,307 | 119,374 | 90,639 | 73,292 |
| Capital Cost | 91,884 | 114,334 | 130,111 | 44,091 | 52,969 | 57,293 |
| FOM | 10,014 | 11,979 | 13,232 | 4,916 | 5,644 | 5,869 |
| VOM | 15,666 | 14,404 | 13,857 | 7,782 | 7,317 | 7,071 |
| Energy Efficiency | 0 | 5,540 | 6,808 | 0 | 1,511 | 1,966 |
| **Total** | 367,019 | 312,821 | 284,315 | 176,163 | 158,080 | 145,492 |

## 9.5 Fuel Price Sensitivity

Figure 108 plots the LCOE of the BAU, SES and ASES as discussed in section 9.2. In addition, it plots the LCOE for a 50% increase to the fuel prices, which reflects the difference between IEA's crude oil pricing under the 450 Scenario and the Current Policies Scenario ($95/bbl and $150/bbl respectively). It can be seen that the LCOE of the BAU rises more (up to $40/MWh) against a fuel price increase compared with the SES and ASES ($25/MWh and $15/MWh respectively), as would be anticipated as a direct consequence of having a higher thermal generation share in the BAU compared to renewable energy in the SES and ASES. The SES increases, and the ASES to a smaller extent, as a consequence of bioenergy generation, but as can be seen it is far less sensitive to fuel price shocks than the BAU.

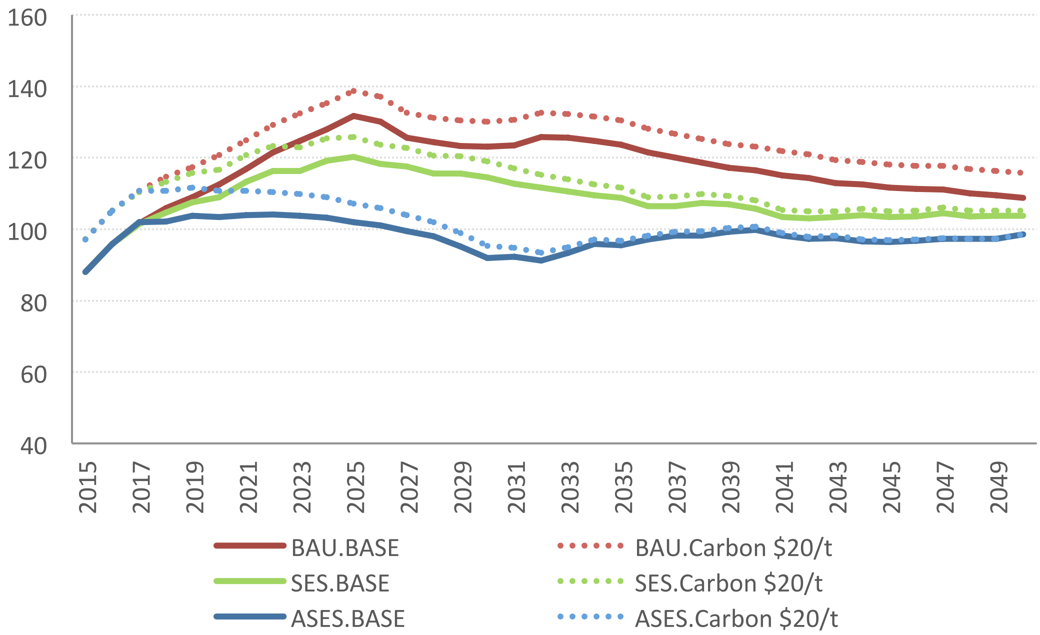
**Figure 108 Thailand Fuel Price Sensitivity ($/MWh)**




## 9.6 Impact of a Carbon Price

In a similar way to the previous section, Figure 109 plots the LCOE under the BAU, SES and ASES and the LCOE under a carbon price scenario. The carbon scenario puts a $20/t-CO2 impost throughout the entire modelled period. This is intended to show the sensitivity of the BAU, SES and ASES to the carbon prices. In a similar way to the previous section, this shows that LCOE in the SES is relatively insensitive ($4/MWh), and the ASES insensitive, to carbon prices by 2050 while for the BAU, it adds an additional $8 Real 2014 USD/MWh to the LCOE.

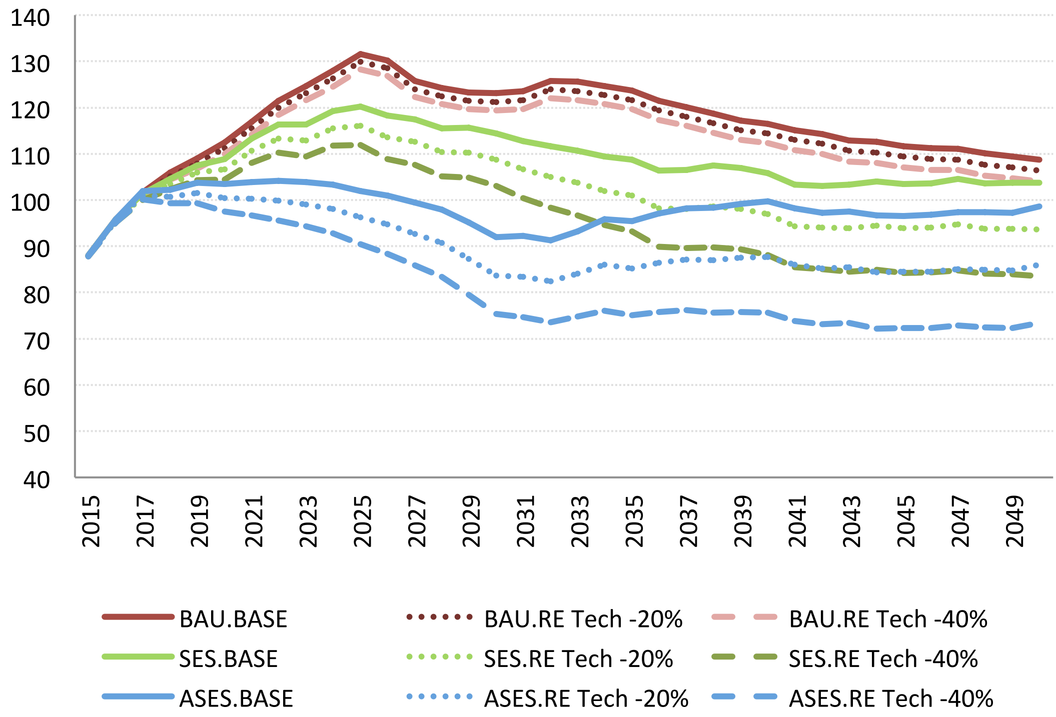
**Figure 109 Thailand Carbon Sensitivities ($/MWh)**




## 9.7 Renewable Technology Cost Sensitivity

Figure 110 shows the LCOE sensitivity to 20% and 40% decreases in renewable technology costs. As expected the ASES followed by the SES is the most sensitive with potential declines of up to $25/MWh. The SES and ASES LCOE is already well below the BAU because of gas fuel price assumptions.

**Figure 110 Thailand Renewable Technology Cost Sensitivities ($/MWh)**




## 9.8 Jobs Creation

To assess the implications for Job Creation for each scenario we applied the methodology used by the Climate Institute of Australia. The methodology is summarised in Appendix C. The numbers of jobs created for each of the scenarios are shown in Figure 111, Figure 112 and Figure 113. The job categories shown include: manufacturing, construction, operations and maintenance and fuel supply management. Figure 114 provides a comparison of total jobs created for BAU, SES and ASES. The key observations are:

- Across all scenarios, manufacturing and construction account for most of the jobs with a much smaller share attributable to O&M and fuel supply.
- The BAU job creation profile peaks at around 145,000 jobs compared to SES job creation peaking towards 320,000 or more than two times that in the BAU. This is entirely driven by renewable energy developments that require more jobs in the manufacturing and construction phases. See Appendix C for assumptions.
- The ASES job creation peaks at 500,000 jobs, more than three times that of the BAU driven by even more renewable energy projects required as the region moves towards a 100% renewable generation target by 2050.

- Different skills are required between the scenarios, BAU has people working on conventional coal and hydro, whereas the SES and ASES has people mainly working on solar & battery storage systems.
- Note that the manufacturing and fuel supply jobs shown to be created may not be created within Thailand with manufacturing of equipment and fuel management (for imported fuels) occurring in other countries.

**Figure 111 Job Creation by Category (BAU)**

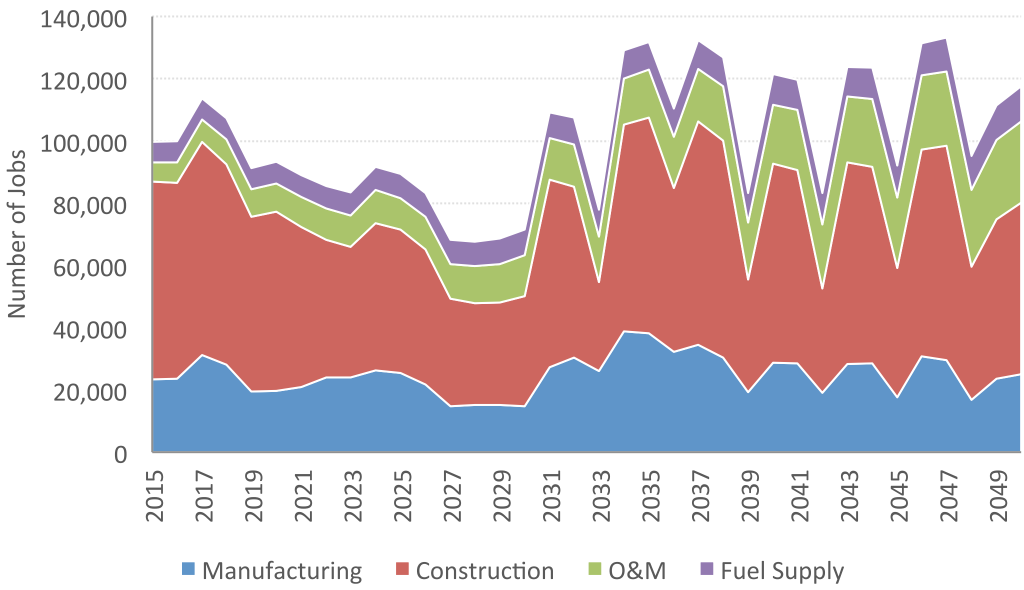


**Figure 112 Job Creation by Category (SES)**

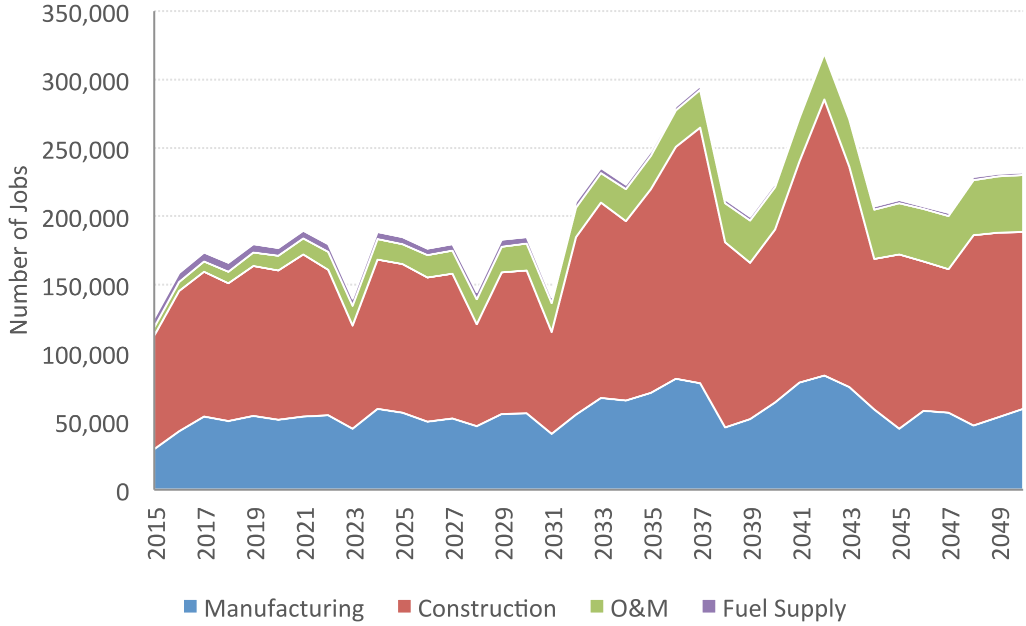



**Figure 113 Job Creation by Category (ASES)**

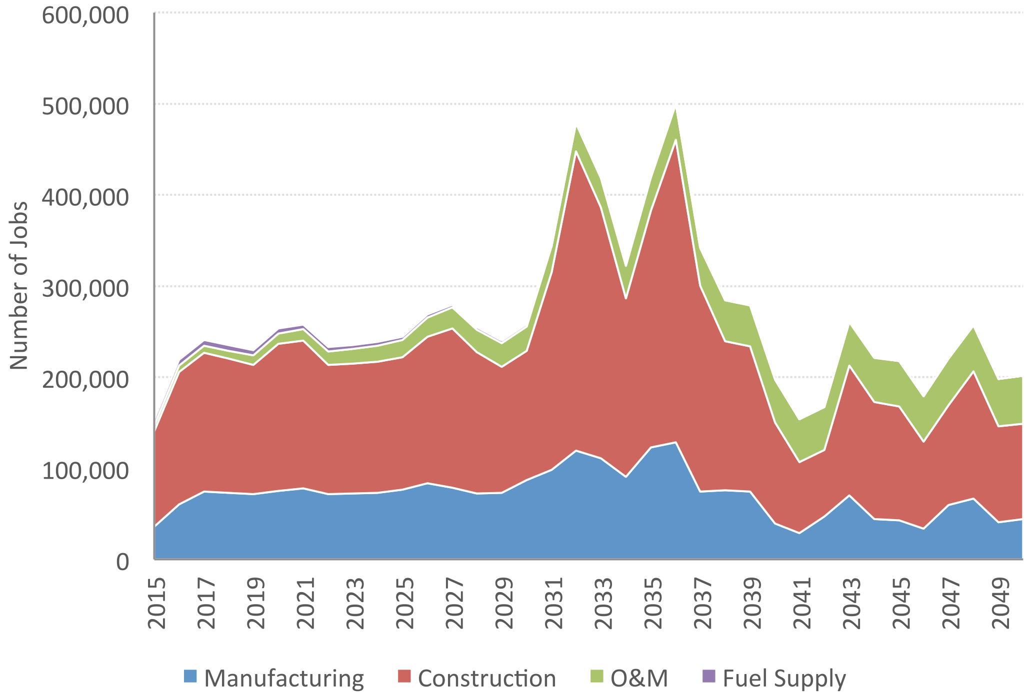
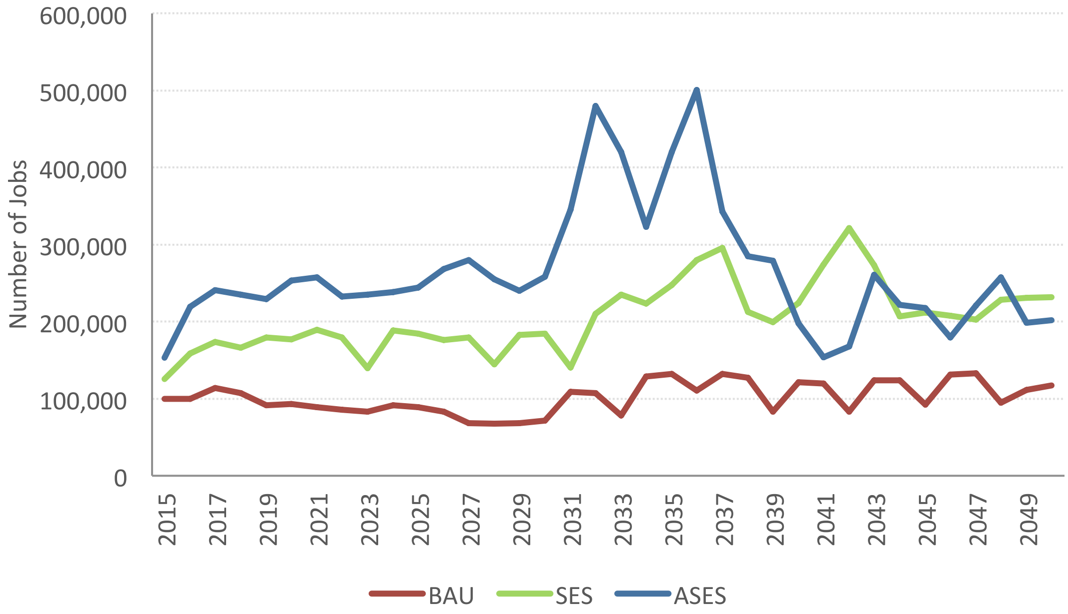


**Figure 114 Total Job Creation Comparison BAU, SES and ASES**



# 10 Conclusions

Compared to other GMS countries, the development of traditional primary energy resources in Thailand for electricity generation face a number of challenges. Thailand's proven offshore gas reserves in the Gulf of Thailand and Thailand-Malaysia Joint Development Area (JTA) are being utilised with contracted gas from these reserves expected to be depleted by 2030. Liquefied natural gas (LNG) has been available since 2011 as a stop-gap measure with terminal sized at an initial capacity of 5 MTPA[54] and an option to double capacity to 10 MTPA. Reserves of domestic coal consist mainly of lignite to sub-bituminous grade concentrated around two main reserves: Mae Moh in the north and Krabi in the south, with the former being exploited, and the latter being considered for exploitation. There has also been a focus on developing an option for Nuclear Power with efforts over the last decade taken by Thailand to enhance knowledge and capability to enable nuclear power to be a long-term option should it be needed to address power supply shortages.

In contrast to the fossil fuel situation, Thailand has substantial potential for the development of renewable energy; most notably, biomass, solar, and wind. Large scale hydro power potential in Thailand is estimated to be around 15 GW. However, the environmental externalities associated with exploiting hydro beyond the current 3.5 GW of large scale hydro already developed is regarded to be unsustainable and there is strong resistance to further developments. With areas of the country experiencing average wind speeds of 6-7 m/s, most notably in the mountain ranges in the south and the northeast during the period of the monsoons, there is significant potential for the deployment of wind turbines for power generation throughout the country, particularly along the sea shores and on islands either in the Gulf of Thailand or Andaman Sea. Being located near to the equator area, Thailand has substantial potential for solar photovoltaic development. Having a number of large areas with Direct Normal Irradiation (DNI) in the range of 1600 to as high as 1950 kWh/m^2/year, located mostly in the north western part of the country is evidence for potential for deployment of Concentrated Solar Power (CSP). As an agricultural country, Thailand's potential for biomass in the form the form of agricultural residues is significant. With the abundance of industrial waste and livestock manure, Thailand also has significant biogas potential.

In this report we have developed a Business as Usual (BAU) and Sustainable Energy Sector (SES) outlook for Thailand. The BAU outlook assumed that future power sector developments would be based on a gas, coal, large scale hydro and eventually nuclear in the future. These have been developed based on information provided in the PDP2015. We have incorporated the AEDP2015 as well and adopted gains in energy efficiency that are consistent with our understanding of the

[54] Million Tons per Annum

EEDP2015. In contrast, the SES and ASES were developed to explore what happens when measures are taken to deploy a maximal amount of renewable energy and put in place significant energy efficiency measures. In this way, we have developed some alternative scenarios for the country's power sector. The SES and ASES both also assume a more rapid program of cross-border interconnection in the GMS, which allows the region to more fully exploit diversity in demand as well as geographically dispersed areas with high renewable energy potential.

## 10.1 Comparison of Scenarios

The following are the key conclusions that have been drawn from the analysis presented in this report:

- The SES delivers an energy efficiency gain beyond the BAU case of about 27% compared to the BAU. The ASES delivers efficiency gains of 25% after doubling transport electricity demand;
- The SES is able to achieve a power system that delivers 84% of generation from renewable energy resources (including large-scale hydro) by 2050, and the ASES is able to achieve 100%. In contrast, 37% of the generation in the BAU is provided by renewable energy resources by 2050[55];
- By 2050, the SES and ASES avoids around 157 and 184 million tons of greenhouse gas emissions per year compared to the BAU. The SES intensity declines to 0.07 t-CO2/MWh by 2050 vs. 0.135 t-CO2/MWh for the BAU case. The BAU case achieves a higher emissions intensity level because of increased coal generation reliance while the SES deliver a low emissions intensity due to widespread deployment of solar and wind technologies. The ASES reaches 100% renewable generation by 2050.
- Based on some simple measures for energy security:
  - Under the ASES and SES, Thailand benefits from a more diverse mix of technologies and is not as dependent on a single source of primary energy as the BAU; for example, the BAU is highly dependent on imported coal, while the SES diversifies supply across a range of renewable energy technologies with no generation type accounting for more than 30% of the generation share;
  - The ASES and SES has around 92% and 81% of its electricity being generated from domestically controlled and managed resources, while the BAU needs to import primary energy resources in the form of gas and coal, which drives down the level of domestic control and management of primary energy resources – by 2050 this level reaches around 36% in the BAU. Under the ASES and SES generation developments are optimised across the region and Thailand imports up to 10% of its requirements by 2050; and

[55] Large-scale hydro is included

 - The ASES and SES achieves a reliable power system through coordination on both the supply and demand side of the industry, with similar energy reserve margins as the BAU. Though as a measure of energy supply storage and flexibility the ASES and SES overall is lower than the BAU, which means that the BAU would be more resilient against extreme events but is slightly offset by a more integrated regional power system through cross-border trading. While modelling has shown that the ASES and SES is operationally feasible (even with less directly dispatchable resources in the SES compared to the BAU), stress testing of both the BAU and SES scenarios against more significant threats to the operation of the power system would likely not be handled as well compared to the BAU. More work to understand and develop appropriate mitigation measures is required.

## 10.2 Economic Implications

### 10.2.1 Electricity Costs

Based on the outcomes of modelling the BAU, SES and ASES scenarios, we also examined the following issues in relation to electricity costs: (1) levelised cost of electricity, (2) investment requirements, (3) sensitivity of electricity prices to fuel price shocks, and (4) the implications of a price on carbon equivalent emissions for electricity prices. Based on this analysis we draw the following conclusions:

- The BAU requires lower levels of capital investment than the SES and ASES, and in relation to generation costs, the SES and ASES across the modelling period delivers a lower overall short-run marginal cost of electricity and LCOE to Thailand;
- Under the SES and ASES significant benefits are gained in the form of avoided fuel costs and this contributes to achieving a lower overall dollar cost for Thailand. The observation is made that the composition of LCOE under the SES and ASES is largely driven by investment costs, hence exposure to fuel shocks is significantly reduced; and
- The LCOE under the SES and ASES is also largely insensitive to a carbon price, as could be reasonably anticipated for a power system that is entirely dominated by renewable energy.

### 10.2.2 Investment Implications

From 2015 to 2050, the overall investment for is lower in the BAU than the SES and ASES: $176 billion in the BAU compared to $284 billion in the SES and $323 billion in the ASES (Real 2014 USD). However, the important difference is that the composition of the investments are quite different. The BAU directs most investment (55%) to coal and hydro projects, while in the SES (and ASES) some 38% (41%) is directed to solar and battery system technologies, with other significant investments in energy efficiency measures, bioenergy, wind and off-grid. Clearly, compared to the BAU, the SES and ASES will require investments across a more diverse range of technologies and such technologies will tend to be smaller and distributed rather than being large in scale.

### 10.2.3 Job Creation

The SES and ASES scenarios both result in quite different technology mixes for Thailand compared to the BAU. Each has quite different implications for the workforce that would be required to support each scenario. Based on analysis of the required jobs we estimate that[56]:

- The BAU from 2015 to 2050 would be accompanied by the creation of some 3.7 million jobs years[57] (25% manufacturing, 52% construction, 15% operations and maintenance, and 3% fuel supply);
- The SES would involve the creation of some 7.4 million job years (28% in manufacturing, 59% in construction, 11% in operations and maintenance and 2% in fuel supply); and
- The ASES would involve the creation of 3.8 million job years (27% in manufacturing, 60% in construction, 12% in operations and maintenance and 1% in fuel supply).

For the SES, Thailand will need to develop a skilled workforce capacity of supporting some 25 GW of solar technologies by 2030 and 59 GW by 2050. Enhancing the capability and quality of existing solar PV enterprises will be crucial in order to increase the likelihood of the new permanent jobs being occupied by local workers. Engaging with low skilled to medium skilled labourers and craftsman in a bottom up approach is strongly recommended in order to absorb existing labour and future labour that will be in need of employment.

## 10.3 Identified Barriers for the SES and ASES for Renewable Energy

Thailand has the most developed renewable energy policy among the ASEAN countries, with many incentives implemented in recent years. Despite this success, renewable energy investment in Thailand still faces a number of economic and non-economic barriers. These are summarised as follows.

### 10.3.1 Economic Barriers

The lack of interest and experience of banks in investing in new renewable technologies was one of the barriers to securing finance in the past. However, the ENCON revolving fund has demonstrated the potential of renewable energy projects to the banks. As a result, banks are now more willing to invest in

[56] Based on the employment factors presented in Appendix C.
[57] A job year is one job for one person for one year. We use this measure to make comparisons easier across each scenario as the number of jobs created fluctuates from year to year.

renewable energy projects. The Thai government is no longer supporting the banks with zero-interest loans as in the past.

The adder program first introduced in 2007 was considered by investors to be the most attractive and effective support instrument for investment in renewable energy in Thailand due to its high rates, especially for solar PV projects. Moreover, the rate structure is simple and easy for investors to integrate into investment plans. Under the adder program, renewable investors received adder rates on top of based electricity prices for a period of 7 or 10 years depending on the technology type. The adder program has been very successful in driving the growth of renewable energy in Thailand to such an extent that the initial renewable targets have had to be revised from the initial 5.6 GW by 2021 to 16.7 GW by 2036.

However, the adder program has also created some burdens which affect consumer electricity bills since the adder is directly passed through to consumers. Under the adder program, renewable energy investors initially benefited from high tariffs at the expense of consumer electricity bills. Due to concerns over the long-term impact on electricity bills, the adder program has subsequently been replaced by the Feed-in Tariff (FiT) scheme with the intention of moving towards a new competitive bidding method in coming years. The FiT scheme is intended to better reflect the actual costs of renewable energy as well as reducing the impact on ratepayers. With the new FiT scheme, renewable investors are paid fixed-price FiT rather than depending on the based electricity prices which fluctuate over time. The fixed FiT rates are considerably lower than the adder rates but the contracted period is either 20 or 25 years, which is much longer than that offered under the adder program. Although the changes are expected to provide greater financial certainty over a longer period to renewable investors, it still remains to be seen whether the FiT scheme can still provide sufficient incentives to further drive investment in renewable energy in Thailand. Moreover, there are still considerable uncertainties over future renewable policy since the Government is still exploring options to minimise the impact of FiT on electricity bills through the introduction of a competitive bidding process.

### 10.3.2 Non-economic Barriers

Non-economic barriers include both regulations and technical barriers. The accessibility of transmission-line information still remains a risk factor for renewable-energy investors. A coordinated approach between electricity utilities would help to address some of this uncertainty. The limited capacity of transmission lines, coupled with the high cost of investment and an increase in renewable energy projects in remote areas with low electricity demand, creates a challenge for the sector. Transmission constraints are a bottleneck which should be addressed by government in order to support the development of Thailand's abundant renewable energy resources in the future. The variability and partly dispatchable nature of wind and solar generation also increase the challenge for power system operation and the way in which thermal power plants are operated.

In order to encourage sustainable renewable energy investment in Thailand, both the Thai government and private sector need to work together to learn from the failures of the past and to improve implementation by tackling economic and non-economic barriers. The technical barriers could potentially be addressed through a number of measures including transmission network augmentations, the implementation of smart grids and improved wind and solar forecasting to predict their generation outputs more accurately. Incentives with a clear and unified policy, as well as appropriate regulations that result in attractive - but not excessive - prices would be the best solution to support investment in renewable energy Thailand.

## 10.4 Identified Barriers for the SES and ASES for Energy Efficiency

The key success factors to achieve the target of energy efficiency for Thailand depend on how the energy-saving plans and policies could be implemented and managed effectively rather the plans themselves. Although the EEDP has set forth detailed plans and targets for driving energy efficiency, implementation is the most difficult part as there are many barriers and challenges[58].

### 10.4.1 Institutional Barriers

Institutional factor is one of the largest barriers in implementing energy efficiency. This barrier is found in government agencies which usually work in vertical hierarchy of management and lack of coordination between different agencies. On the other hand, implementing energy efficiency often requires a working team consisting of experts/representatives across government agencies, and sometime even from private sectors. For example, Ministry of Energy may launch an energy building code to improve energy efficiency in commercial buildings, but Department of Public Works and Town & Country Planning is the one who has authority to enforce such code. Therefore, lack of coordination and collaboration among different public agencies posting a challenge to implementing energy efficiency.

### 10.4.2 Financial Barriers

A financial incentive is an important tool to overcome barriers and challenges in implementing energy efficiency. Thailand has had many financial tools for promoting energy efficiency such as Energy Efficiency Revolving Fund which considered as a successful case that encouraged commercial banks to invest in energy efficiency projects. However, one may argue that such financial supports are not yet well known among small entrepreneurs and SMEs. In addition, a solid

[58] http://www.jgsee.kmutt.ac.th/jgsee1/NewsEvents/2014/feb2014/2014-02-10/1.%20EE%20template%20(edited).pdf

technical knowledge is also necessary for preparing a sound proposal for getting a financial support. Unfortunately, such common wisdom and expertise are generally unfound in most small entrepreneurs and SMEs in Thailand.

Implementing energy efficiency should be market oriented and should include private sector. Both producer and end user should be taken as a leading role. However, to let the market developed by itself may take a long time, so government intervention in the beginning is crucial. For example, government agencies should promote green procurement to lift up those regulations preventing energy efficiency improvement. Implementing energy efficiency in government buildings has a large untapped market potential. This can help professional like energy service company (ESCO) to develop their business plan, experience and reputation. However, least cost procurement regulation used by government agency does not allow adopting those new innovative energy efficiency technologies which often have high initial costs even though they make more economical sense in long run.

### 10.4.3 Technical Barrier

Thailand still lacks of measurements, reporting and verification (MRV) system to follow up energy conserved by measures. Without a clear result on how much a measure or a project can conserve energy, it is unlikely that planners can conserve energy and improve efficiency effectively in order to meet the target in a long term. In case of ESCO, lacking in measurement and verification (M&V), a process of quantifying energy conservation, may lead to unclear result and contract being void.

### 10.4.4 Lack of a Well-Functioning Database

Although energy intensity is one of the main indicators for energy efficiency, more indicators by sector is needed to be simplified for ease of implementing energy efficiency and to analyse barriers. This is crucial since energy intensity does not show energy efficiency in details for each sector, and different sectors need different energy efficiency indicators in order to effectively implement measures and follow up.

## 10.5 Recommendations

The following are key recommendations to reduce the barriers and “enable” the SES and ASES:

- Thailand has in place energy policies that create an environment that aims to be conducive for investment in renewable energy technologies. However, experience to date suggests that there remain barriers ranging from project developers experiencing difficulties in securing finance, presence of regulatory uncertainty and technical barriers in the form of problems related to licensing and grid connection. This suggests that efforts to improve regulatory frameworks and technical codes may be warranted.

- Formation of electricity pricing policies and mechanisms that encourage efficient behavior and investment in generation technologies, transmission and distribution equipment and end use energy consumption.
- Continue efforts to perform more detailed assessments of renewable energy potential and make the results publicly available to enable prospective investors to understand the potential, identify the best opportunities and subsequently take steps to explore investment and deployment.
- Knowledge transfer and capability building in the renewable energy technologies and energy efficiency for policy makers, staff working in the energy industry, as well as within education institutions to ensure the human capacity is being developed to support a national power system that has a high share of generation from renewable energy.
- Investments in ICT systems to enhance real-time power system operations of both supply and demand sides of the industry such as smart-grid technology and integration of renewable energy forecasting systems and tools into present systems for centralized real-time system operations. This will enable efficient real-time dispatch and control of all resources in Thailand's national power system and will create an environment more conducive for the management of high levels of renewable energy and flexible (dispatchable) demand.
- Take measures to encourage a coordinated approach to enhancing cross-border power trade in the region since this works to the advantage of exploiting diversity in renewable energy resource potential and diversity in electricity demand. This would require a shift from investment in dedicated import projects in neighboring countries, towards a platform that is able to support multilateral power trade.

  Some features of the recommended approach are:

  - Develop an overarching transmission plan that has been informed by detailed assessments and plans to leverage renewable energy potential in the region and diversity in demand and hydrological conditions.
  - Enhance / adapt technical standards and transmission (or Grid) codes in each country to allow for better interoperation of national power systems.
  - Establish dispatch protocols to better coordinate real-time dispatch of power systems in the region to make the best use of real-time information and continuously updated demand and renewable generation forecasts.
  - Develop a framework to encourage energy trade in the region, and in particular towards a model that can support multilateral power trading via a regional power market or exchange (for example).
- Take measures to improve power planning in the region to:

- Explicitly account for project externalities and risks,
- Evaluate a more diverse range of scenarios including those with high levels of renewable energy,
- Take into consideration energy efficiency plans,
- Take into consideration overarching plans to have tighter power system integration within the region, and
- Carefully evaluate the economics of off-grid against grid connection where this is relevant.

# Appendix A Technology Costs

Table 27 sets out the technology cost assumptions that were used in the modelling presented in this report for the BAU and SES scenarios. Table 28 sets out the technology costs used in the ASES. The technology costs of coal and gas do not include overheads associated with infrastructure to develop facilities for storing / managing fuel supplies. These costs were however accounted for in the modelling.

Figure 115 and Figure 116 presents the levelised cost of new entry generation based on assumed capacity factors. LCOE levels presented in Section 9 are based on weighted average LCOE's and modelled output and will differ from the LCOE's presented here. The LCOE for battery storage is combined with solar PV technology assuming 75% of generation is stored for off-peak generation.

**Table 27 Technology Costs Assumptions for BAU and SES Scenarios**

| | Technology Capital Cost (Unit: Real 2014 USD/kW) | | | |
|---|---|---|---|---|
| **Technology** | **2015** | **2030** | **2040** | **2050** |
| Generic Coal | 2,492 | 2,474 | 2,462 | 2,450 |
| Coal with CCS | 5,756 | 5,180 | 4,893 | 4,605 |
| CCGT | 942 | 935 | 930 | 926 |
| GT | 778 | 772 | 768 | 764 |
| Wind Onshore | 1,450 | 1,305 | 1,240 | 1,175 |
| Wind Offshore | 2,900 | 2,610 | 2,480 | 2,349 |
| Hydro Large | 2,100 | 2,200 | 2,275 | 2,350 |
| Hydro Small | 2,300 | 2,350 | 2,400 | 2,450 |
| Pumped Storage | 3,340 | 3,499 | 3,618 | 3,738 |
| PV No Tracking | 2,243 | 1,250 | 1,050 | 850 |
| PV with Tracking | 2,630 | 1,466 | 1,231 | 997 |
| PV Thin Film | 1,523 | 1,175 | 1,131 | 1,086 |
| Battery Storage - Small | 600 | 375 | 338 | 300 |
| Battery - Utility Scale | 500 | 225 | 213 | 200 |
| Solar Thermal with Storage | 8,513 | 5,500 | 4,750 | 4,000 |
| Solar Thermal No Storage | 5,226 | 4,170 | 3,937 | 3,703 |
| Biomass | 1,800 | 1,765 | 1,745 | 1,725 |
| Geothermal | 4,216 | 4,216 | 4,216 | 4,216 |
| Ocean | 9,887 | 8,500 | 7,188 | 5,875 |
| Biogas (AD) | 4,548 | 4,460 | 4,409 | 4,359 |

**Battery technology quoted on a $/kWh basis*

**Figure 115 Levelised Cost of New Entry (BAU & SES, $/MWh)**

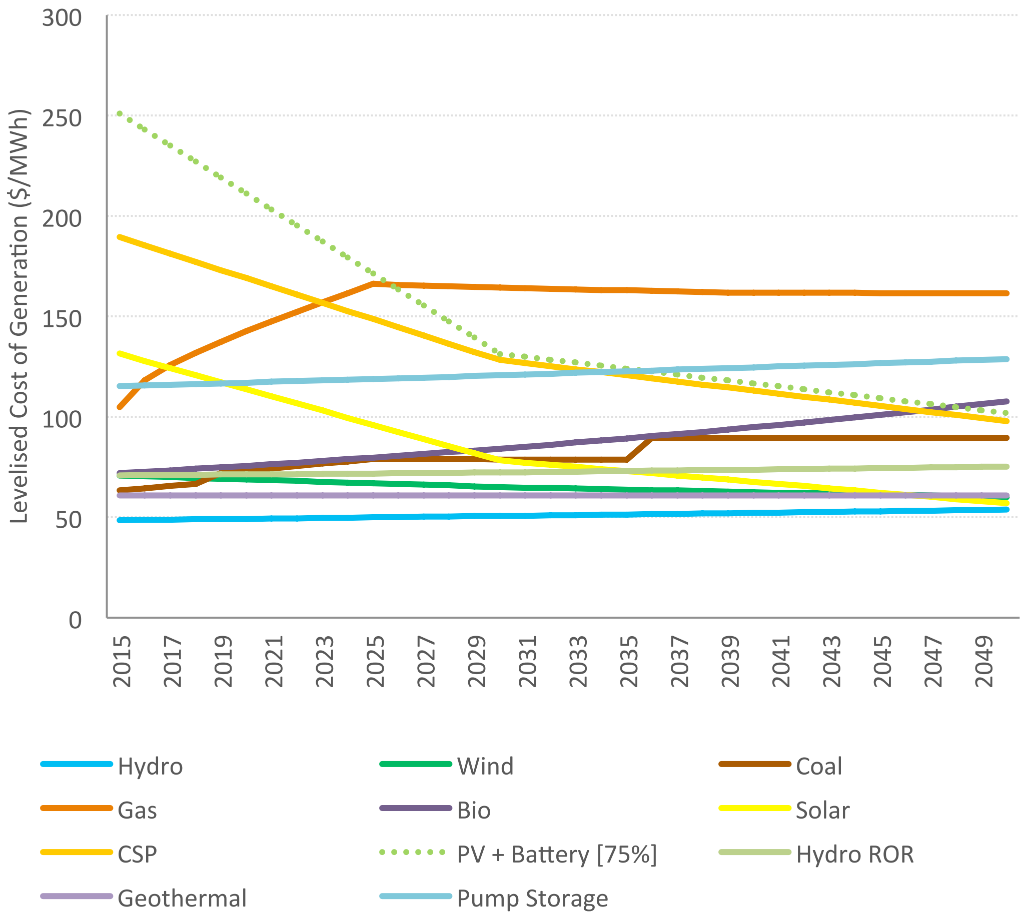
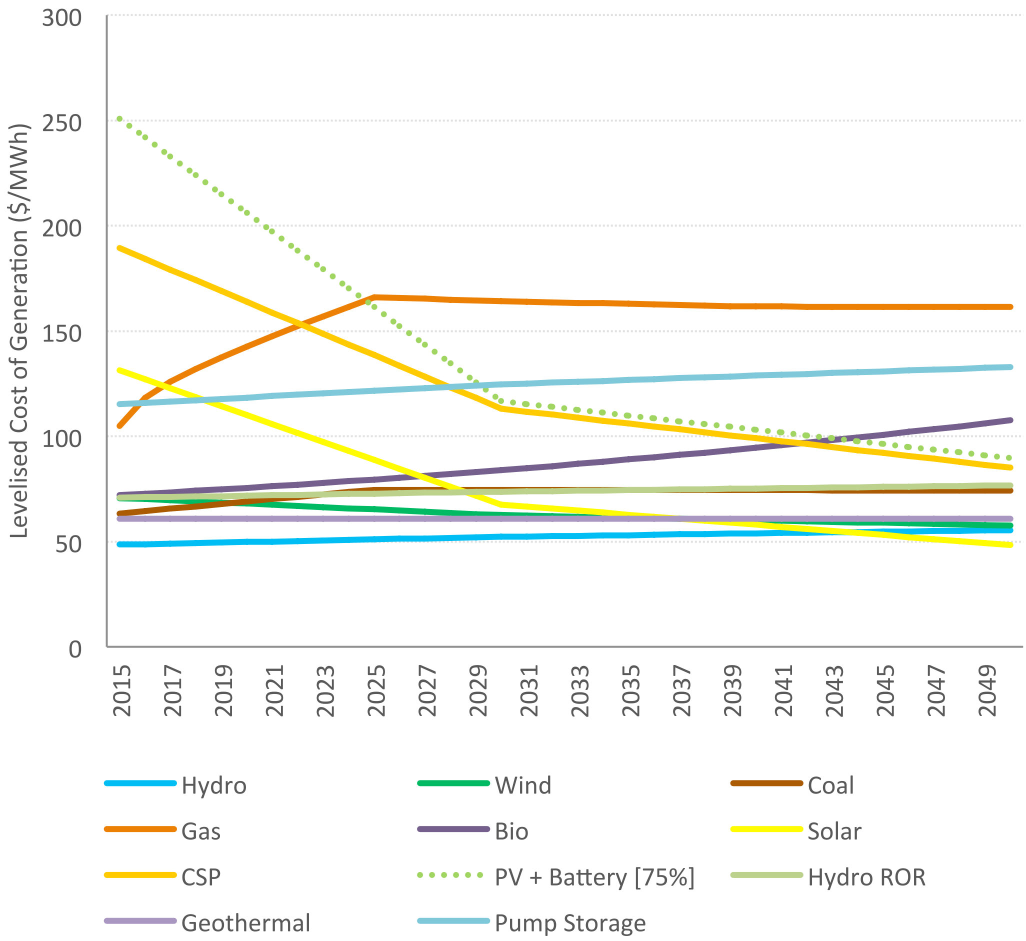


**Table 28 Technology Costs Assumptions for ASES Scenario**

| | Technology Capital Cost (Unit: Real 2014 USD/kW) | | | |
|---|---|---|---|---|
| **Technology** | **2015** | **2030** | **2040** | **2050** |
| Generic Coal | 2,492 | 2,462 | 2,450 | 2,437 |
| Coal with CCS | 5,756 | 4,893 | 4,605 | 4,334 |
| CCGT | 942 | 930 | 926 | 921 |
| GT | 778 | 768 | 764 | 761 |
| Wind Onshore | 1,450 | 1,240 | 1,175 | 1,113 |
| Wind Offshore | 2,900 | 2,480 | 2,349 | 2,225 |
| Hydro Large | 2,100 | 2,275 | 2,350 | 2,427 |
| Hydro Small | 2,300 | 2,400 | 2,450 | 2,501 |
| Pumped Storage | 3,340 | 3,618 | 3,738 | 3,861 |
| PV No Tracking | 2,243 | 1,050 | 850 | 688 |
| PV with Tracking | 2,630 | 1,231 | 997 | 807 |
| PV Thin Film | 1,523 | 1,131 | 1,086 | 1,043 |
| Battery Storage - Small | 600 | 338 | 300 | 267 |
| Battery - Utility Scale | 500 | 213 | 200 | 188 |
| Solar Thermal with Storage | 8,513 | 4,750 | 4,000 | 3,368 |
| Solar Thermal No Storage | 5,226 | 3,937 | 3,703 | 3,483 |
| Biomass | 1,800 | 1,745 | 1,725 | 1,705 |
| Geothermal | 4,216 | 4,216 | 4,216 | 4,216 |
| Wave | 9,887 | 7,188 | 5,875 | 4,802 |
| Biogas (AD) | 4,548 | 4,359 | 4,309 | 4,259 |

**Battery technology quoted on a $/kWh basis*

**Figure 116 Levelised Cost of New Entry (AES, $/MWh)**



# Appendix B Fuel Prices

Table 29 sets out the Free on board (FOB) fuel price assumptions that were used in the modelling presented in this report. This fuel price set was common to all three scenarios.

## Table 29 Fuel Price Assumptions (Real 2014 USD/GJ)

| Year | Coal | Gas | Diesel | Uranium | Fuel Oil | Biomass | Biogas |
|---|---|---|---|---|---|---|---|
| 2015 | 2.39 | 10.08 | 13.34 | 0.72 | 9.13 | 2.57 | 1.00 |
| 2016 | 2.51 | 11.88 | 15.24 | 0.76 | 10.49 | 2.62 | 1.00 |
| 2017 | 2.63 | 12.91 | 15.28 | 0.80 | 11.68 | 2.67 | 1.00 |
| 2018 | 2.74 | 13.72 | 16.41 | 0.80 | 12.43 | 2.72 | 1.00 |
| 2019 | 2.86 | 14.47 | 17.53 | 0.80 | 13.18 | 2.78 | 1.00 |
| 2020 | 2.98 | 15.16 | 18.64 | 0.80 | 13.93 | 2.83 | 1.00 |
| 2021 | 3.10 | 15.81 | 19.73 | 0.80 | 14.65 | 2.89 | 1.00 |
| 2022 | 3.21 | 16.46 | 20.80 | 0.80 | 15.36 | 2.95 | 1.00 |
| 2023 | 3.33 | 17.10 | 21.86 | 0.80 | 16.06 | 3.01 | 1.00 |
| 2024 | 3.45 | 17.72 | 22.90 | 0.80 | 16.76 | 3.07 | 1.00 |
| 2025 | 3.56 | 18.34 | 23.93 | 0.80 | 17.44 | 3.13 | 1.00 |
| 2026 | 3.56 | 18.29 | 23.86 | 0.80 | 17.39 | 3.19 | 1.00 |
| 2027 | 3.56 | 18.24 | 23.79 | 0.80 | 17.34 | 3.25 | 1.00 |
| 2028 | 3.56 | 18.19 | 23.72 | 0.80 | 17.29 | 3.32 | 1.00 |
| 2029 | 3.56 | 18.14 | 23.65 | 0.80 | 17.24 | 3.39 | 1.00 |
| 2030 | 3.56 | 18.09 | 23.58 | 0.80 | 17.19 | 3.45 | 1.00 |
| 2031 | 3.56 | 18.06 | 23.53 | 0.80 | 17.15 | 3.52 | 1.00 |
| 2032 | 3.56 | 18.02 | 23.49 | 0.80 | 17.12 | 3.59 | 1.00 |
| 2033 | 3.56 | 17.99 | 23.44 | 0.80 | 17.08 | 3.67 | 1.00 |
| 2034 | 3.56 | 17.96 | 23.40 | 0.80 | 17.05 | 3.74 | 1.00 |
| 2035 | 3.56 | 17.92 | 23.35 | 0.80 | 17.02 | 3.81 | 1.00 |
| 2036 | 3.56 | 17.89 | 23.30 | 0.80 | 16.98 | 3.89 | 1.00 |
| 2037 | 3.56 | 17.86 | 23.26 | 0.80 | 16.95 | 3.97 | 1.00 |
| 2038 | 3.56 | 17.83 | 23.21 | 0.80 | 16.92 | 4.05 | 1.00 |
| 2039 | 3.56 | 17.79 | 23.16 | 0.80 | 16.88 | 4.13 | 1.00 |
| 2040 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 4.21 | 1.00 |
| 2041 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 4.29 | 1.00 |
| 2042 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 4.38 | 1.00 |
| 2043 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 4.47 | 1.00 |
| 2044 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 4.56 | 1.00 |
| 2045 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 4.65 | 1.00 |
| 2046 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 4.74 | 1.00 |
| 2047 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 4.84 | 1.00 |
| 2048 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 4.93 | 1.00 |
| 2049 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 5.03 | 1.00 |
| 2050 | 3.56 | 17.76 | 23.12 | 0.80 | 16.85 | 5.13 | 1.00 |

# Appendix C Methodology for Jobs Creation

This section briefly summarises the methodology that we adopted for jobs creation. The methodology that we have adopted has been based on an approach developed by the Institute for Sustainable Futures at the University of Technology, Sydney and used by the Climate Institute of Australia[59]. In essence the jobs created in different economic sectors (manufacturing, construction, operations & maintenance and fuel sourcing and management) can be determined by the following with the information based on the numbers provided in Table 30.

## Figure 117 Job Creation Calculations

**Jobs = manufacturing + construction + operations and maintenance (O&M) + fuel**, where:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Manufacturing | = | MW installed per year | x | Manufacturing employment multiplier | x | Annual decline factor (years) | x | % local manufacturing |
| Construction | = | MW installed per year | x | Construction employment multiplier | x | Annual decline factor years | | |
| O&M | = | Cumulative capacity | x | O&M employment multiplier | x | Annual decline factor years | | |
| Fuel supply (coal) | = | Electricity generation | x | Fuel employment multiplier | x | Annual decline factor years | | |
| Fuel supply (gas) | = | Electricity generation | x | Fuel employment multiplier | x | Annual decline factor years | x | % local fuel supply |

We have applied this methodology to the results in each scenario discussed in this report in order to make estimates of the jobs creation impacts and allow comparisons to be made[60].

[59] A description of the methodology can be found in the following reference: The Climate Institute, "Clean Energy Jobs in Regional Australia Methodology", 2011, available: http://www.climateinstitute.org.au/verve/_resources/cleanenergyjobs_methodology.pdf.

[60] The percentage of local manufacturing and local fuel supply is assumed to be 1 to reflect the total job creation potential.

## Table 30 Employment Factors for Different Technologies

| | Annual decline applied to employment multiplier | | Construction time | Construction | Manufacturing | Operations & maintenance | Fuel |
|---|---|---|---|---|---|---|---|
| **Technology** | **2010- 20** | **2020-30** | **years** | **per MW** | **per MW** | **per MW** | **per GWh** |
| Black coal | 0.5% | 0.5% | 5 | 6.2 | 1.5 | 0.2 | 0.04 (include in O&M) |
| Brown coal | 0.5% | 0.5% | 5 | 6.2 | 1.5 | 0.4 | |
| Gas | 0.5% | 0.5% | 2 | 1.4 | 0.1 | 0.1 | 0.04 |
| Hydro | 0.2% | 0.2% | 5 | 3.0 | 3.5 | 0.2 | |
| Wind | 0.5% | 0.5% | 2 | 2.5 | 12.5 | 0.2 | |
| Bioenergy | 0.5% | 0.5% | 2 | 2.0 | 0.1 | 1.0 | |
| Geothermal | 1.5% | 0.5% | 5 | 3.1 | 3.3 | 0.7 | |
| Solar thermal generation | 1.5% | 1.0% | 5 | 6.0 | 4.0 | 0.3 | |
| SWH | 1.0% | 1.0% | 1 | 10.9 | 3.0 | 0.0 | |
| PV | 1.0% | 1.0% | 1 | 29.0 | 9.0 | 0.4 | |