ERIA Research Project Report 2020, No. 17

Feasibility Study on the Transmission Highway in ACMECS

Edited by

Shigeru Kimura

Keisuke Ueda

Feasibility Study on the Transmission Highway in ACMECS

Economic Research Institute for ASEAN and East Asia (ERIA)

Sentral Senayan II 6th Floor

Jalan Asia Afrika no.8, Gelora Bung Karno

Senayan, Jakarta Pusat 12710

Indonesia

ERIA Research Project Report FY2020 No. 17

Published in December 2021

Preface

We all know that member countries of the Ayeyawady-Chao Phraya-Mekong Economic Cooperation Strategy (ACMECS) have varying energy priorities, opportunities, and challenges. In contrast, our energy systems are increasingly interconnected. But we have a high potential for possible future expansion of power grid interconnection.

With the outcome of this study, we need to continue exploring how we move the regional grid inclusively towards a more accessible, affordable, and sustainable future power sector through the transmission highway concept.

Moreover, ASEAN Member States have been instrumental in the region's first steps towards regional power trade through its efforts to advance some initiatives, such as the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP) as part of the game.

For this, much appreciation and thanks go to the Economic Research Institute for ASEAN and East Asia (ERIA), Indonesia, TEPCO Power Grid (TEPCO PG) Incorporated, Japan, and the expert team in conducting this important study for our region. Sincerest appreciation also goes to all ACMECS member countries for their continued support and contribution to this effort for mutual benefit, understanding, and cooperation on future transmission systems.

Having achieved the successful outcomes of this study, we can foresee clearer activities, particularly a continued multilateral spirit of cooperation under the ACMECS framework.

I believe the success of this project will help enhance the regional power trade and make it more secure, stable, and sustainable while promoting opportunities for the energy market, trade, and investments for our mutual benefit.

Definitely, we need supporting policies from the governments and a technical platform from ERIA to help ACMECS countries and partners encourage successful multi-stakeholder collaboration.

On behalf of the Ministry of Energy of Thailand, I would like to thank the working group members again. And I hope that, with the continued support from ERIA and TEPCO PG, we will move the study's outcomes to the attention of higher authorities as a next step.

Dr Weerawat Chantanakome
Ministry Counsellor for International Affairs
Ministry of Energy, Thailand

July 2021

Acknowledgement

This report was developed by a joint working group comprising teams from Cambodia, the Lao PDR, Myanmar, Thailand, Viet Nam, and the Economic Research Institute for ASEAN and East Asia (ERIA). The joint working group consisted of the Ministry of Industry, Mines and Energy; Electricite du Cambodge, Ministry of Mines and Energy (Cambodia); Electricité du Laos (Lao PDR); Ministry of Electricity and Energy, Ministry of Electric Power (Myanmar); Ministry of Energy, Energy Policy and Planning Office, Electricity Generating Authority of Thailand (Thailand); and Electricity and Renewable energy Authority (Viet Nam). In addition, some experts, Kitti Kampeera, Suthep Chimklai, and Boonrod Sajjakulnukit, also joined our working group as advisors. The ERIA team was composed of researchers of its energy unit, TEPCO Power Grid (TEPCO PG) Incorporated, Japan. We would like to thank the members of the working group for their excellent work and contributions.

ERIA's energy unit prepared this report. The main authors are Shigeru Kimura and Keisuke Ueda. Other principal contributors are Kin Sothea, Pauk Kyaing Sahm, Parinya Eakponpisan, and Masaharu Yogo. They each provided essential contributions to the current power system situation in ACMECS countries and various other chapters. This study could not have been realised without many people's invaluable support and contribution (please see details in the list of Project Members).

Special acknowledgement is given to Weerawat Chantanakome, Special Councillor and Senior Advisor to the Minister of Energy, Thailand, for his very helpful comments and suggestions.

Special thanks also go to the ERIA Publications Department – Stefan Wesiak, Fadriani Trianingsih, Rachmadea Aisyah, and its team of editors – for helping edit the report and prepare it for publication.

Shigeru Kimura
Special Adviser to the President on Energy Affairs
Economic Research Institute for ASEAN and East Asia

July 2021

Contents

List of Project Members

Shigeru Kimura (Leader): Special Advisor to President on Energy Affairs, Economic Research Institute for ASEAN and East Asia (ERIA)

Keisuke Ueda (Sub-leader): Senior Policy Advisor, ERIA

Weerawat Chantanakome: Special Councillor and Senior Advisor to the Minister of Energy, Thailand

Masaharu Yogo: General Manager of International Business Development Office, TEPCO Power Grid Inc., Japan

Shinichi Suganuma: Manager of Engineering Research Group, Power System Operation Department, TEPCO Power Grid Inc., Japan

Kin Sothea: Deputy Director of Energy Development Department, Ministry of Mines and Energy, Cambodia

Leng Sovannarith: Deputy Director of Transmission Department, Electricite du Cambodge, Cambodia

Somsanith Sadettan: Director of System Planning Department, Electricité Du Laos, Lao PDR

Souksavart Sosouphanh: Director of Investment Division, Department of Planning and Cooperation, Ministry of Energy and Mines (MEM), Lao PDR

Soukvilay Phimmasene: Department of Energy Policy and Planning, MEM, Lao PDR

Pauk Kyaing Sahm: Assistant Director, Department of Power Transmission and System Control, Ministry of Electricity and Energy, Myanmar

Uthai Mungseemuengdee: Director, Strategic and Planning Group, Energy Policy and Plannig Office, Thailand

Titiporn Sangpetch: Transmission System Engineering Division, Electricity Generating Authority of Thailand (EGAT), Thailand

Parinya Eakponpisan: Chief, Power System Connection and Cooperation Planning Department, EGAT, Thailand

Nguyen Phuong Mai: Deputy Chief of the Office, Electricity and Renewable Energy Authority, Viet Nam

Kitti Kampeera: Director, Kenan Institute Asia (K.I.Asia), Thailand

Suthep Chimklai: Executive Director, ATT Consultants Company Limited, Thailand

Boonrod Sajjakulnukit: The Joint Graduate School of Energy and Environment, Thailand

List of Figures

List of Tables

List of Abbreviations and Acronyms

AC	alternating current
ACMECS	Ayeyawady-Chao Phraya-Mekong Economic Cooperation Strategy
ADB	Asian Development Bank
AIMS	ASEAN Interconnection Master Plan Study
AMS	ASEAN Member State
APG	ASEAN Power Grid
ASEAN	Association of Southeast Asian Nations
DC	direct current
CTS	Cambodia Transmission System
EAC	Electricity Authority of Cambodia
EDC	Electricite du Cambodge
EDL	Electricité du Laos
EDL-Gen	EDL-Generation Public Company
EGAT	Electricity Generating Authority of Thailand
EGDP	Ethnic Group Development Plan
EIA	US Energy Information Administration
EIRR	economic internal rate of return
ERAV	Electricity Regulatory Authority of Viet Nam
EREA	Electricity & Renewable Energy Authority
ERIA	Economic Research Institute for ASEAN and East Asia
EVN	Viet Nam Electricity
FIRR	financial internal rate of return
GDP	gross domestic product
GENCO	generation company
GHG	greenhouse gas
GMS	Greater Mekong Subregion
HAPUA	Heads of ASEAN Power Utilities/Authorities
IEA	International Energy Agency
IPP	independent power producer

IRR	internal rate of return
JICA	Japan International Cooperation Agency
LTMS-PIP	Laos-Thailand-Malaysia-Singapore Power Integration Project
MBTU	Mega British Thermal Unit
MEA	Metropolitan Electricity Authority
MEM	Ministry of Energy and Mines (Lao PDR)
MIME	Ministry of Industry, Mines and Energy (Cambodia)
MME	Ministry of Mines and Energy (Cambodia)
MoEE	Ministry of Electricity and Energy (Myanmar)
MoEN	Ministry of Energy, Thailand
MOIT	Ministry of Industry and Trade (Viet Nam)
NPT	National Power Transmission Cooperation
NPV	net present value
O&M	operation and maintenance
PDP	power development plan
PMB	project management board
PV	photovoltaic
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SAPP	South African Power Pool
SIL	surge impedance loading
SPP	small power producer
US	United States

Executive Summary

The Economic Research Institute for ASEAN and East Asia (ERIA) implemented the project 'Feasibility Study on Transmission Highway in ACMECS (Ayeyawady-Chao Phraya-Mekong Economic Cooperation Strategy)'. The study aimed to carry out a cost–benefit analysis by utilising high-voltage cross-border interconnections for power trade. In this study, the concept of a high-voltage transmission network through ACMECS countries, called 'Transmission Highway', includes the cross-border interconnection and some domestic transmission lines in Thailand.

Presently, energy resources vary in ACMECS: huge hydro potential in the Lao PDR and Myanmar, large gas potential in Myanmar, and coal potential in Viet Nam. But the abundant resources, especially hydropower, are underutilised because ACMECS countries have no existing bulk transmission network covering their entire area. Some cross-border interconnections already exist in ACMECS. Most of them serve as dedicated transmission lines for power purchase agreements. Power trade is implemented mutually on a few cross-border interconnections, but their voltage is low and the transmission capacity is small. Thus, there is no 500 kV cross-border interconnection for mutual power trade.

The high-voltage transmission network can bring multiple benefits, including reduced fuel costs of thermal power generation, reduced CO_2 emission, improved electricity access, and the ability to consolidate higher shares of variable renewable energy.

This study focused on two main parts: cost estimation of the candidate cross-border interconnections and benefit analysis.

Selected as the Transmission Highway are six routes of cross-border interconnections and three routes of domestic transmission lines in Thailand. The voltage level and capacities of the candidate transmission lines were set based on the surge impedance loading and the amount of expected power trade. The total construction cost of the Transmission Highway is about US$1,500 million.

The electric power trade to be transmitted from the Lao PDR through the candidate interconnections is expected to be from the increase in energy export volume from the domestic power grid of the Lao PDR and new export-dedicated independent power producers (IPPs) in the Lao PDR. In addition, the increase in power energy import from Thailand into the domestic power grid of the Lao PDR during the dry season is also expected. According to IRENA (2019, installing the hydropower plant in China has a unit cost of US$1,264/kW, and that for installing the onshore wind power in China is US$1,223/kW. Based on this price, the total installation cost of new IPPs is about US$4,016 million.

Based on the expected power trade, this study carried out the benefit analysis. Power trade through cross-border interconnections can yield a lot of benefits. One is the fuel cost reduction of a thermal power plant. Fuel cost reductions for 25 years amount to US$1,569 million in Thailand; US$2,614 million in Viet Nam; US$1,667 million in Myanmar; and US$448 million in Cambodia. The total fuel cost reduction is expected to be US$6,298 million.

The second benefit is a reduction in new investment of a thermal power plant. A new investment of US$2,093 million with 1,504 MW of total thermal generation capacity can be reduced by power trade through the Transmission Highway.

The third benefit is reduced CO_2 emissions through decreased thermal power generation. This result is calculated as a social benefit. CO_2 emission reduction for 25 years totals 3 Mt-C in Thailand, 31 Mt-C in Viet Nam, 21 Mt-C in Myanmar, and 5 Mt-C in Cambodia. Total CO_2 emission reduction is expected to be 60 Mt-C. In addition, reduced thermal power generation yields the benefit of carbon pricing. No carbon pricing incentive exists in ACMECS countries. If carbon pricing incentive is introduced, we can expect carbon pricing benefits for 25 years of US$46.2 million in Thailand; US$1,984.1 million in Viet Nam; US$1,294.1 million in Myanmar; and US$365.7 million in Cambodia.

The fourth benefit, improved gross domestic product (GDP) through electricity access, is both social and economic. The electricity access ratios in Myanmar and Cambodia are still low. Thus, this study assumed that imported electricity reduces thermal power generation and improves electricity access in Myanmar and Cambodia. Using electricity imports from Thailand for electricity access will improve Myanmar's GDP by 0.7% in 2030 and 0.5% in 2035 and Cambodia's by 0.6% in 2030 and 0.3% in 2035, based on the ERIA's energy outlook report data (ERIA, 2019).

The fifth benefit is income from the wheeling charge. The study team roughly conducted a benefit analysis of wheeling charge, assuming a unit price of 1.0 cent/kWh for all candidate cross-border interconnections. The income from wheeling charge for 25 years in each candidate cross-border interconnection ranged from US$446 million to US$1,500 million. The total income from the wheeling charge is expected to be US$5,545 million.

Based on these benefits, the study team analysed the financial internal rate of return (FIRR), economic internal rate of return (EIRR), and net present value (NPV) of the Transmission Highway. The FIRR is 15.9%. In the case of a discount rate of 8%, the estimated results for the Transmission Highway are an NPV of US$859 million and a payback period of 8.9 years. For a discount rate of 10%, the results are an NPV of US$557 million and a payback period of 10.1 years. The FIRR is higher than Myanmar's long-term interest rate (9.5%). Furthermore, the EIRR is 13.9%. For a discount rate of 8%, the estimated results for the Transmission Highway are an NPV of US$2,170 million and a payback period of 9.9 years. For a 10% discount rate, the NPV is US$1,249 million and with a payback period of 11.9 years. The EIRR is also higher than 9% of the standard adopted by the Asian Development Bank (ADB). From these results, the Transmission Highway is financially and economically feasible.

Through this study, the Transmission Highway greatly benefits ACMECS countries. Multilateral power trade should be realised in the Association of Southeast Asian Nations (ASEAN) region to maximise such benefits. The ASEAN Power Grid (APG) aims to expand power trade gradually and ultimately achieve a total integrated Southeast Asia power grid system. Multilateral power trade is envisioned to take place in three subregions. In this stage, the subregion closest to the realisation of multilateral power trade amongst these three regions is the northern part, ACMECS. ACMECS countries have been discussing multilateral power trade within the framework of the Greater Mekong Subregion (GMS) for many years, and they have accumulated knowledge. In addition, the Lao PDR and Thailand are included in the Laos-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP) framework. Based on this experience, ACMECS as a pioneer will develop multilateral power trade on a subregional basis. The knowledge gained in ACMECS will be expanded to other subregions, the best way to realise the APG. After multilateral power trade is realised in the three subregions, it is expected to be developed throughout ASEAN as the APG. This study aims in that direction.

Chapter 1

Introduction

1.1. Background

The Association of Southeast Asian Nations (ASEAN) is one of the most dynamic and fastest-growing economic regions globally. According to the Energy Outlook and Energy Saving Potential in East Asia 2019 prepared by the Economic Research Institute for ASEAN and East Asia (ERIA, 2019), the power demand in ASEAN countries will considerably increase in line with the expected economic and population growth by gas and oil. Furthermore, as improving the electricity access rate is an important policy task in some countries such as Myanmar and Cambodia, power demand appears almost certain to increase in the future in line with rising living standards. Meanwhile, as the gross domestic product (GDP) is relatively low in this region, supplying electricity at the minimum possible cost is necessary.

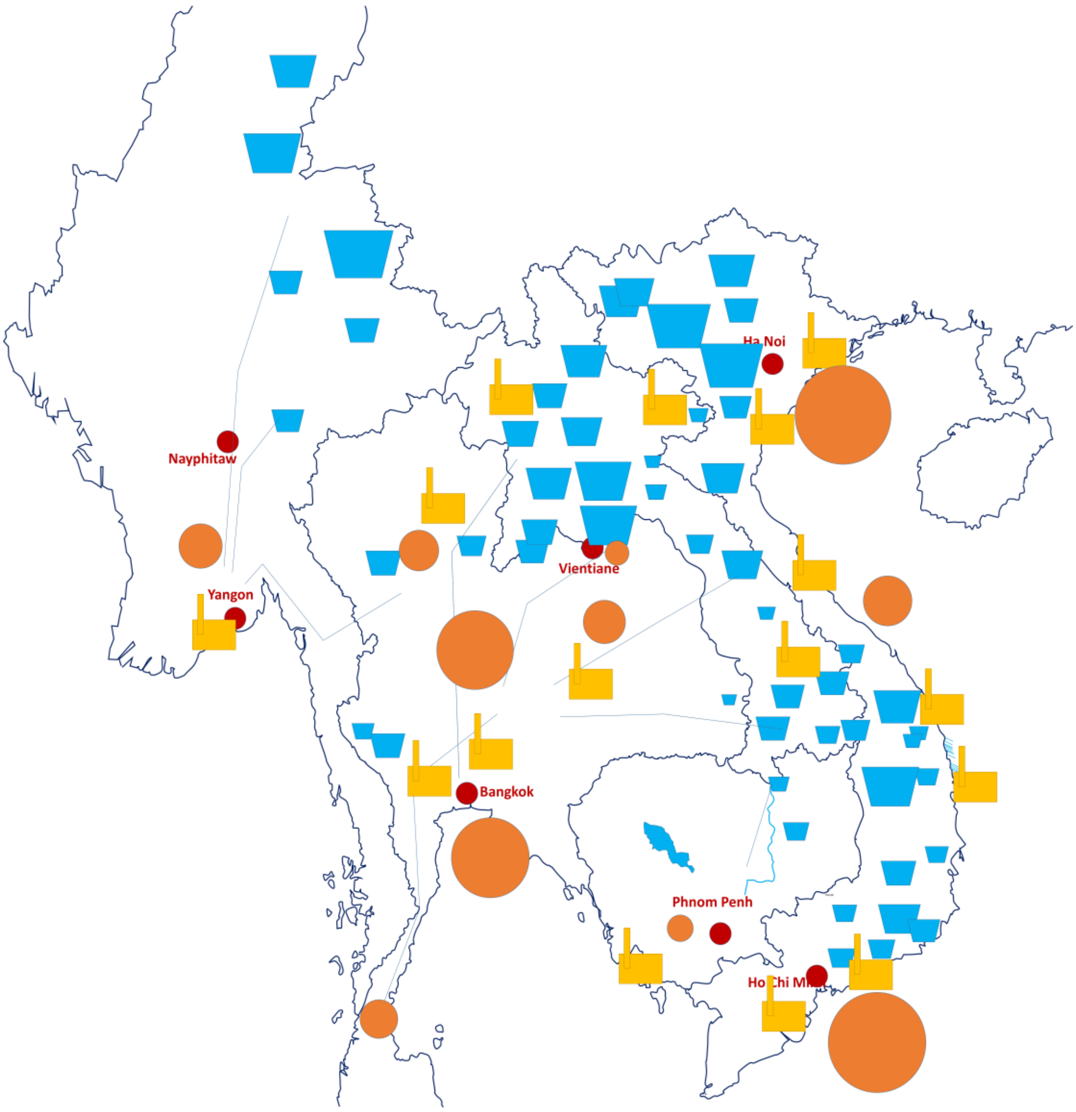
A country formulates a power development plan (PDP) on the premise of self-sufficiency in energy security. However, when power demand growth outstrips the capacity to supply necessary domestic resources such as manufacturing and human and financial resources, or when economically efficient power development is difficult due to some constraints, importing electricity from neighbouring countries should be considered.

In such a situation, energy resources vary in the Indochina region, so-called the Ayeyawady-Chao Phraya-Mekong Economic Cooperation Strategy (ACMECS): huge hydro potential in the Lao PDR and Myanmar, large gas potential in Myanmar, and coal potential in Viet Nam. But the abundant resources, especially hydropower, is underutilised because ACMECS countries have no existing bulk transmission network covering their entire area. Some cross-border interconnections already exist in ACMECS. Most of them are used as dedicated transmission lines for power purchase agreements. System-to-system interconnections also exist, but most are of low voltage; there is no 500 kV cross-border interconnection for mutual power trade.

To date, regional power trade has been limited to a series of uncoordinated bilateral arrangements. To economically use resources, the high-voltage transmission network and multilateral power trade system amongst the ACMECS countries are required. If high-voltage transmission network such as east–west and north–south could connect Cambodia, the Lao PDR, Myanmar, Thailand, and Viet Nam, power generation could be optimised in these five countries. A large amount of power trade through the utilisation of a high-voltage transmission network can bring multiple benefits, including reduced fuel costs of thermal power generation, reduced CO_2 emission, improved electricity access, and the ability to consolidate higher shares of variable renewable energy. In this study, the concept of this high-voltage transmission network through ACMECS countries is from now on called the 'Transmission Highway'.

ASEAN Member States (AMSs) have a long-standing goal of realising the ASEAN Power Grid (APG). The APG is an initiative aimed at constructing a regional cross-border interconnection to link the region, first, on cross-border bilateral terms, then gradually expand subregionally, subsequently leading to a total integrated Southeast Asia power grid system. The Transmission Highway will play a huge role in the APG initiative. In addition, ACMECS can become a pioneer in multilateral power trade in ASEAN.

Figure 1-1 Energy Resources in the Indochina Region



Source: Authors.

1.2. Objectives

The Working Group's study, 'Feasibility Study on the Transmission Highway in ACMECS', quantifies the benefits of regional optimisation by utilising the system-to-system high-voltage cross-border interconnections development in the ACMECS region. By doing so, the study provides clues for improving the efficiency of cross-border interconnection. The background of this study was developed by referring to the Greater Mekong Subregion (GMS) program of the Asian Development Bank (ADB), the APG program of the Heads of ASEAN Power Utilities/Authorities (HAPUA), the Study on Power Network System Master Plan in the Lao People's Democratic Republic by the Japan International Cooperation Agency (JICA, 2020b), thus making the study consistent with these existing initiatives.

Chapter 2

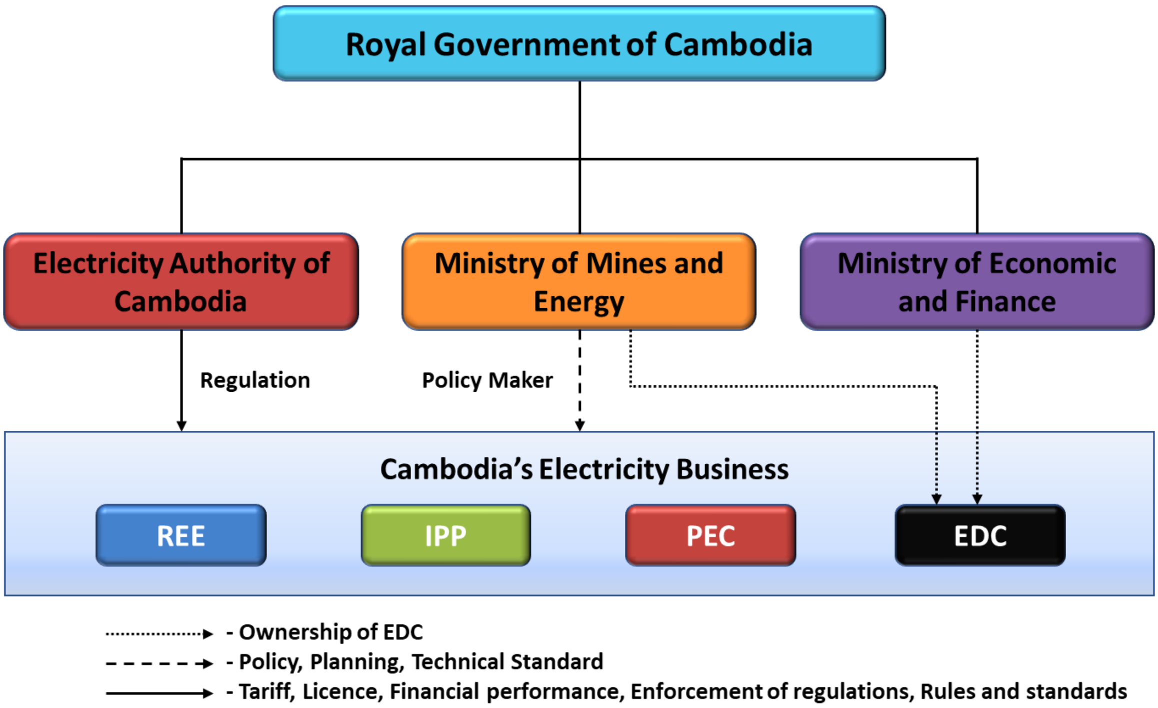
Current Situation of Power System in ACMECS Countries

2.1. Cambodia

2.1.1 Organisation of the Electricity Sector

The Electricity Law of the Kingdom of Cambodia (Electricity Law), issued on 2 February 2001, covers the totality of electricity business from electricity supply services to electricity use. It provides the fundamental concept of electricity business operation, consolidation of requirements for private investment and commercial operation, promotion of electric supply facility operation by the private sector, and rule of principle for a competitive environment. To actualise stable nationwide electricity supply services, the Electricity Law established the Electricity Authority of Cambodia (EAC). The EAC is an independent regulatory agency that executes duties provided in the Electricity Law and authorises the Ministry of Mines and Energy (MME) to manage, create policies, take necessary measures, and create plans for the power sector. Electricite du Cambodge (EDC) is the largest electricity business organisation in Cambodia and is involved in the generation and transmission of bulk electric power as well as electricity supply and distribution. The EDC is jointly owned by the MME and the Ministry of Economy and Finance. Major electricity enterprises, the MME, and the EAC are interrelated (Figure 2-1).

Figure 2-1 Organisational Structure of the Electricity Sector in Cambodia



REE = rural electricity enterprise, IPP = independent power producer, PEC = Provincial Electricity Company, EDC = Electricite du Cambodge
Source: Ministry of Mines and Energy (Cambodia).

1) Ministry of Industry, Mines and Energy

In 2013, the Ministry of Industry, Mines and Energy (MIME) was split into two ministries: the Ministry of Industry and Handicrafts and the MME. The MME shares electricity administration with the EAC, established under the Electricity Law in February 2001. The MME is also responsible for controlling the whole power sector. It sets and administers the energy policies; electric power strategies; power development plan; and technical, safety, and environmental standards.

2) Electricity Authority of Cambodia

The Electricity Authority of Cambodia (EAC) became independent of MIME to ensure effective, high-quality, continuous, and transparent conduct of the electricity business and electricity use per the Electricity Law of February 2001. The EAC is responsible for the regulation and guidance of the electricity business and operates on a stand-alone basis, supported by licensing fees from electricity enterprises. The main functions of the EAC are as follows:

- **Issue and suspend the business licence of electricity enterprises**
- **Approve electricity tariffs**
- **Plan electricity supply regulations**
- **Audit electricity enterprises**
- **Guide electricity enterprises on accounting standardisation**
- **Collect electricity business-related information and produce periodicals**

3) Electricite du Cambodge

The Electricite du Cambodge (EDC) was established in October 1958 as a public corporation when the Royal Government of Cambodia purchased the Compagnie des Eaux et Electricité, which supplied electricity to Phnom Penh, and the Union d' Electricité d' Indochine, which supplied areas other than Battambang. However, since most facilities were destroyed during the civil war, it was reconstructed as Electricité de Phnom Penh in 1979 under the Ministry of Industry to supply electricity to Phnom Penh. In 1992, the name was changed to the EDC and fell under the jurisdiction of the Ministry of Energy. Following the 1993 national election, it became under the jurisdiction of MIME. The ministerial ordinance of March 1996 turned it into a public corporation that generates, transmits, and distributes power throughout Cambodia.

4) Rural electricity enterprise

A rural electricity enterprise (REE) comprises private electricity companies. One group of REEs distributes self-generated electricity, and the other group purchases electricity from the EDC and IPPs and distributes it amongst residents of the area.

2.1.2 Power generation

2.1.2.1 *Oil and natural gas*

Cambodia has promising oil and gas resources. There is an urgent need to assess the extent of these energy resources and start their exploration. Renewable energy sources, such as solar, small hydro, and modern biomass, are available and being used. A large amount of traditional biomass is already being utilised, mainly in rural areas and some urban areas.

The Government of Cambodia has the policy to explore and utilise the country's national resources to enhance the security of energy supply to support the country's economic growth. The government expects to generate electricity from domestic gas by 2025. Table 2-1 shows the assumed production profiles of gas and oil resources in this study.

Table 2-1 Assumption of Natural Gas and Oil Production

Year	Natural Gas Production		Crude Oil Production	
	Million toe	MW/year	Million toe	MW/year
2025	0.5	666	0.5	666
2030	1.0	1,332	1.0	1,332
2035	2.0	2,664	2.0	2,664
2040	2.5	3,330	3.0	3,996

Source: MME data, modified by the author.

2.1.2.2 *Coal*

Cambodia has domestic coal resources, but it is of low quality (2,800 cal/kg–4,500 cal/kg). The country imports coal from Indonesia and Australia for the power and industry sectors. The future expansion plan of the power sector includes imported coal-based power plants. The gross heating value of imported coal is 6,210 cal/kg (net HV: 5,900 cal/kg). The imported coal price from Indonesia is US$85/tonne).

2.1.2.3 *Hydropower*

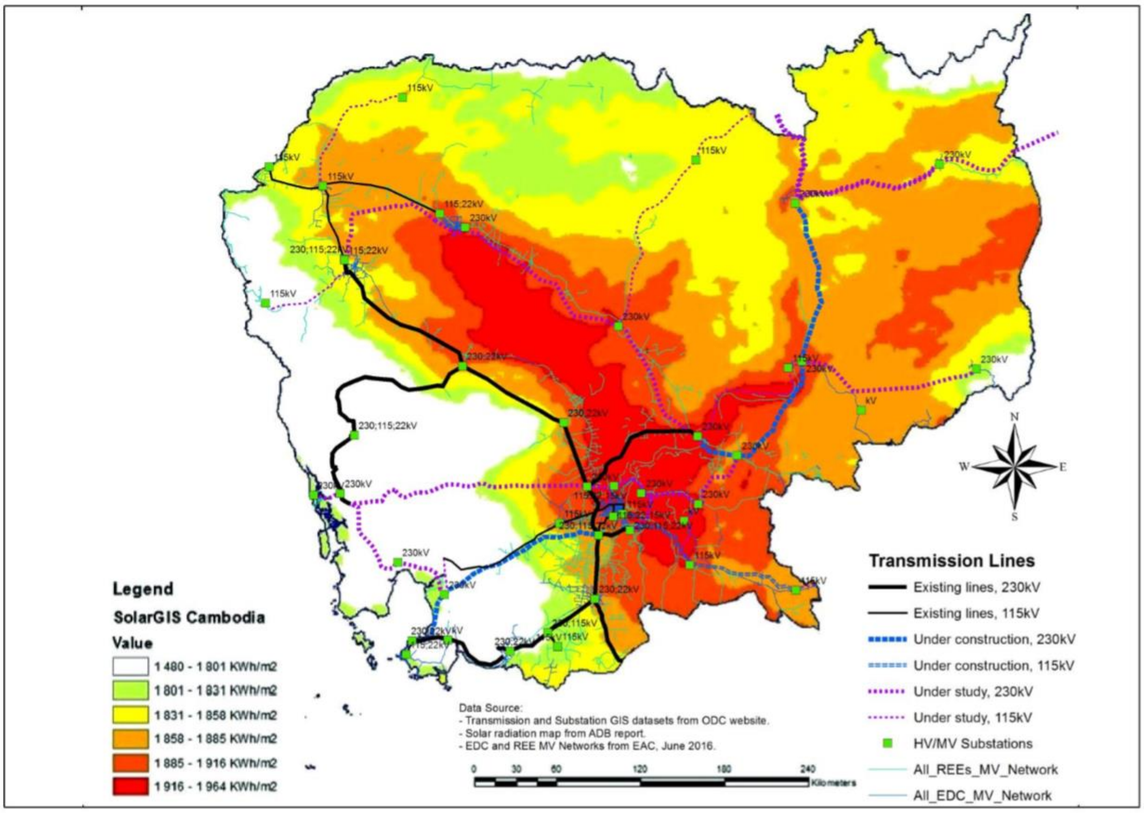
Cambodia has a good potential for hydropower at about 10,000 MW. Various small and medium-sized hydropower projects—Kirirom I, Ochum, Kirirom III, Kamchay, Atay, Lower Russei Chrum, Tatay, Lower Sesan II—are implemented, making about 13% of the potential. With a total installed capacity of around 1,300 MW, these projects would be fully operational by 2019. However, high investments in the construction of hydropower plants and sociopolitical issues hinder large-scale hydropower development. Feasibility and design engineering work on hydro projects is in progress.

The government aims to increase the diversification of power supply, such as hydropower, coal, solar, biomass, and other renewable energy resources. It also intends to limit imported electricity to meet the electricity demand and reduce fuel oil for power generation.

2.1.2.4 *Renewable energy*

Cambodia has excellent solar resources throughout the country. The white area on the map represents the solar radiation, ranging between 1,400–1,800 kWh/m2-year, which is considered very good to excellent. This is equal to or better than the solar resource in southern Europe, the coastal areas of eastern Australia, and the southeast United States (US). The peak solar resource (over 1,900 kWh/m2 per year) around the middle of Cambodia, the solar resource potential, existing, and planned transmission networks, and significant demand centres are well-aligned.

Figure 2-2 Cambodia Solar Radiation Map with Existing and Planned Transmission Network Lines



Source: EDC (2019).

Biomass energy resources are used to meet most of the country's rural population's basic needs (cooking, water heating, etc.). Besides fuelwood, agro-industrial residues such as rice, sugarcane, maize, and cattle excreta are available as fuel. Biomass is also used in the industry sector for copra drying and system generation, and the rice husks in bakeries, brickworks, and other commercial establishments.

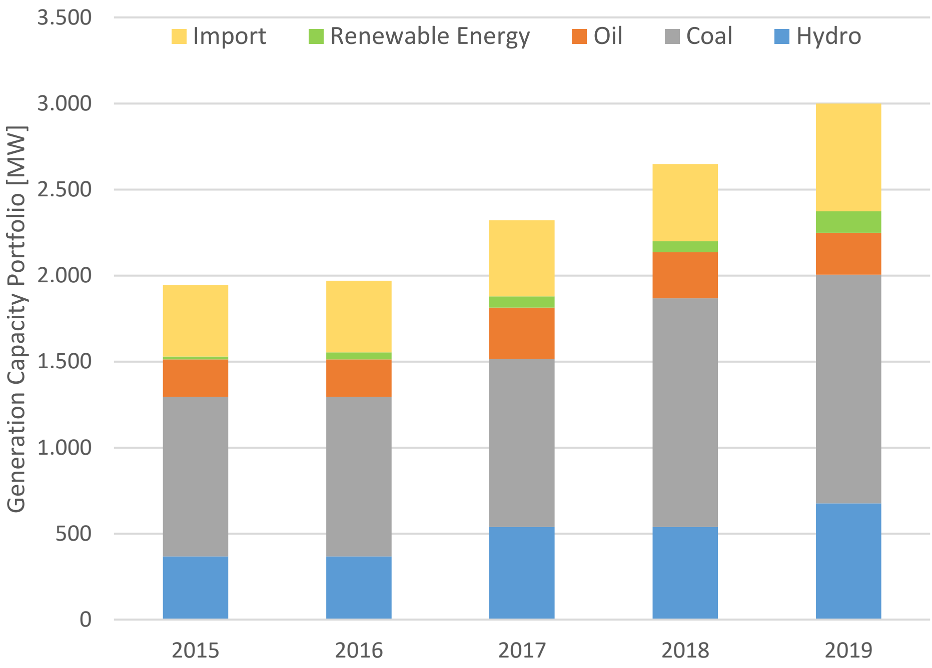
2.1.2.5 *Energy imports*

Due to years of civil war and unrest, little exploration and production activities took place; imports entirely met fuel needs. All commercial fuels in Cambodia are imported – from liquefied petroleum gas, gasoline, diesel, and other petroleum products. Cambodia imports electricity from the Lao PDR, Thailand, and Viet Nam. Due to limited energy resources, oil, natural gas, and electricity are assumed to be imported to meet future energy requirements.

2.1.2.6 *Power generation portfolio*

As of December 2015, the total installed capacity in Cambodia was 1,946 MW. It gradually increased from 2015 and reached 2,999 MW in 2019. The installed capacity growth rate from 2015 to 2019 was 54.1%. Generation relied on coal as the main fuel. The generation capacity of coal accounted for 44.3% in 2019. Next to coal was renewable energy except for hydro, which accounted for 22.5% in 2019. Figure 2-3 shows the generation capacity portfolio in Cambodia.

Figure 2-3 Generation Capacity Portfolio in Cambodia

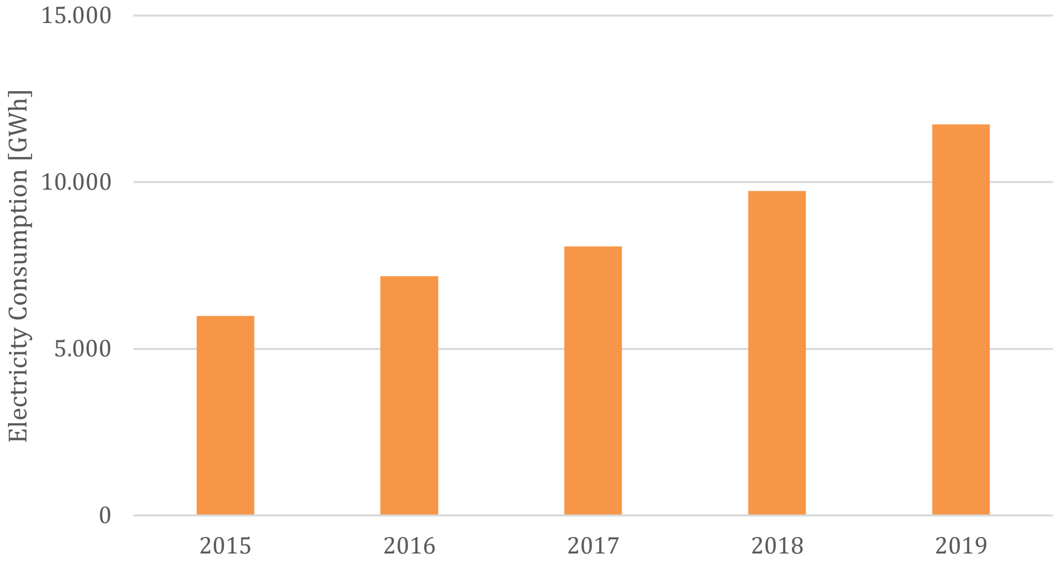


Source: MME data, modified by the author.

2.1.3 Power demand

Figure 2-4 shows the changes in electricity consumption in Cambodia. The electricity consumption in 2015 was 5,990 GWh. However, it skyrocketed from 2015 and reached 11,738 GWh in 2019. Thus, the electricity consumption growth rate from 2015 to 2019 was about 96.0%.

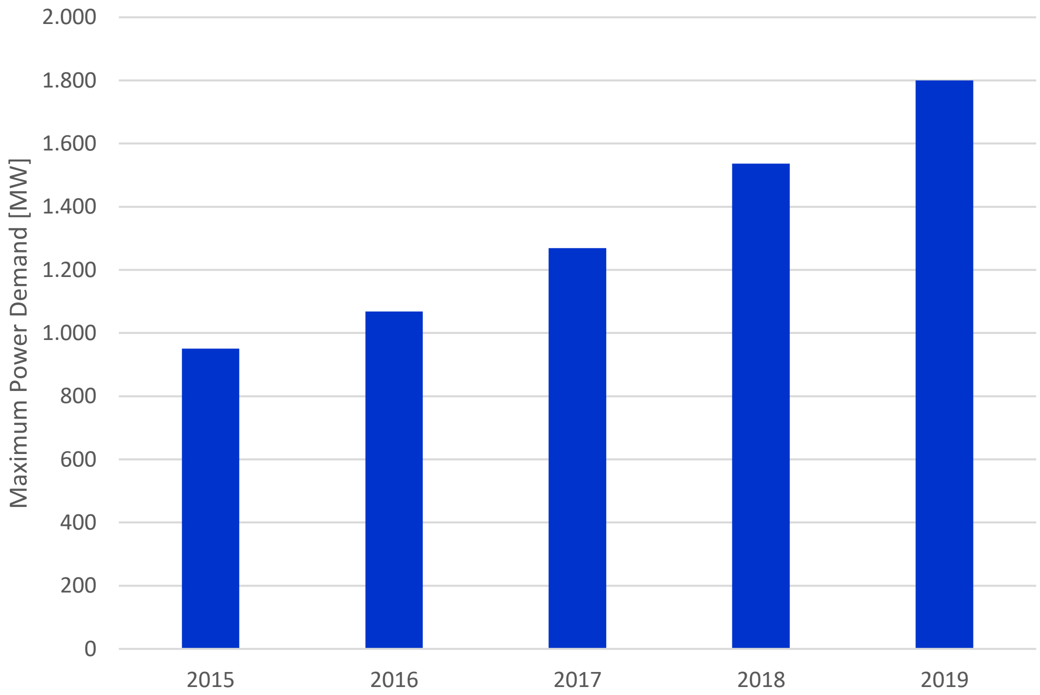
Figure 2-4 Changes in Electricity Consumption in Cambodia



Source: MME data, modified by the author.

The changes in maximum demand is shown in Figure 2-5. Maximum power demand in 2015 was 951 MW. It skyrocketed from 2015 and reached 1,800 MW in 2019. The demand growth rate from 2015 to 2019 was 89.3%.

Figure 2-5 Changes in Maximum Demand in Cambodia



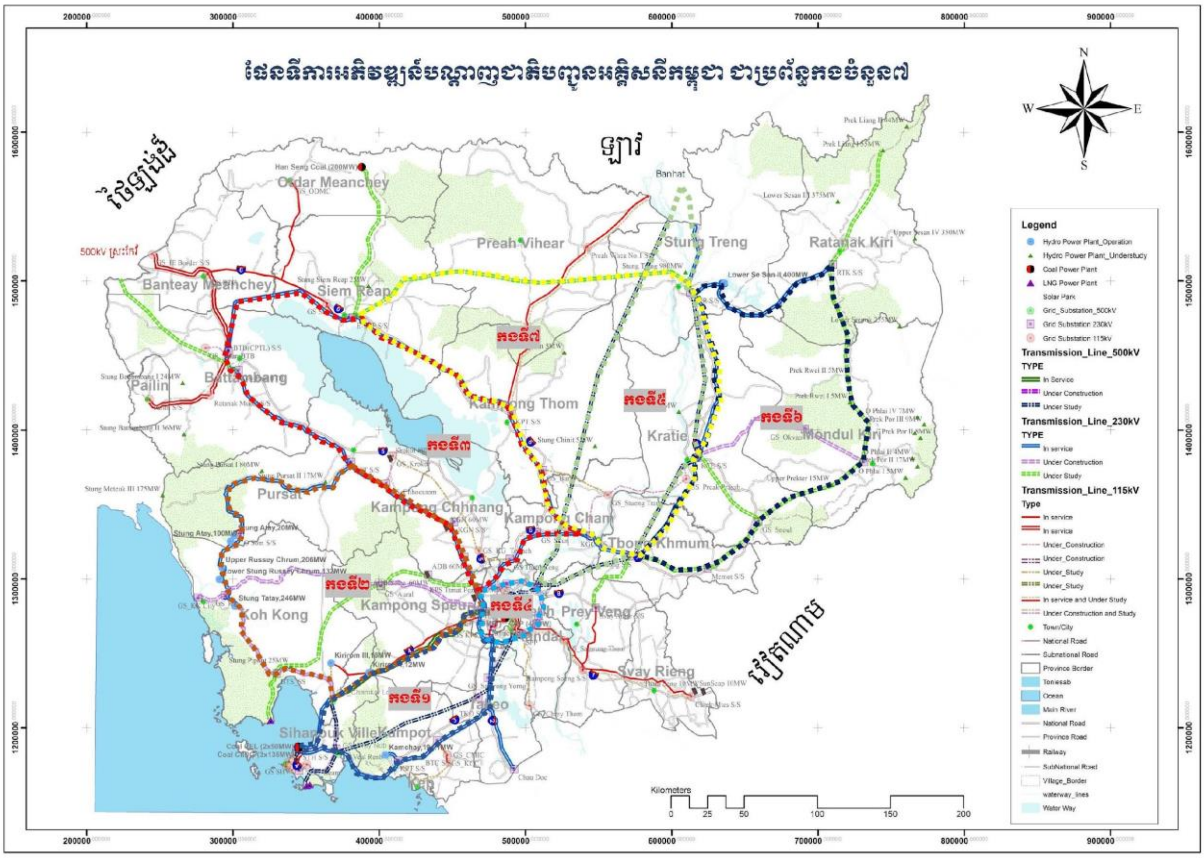
Source: MME data, modified by the author.

2.1.4 Overview of the transmission network

In the Cambodia Transmission System (CTS), electric power demand is overconcentrated in the Phnom Penh metropolitan area; major generators supplying electricity are about 200 or 300 km away from the Phnom Penh demand centre. Surrounded by three neighbouring countries – the Lao PDR, Viet Nam, and Thailand – Cambodia can import electric power from these countries. However, it cannot be connected simultaneously to Thailand's or Viet Nam's power system except with the Lao PDR, which only provides generators. Therefore, if Cambodia would import electric power from both Viet Nam and Thailand, it would be indispensable for the CTS to separate the power system somewhere. The CTS only has 230 kV or less transmission lines for now, but it will be necessary to build a 500 kV transmission line to meet the massive growth of electric demand in the near future.

The power grid map in Cambodia is shown in Figure 2-6.

Figure 2-6 Power Grid Map of Cambodia



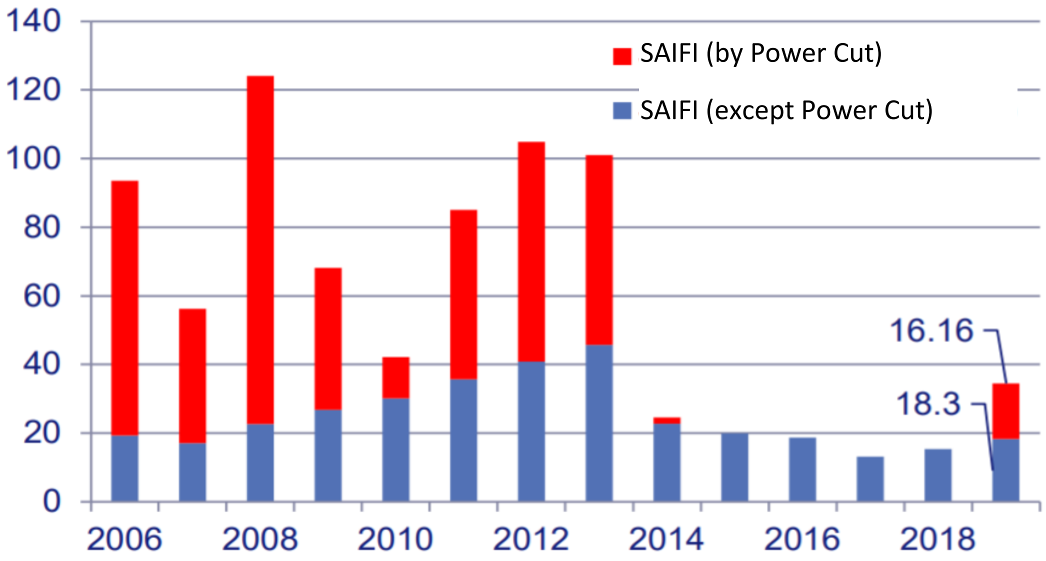
Source: Author via Ministry of Energy and Mines (MEM), Lao PDR.

2.1.5 Power system reliability

The System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI) are international standards used to monitor the distribution systems' reliability. SAIDI is a system index of the average duration of interruption in the power supply in minutes per customer. SAIFI is a system index of the average frequency of interruption in the power supply. These indices serve as valuable tools for comparing the power system reliability of electrical utilities.

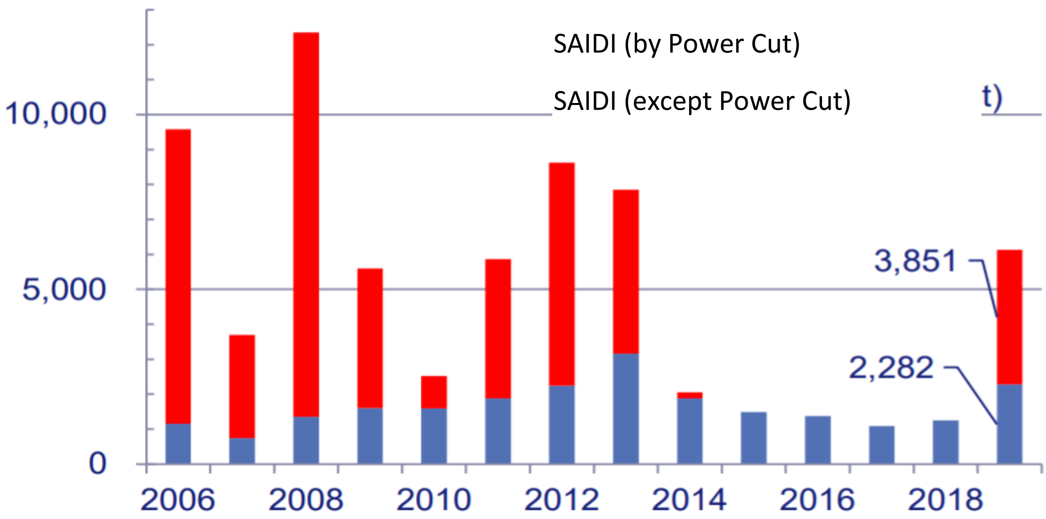
Figures 2-7 and 2-8 show changes in SAIFI and SAIDI in Cambodia, respectively. Before 2014, power outages due to faults and load shedding caused by insufficient supply capacity occurred frequently. Since 2015, the situation has improved, and load shedding has disappeared until 2018. SAIFI in 2015 was about 20 times. It decreased from 2015 to 2018. SAIDI in 2015 was about 1,500 minutes and steadily declined from 2015 to 2018. According to JICA, the power supply became insufficient due to drought, and the load shedding was operated again. Thus, Cambodia's SAIFI and SAIDI are low compared to developing countries (ERIA, 2020).

Figure 2-7 Change in SAIFI in Cambodia



SAIFI = System Average Interruption Frequency Index.
Source: JICA (2020a).

Figure 2-8 Change in SAIDI in Cambodia

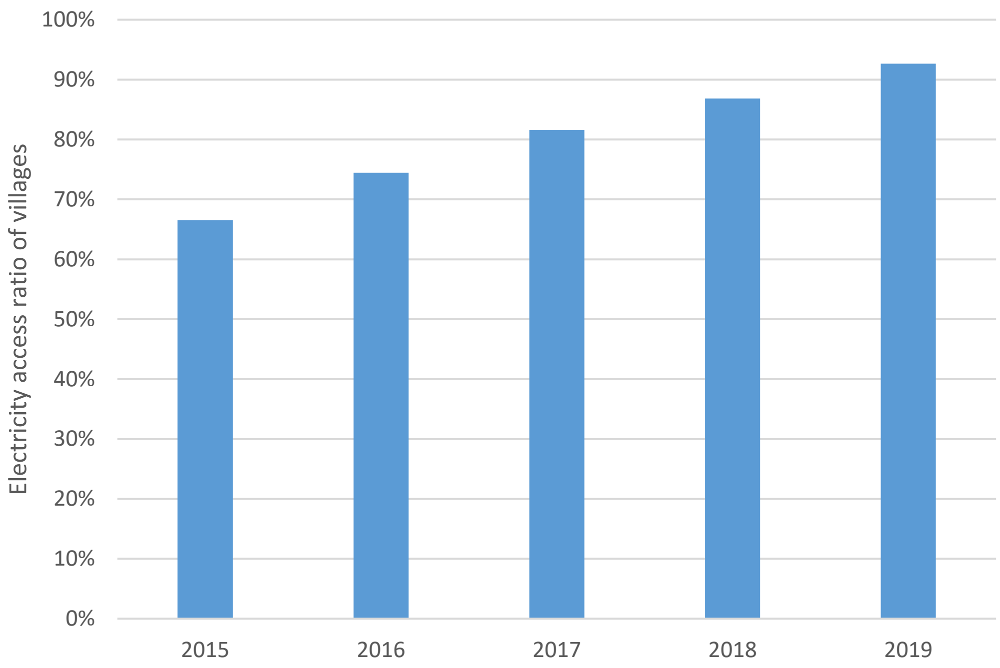


SAIDI = System Average Interruption Duration Index.
Source: JICA (2020a).

2.1.6 Electricity access

Cambodia is amongst the countries in ASEAN with a low electricity access ratio. Figure 2-9 shows the change in the electricity access ratio of villages in Cambodia: from 66.6%, it steadily increased and reached 92.7%. However, this data is just the electricity access ratio of the village; even if the village is electrified, not all households are. According to the MME, households' electricity access ratio is about 20% lower than villages. The MME planned to achieve 100% electricity access of villages in 2020 and at least 70% electricity access of households by 2030. However, the electricity access ratio is still low. Therefore, this study will also analyse the impact of electricity access on GDP in Cambodia.

Figure 2-9 Change in Electricity Access Ratio of Villages in Cambodia



Source: EAC data, modified by the author.

2.1.7 Overview of the power development plan

2.1.7.1 *Background*

The annual increase of nationwide electricity sales from 2012 to 2018 rose 17.6% because of the steady increase in Cambodia's economic growth. Imported electricity from the Lao PDR, Thailand, and Viet Nam was 16.1% of all generated electric power in 2018. In 2017, the first solar power (10 MW) was connected to Cambodia's power grid. Under such a situation, generation development planning has a crucial position in the revision of the power development master plan.

2.1.7.2 *Basic policy*

The basic policy for generation development planning is as follows:

- ❖ Reduce the energy dependency on other countries
  - Utilise hydro potential as much as possible
  - Produce domestic resource
- ❖ Avoid too much overflow or surplus generation at hydropower plants during the rainy season
- ❖ Assume 'no power export' because of the uncertainty of wide-area coordination
- ❖ Consider renewable energy such as wind, solar, and biomass power
- ❖ Finish heavy fuel oil plants when their contracts end.

2.1.7.3 *Peak demand and supply balance*

In general, several approaches exist for reliability evaluation; some are deterministic, and others are probabilistic. The desirable approach depends on the demand size and database quality. The consultants followed the 'N-1' reliability criterion described in the Cambodian grid cord. This is one of the deterministic methods. This concept is to supply capacity sufficiently with no load reduced even if the largest unit experiences forced outage at peak demand. This approach is appropriate for a growing power system like Cambodia because the unit capacity tends to be dominant than the demand size; the statistical data might also be less.

2.1.7.4 *Overview of the power development plan*

The PDP should be linked with the Transmission Development Plan. Therefore, the Generation Development Plan summary is presented with the result of the Transmission Development Plan. Table 2-2 shows PDP 2020–2030 in Cambodia. In the PDP, new power plants that will operate in November and December next year are listed.

The total installed capacity will skyrocket to 17,279 MW by 2030, including the existing generation capacity (as of 2019) of 2,999 MW, the new generation capacity of 14,280 MW, and the retiring generation capacity of 478 MW. Thus, it will be 5.8 times the installed capacity in 2019.

Table 2-2 Power Development Plan 2020–2030 in Cambodia

Year	Plan	Capacity [MW]	Total Installed capacity [MW]
2020	1. Import from Lao PDR by 115kV	50	3,893
	2. Don Sahong Hydro Lao PDR	195	
	3. Solar Schenitec Kampong Speu + Pursat	20 + 30	
	4. Attapeu Hydro Lao PDR (Part 1)	100	
	5. Import from Thailand by line 115kV	50	
	6. Import from Loa by 115kV	50	
	7. Disel Oil Phnom Penh	400	
	8. Solar Bavet + Battambang + Banteay Meanchey	20 + 60 + 30	
2021	1. Coal Oddor Meanchey (Part 1)	100	4,313

	2. Solar Schneitec Kampong Chhnang + Pursat 3. New Solar	60 + 60 100 x 2	
2022	1. Coal Oddor Meanchey (Part 2) 2. Attapeu Hydro Lao PDR (Part 2) 3. Solar Kampong Chhnang ADB 4. Import from Thailand by line 500 kV 5. Reduce imports from Thailand by 115 kV 6. Coal CIIDG (Part 1) 7. Bio Mass Phnom Penh 8. Complete Disel Oil Engine COLBEN	100 150 60 300 -45 180 350 100 -10	5,183
2023	1. Import from Thailand by 500 kV 2. Reduce imports from Viet Nam 3. Pursat River 1 4. Coal CIIDG (Part 2)	200 -200 80 350	5,613
2024	1. Complete Disel Oil Engine KEP -43MW 2. Attapeu Hydro Lao PDR (Part 3) = 250MW 3. Coal Royal Group (Part 1) 350MW 4. Wind Blue Circle 80MW 5. Coal TSBP Laos (Part 1) 350MW	-43 250 350 80 350	6,600
2025	1. Complete Disel Oil Engine CEP 2. Coal Royal Group (Part 2) 3. Coal TSBP Laos (Part 2) 4. Coal XTPPCL Laos (Part 1)	-45 350 350 350	7,605
2026	1. Ta Tai Leu River 2. Import from Thailand by 500 kV 3. New Solar 4. Coal XTPPCL Loa (Part 2) 5. Russey Chrum Kandal + Veal Thmor Kombot	150 200 100 350 x 2 170	8,925
2027	1. Gas turbine CCGT-CIIDG (Part 1) 2. Coal XTPPCL Loa (Part 4+5) 3. New Solar	600 350 x 2 100	10,325
2028	1. Gas turbine CCGT-CIIDG (Part 2) 2. Coal XTPPCL Loa (Part 6) 3. New Solar 4. SREA PORK Hydro 3A+3B	600 350 200 300 + 68	11,843
2029	1. LOWER SENSAN KROM 3 Hydro 2. STUENG METUEK Hydro 3. Import from Thailand by 500 kV 4. Prek La-Arng Hydro 1+2 5. New Gas turbine CCGT 1 6. New Solar 6, 7, 8	260 100 300 72 + 56 600 200 x 3	13,831
2030	1. New Gas turbine CCGT 2, 3, 4 2. Srea Pork Krom 4 Hydro 3. Stueng TrengNG Hydro 4. New Solar 9	600 x 3 48 1,400 200	17,279

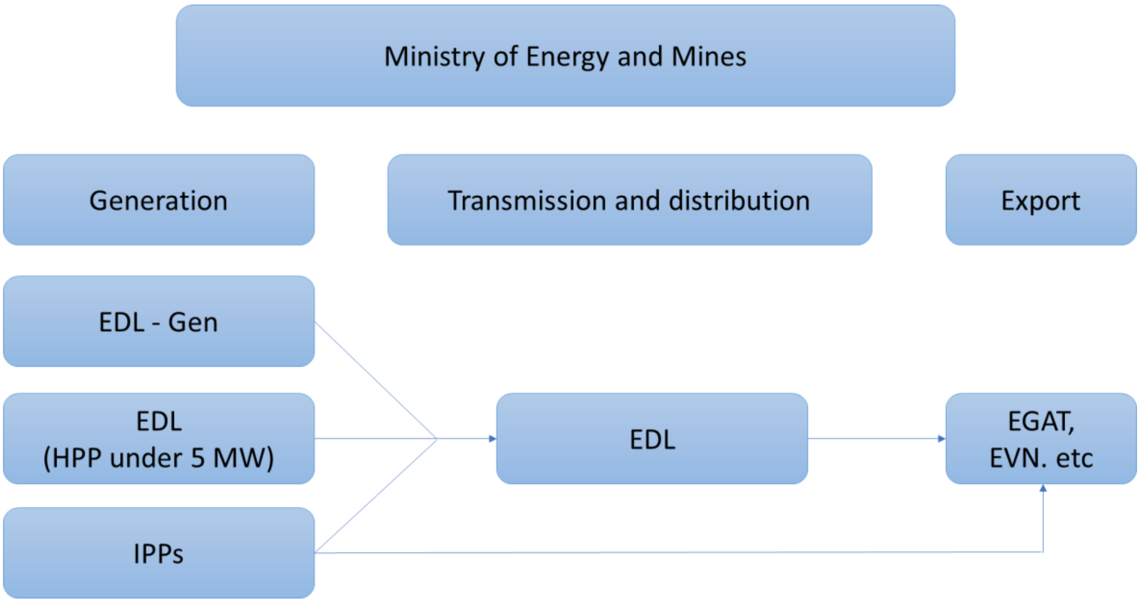
Source: MME data, modified by the author.

2.2. Lao PDR

2.2.1 Organisation of the electricity sector

Figure 2-10 shows the organisational structure of Lao PDR's electricity sector.

Figure 2-10 Organisational Structure of Lao PDR's Electricity Sector



EDL = Electricité du Laos, EDL-Gen = EDL-Generation Public Company, IPP = independent power producer, EGAT = Electricity Generating Authority of Thailand, EVN = Viet Nam Electricity.
Source: JICA (2020b).

1) Ministry of Energy and Mines

The Ministry of Energy and Mines (MEM) of the Lao PDR is the principal authority managing the electricity sector. It has the power to develop and implement laws and regulations governing the sector. Furthermore, in the absence of an independent power sector regulator, the ministry regulates the electricity tariffs. Figure 2-11 illustrates the central departments under MEM.

Figure 2-11 Organisational Structure of MEM (Overview)

Source: JICA (2020b).

2) Electricité du Laos (EDL) is a state-owned electric power utility supplying electricity to domestic consumers through its transmission and distribution lines. The EDL also manages the import and export of electricity. It buys power from several domestic IPPs, EDL-Gen, and from abroad, and exports electricity to neighbouring countries.
3) The EDL-Generation Public Company (EDL-Gen) is an electricity generation company and a subsidiary of the EDL. The EDL-Gen aims to (i) generate energy for the EDL from power plants with a capacity above 5 MW; (ii) invest in or set up joint ventures with other electricity generation projects; and (iii) provide management and maintenance services for other electricity projects.

4) Lao Holding State Enterprise

The Lao Holding State Enterprise is a state-owned enterprise that holds, owns, and manages its shares of four power project companies on behalf of the government.

5) Ministry of Planning and Investment

The main function of the Ministry of Planning and Investment (MPI) is to coordinate with the government's line ministries to prepare for their respective socio-economic development strategies. The MPI is also responsible for implementing investment strategies, promoting regulations, and approving overall investment.

6) Ministry of Finance

The Ministry of Finance defines the financial environment in the country. It determines policies that set the appropriate tax and duties for land use or equipment import.

7) Ministry of Natural Resources and Environment

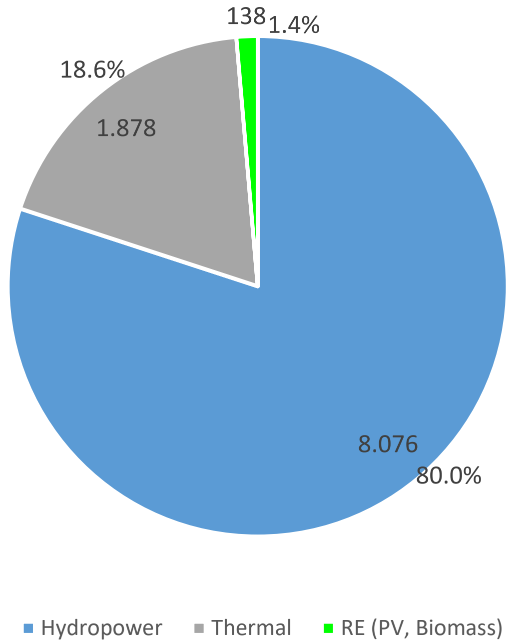
The Ministry of Natural Resources and Environment has overall responsibility for developing and implementing the Reduction of Emissions from Deforestation and Forest Degradation (REDD) and overseeing the management of the forestry sector in the Lao PDR.

2.2.2 Power generation

The Lao PDR has a large potential for hydropower generation. As of 2020, the total installed capacity in the Lao PDR was 10,091 MW, of which 3,734 MW was for domestic use. The total installed capacity portfolio and the total installed capacity portfolio for domestic use are shown in Figures 2-12 and 2-13, respectively. The Lao PDR relies on hydropower as the primary source of generation. The installed capacity of 5 MW or more hydropower accounted for 80%. Next to hydropower was thermal power, which accounted for 18.6%.

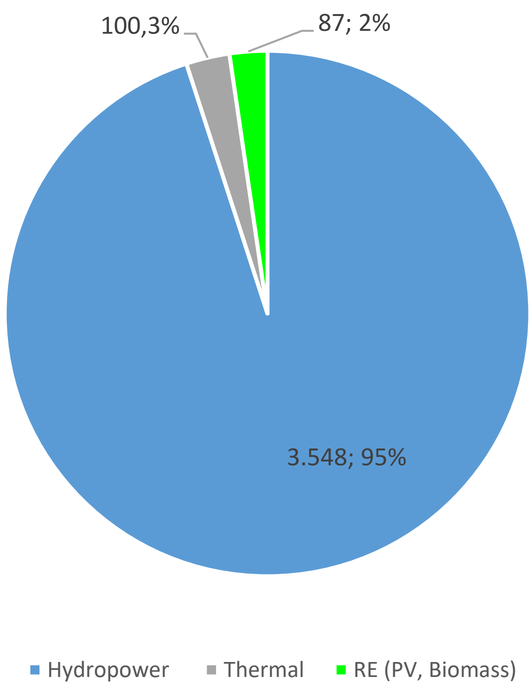
The installed capacity of renewable energy, except for large hydropower, was 138 MW, accounting for 1.4%.

Figure 2-12 Installed Capacity Portfolio in the Lao PDR (as of 2020)



PV = photovoltaic, RE = renewable energy.
Source: MEM data, modified by the author.

Figure 2-13 Installed Capacity Portfolio for Domestic Use in the Lao PDR (as of 2020)

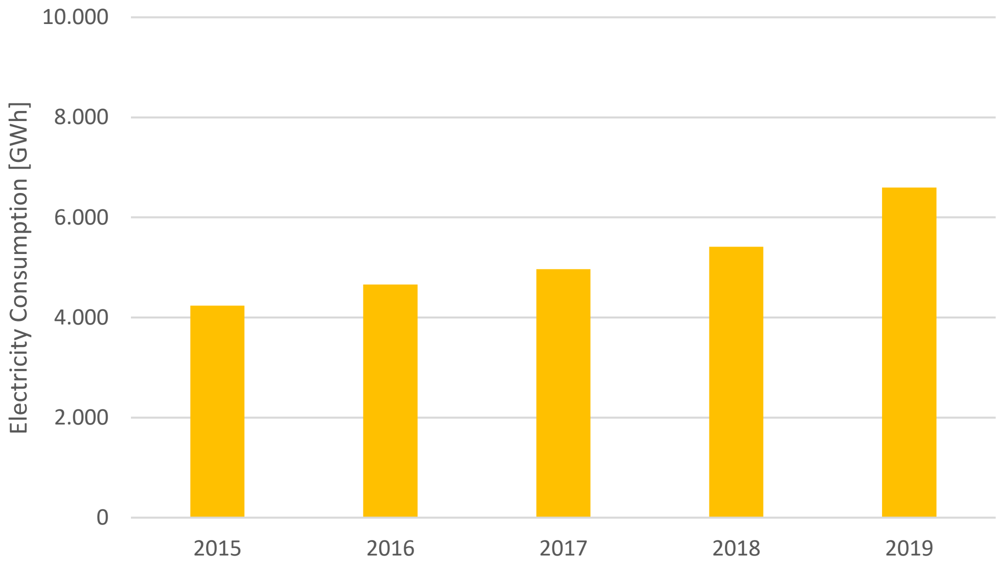


PV = photovoltaic, RE = renewable energy
Source: MEM data, modified by the author.

2.2.3 Power demand

Figure 2-14 shows the changes in the country's electricity consumption. The electricity consumption in 2015 was 4,239 GWh. It steadily increased from 2015 and reached 6,596 GWh in 2019. The electricity consumption growth rate from 2015 to 2019 was about 55.6%.

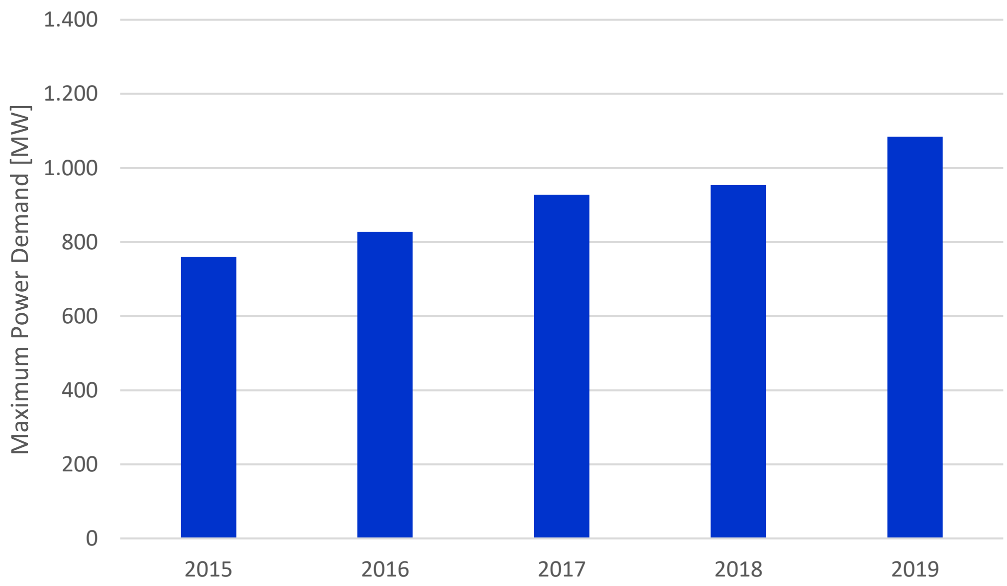
Figure 2-14 Changes in Electricity Consumption in the Lao PDR



Source: MEM data, modified by the author.

Figure 2-15 shows the changes in maximum demand. The maximum power demand in 2015 was 760 MW. It steadily increased and reached 1,085 MW in 2019. The demand growth rate from 2015 to 2019 was approximately 42.8%.

Figure 2-15 Changes in Maximum Power Demand in the Lao PDR



Source: MEM data, modified by the author.

2.2.4 Overview of the transmission network

The current power system comprises transmission and distribution lines at 500 kV, 220 kV, 115 kV, 33 kV, 22 kV, and low voltage. However, the domestic power supply system as of 2017 comprised transmission lines with less than 230 kV because the 500 kV transmission lines are used as a dedicated line to export power to neighbour countries.

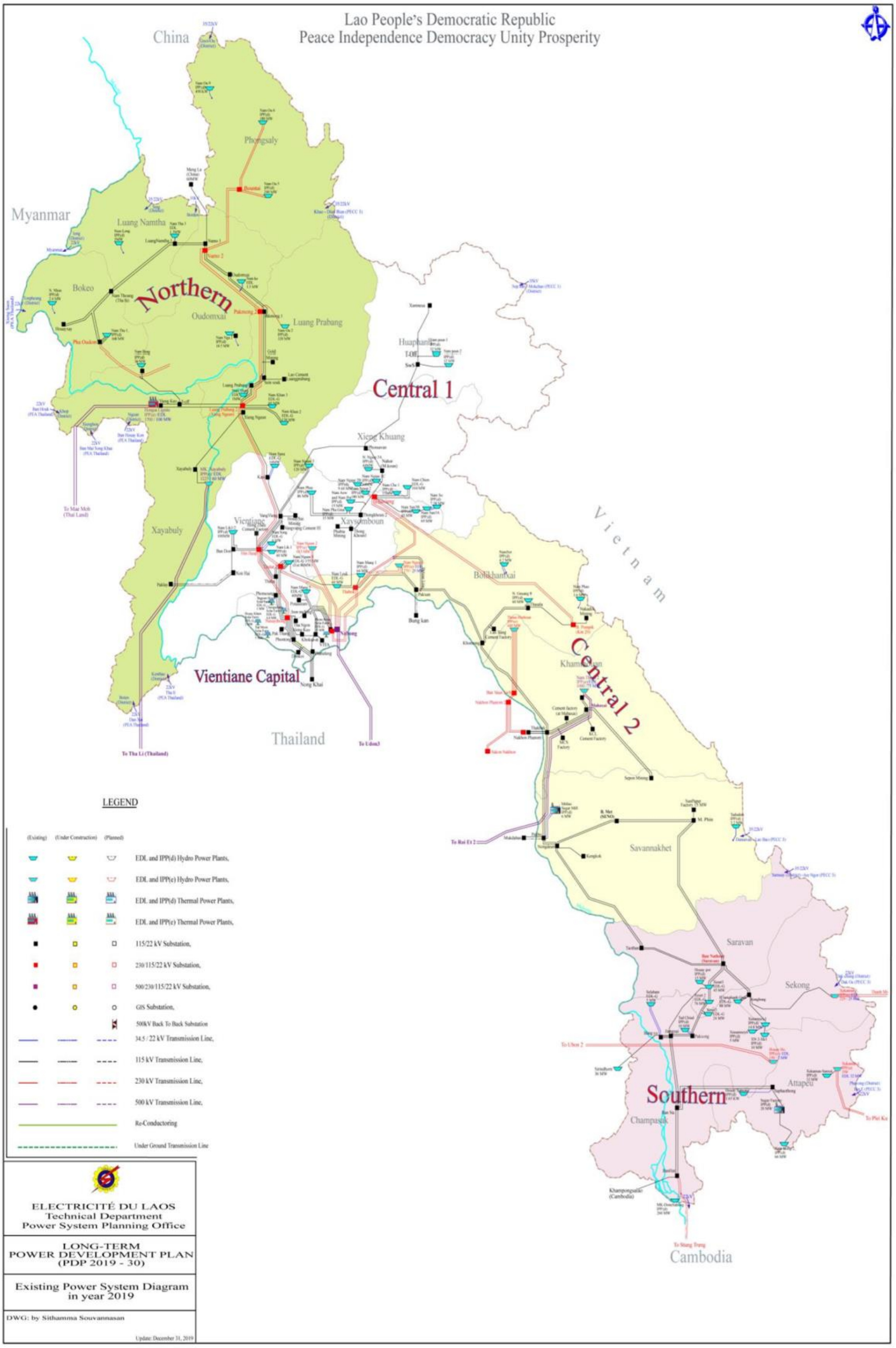
Since the Nam Ngum 1 power station was built in the 1970s and a 115 kV transmission line between Thailand and the Lao PDR was constructed, power generated in the Lao PDR had been exported to Thailand in the wet season, when hydropower generation is abundant. Power is imported from Thailand in the dry season when the generating power is insufficient to meet domestic power demand. In addition, the 115 kV Thakek substation (hereinafter referred to as 'S/S') and Pakbo S/S in Central-2 Area directly received power from Thailand because the interconnection lines between each area (i.e. Northern, Central-1, Central-2, and Southern) had not been constructed. Therefore, the power grid in the Lao PDR was connected to the power grid in Thailand. Power output from power plants and the protection of power flow in the interconnection line between Thailand and the Lao PDR had been controlled by instructions from the national control centre in Thailand.

Recently, the 115 kV transmission line from the independent Northern area to Central-1 area was extended, and transmission and substation facilities connecting Central-2 and Southern started operation in 2016. This means that a single national grid with 115 kV and 230 kV transmission lines were finally actualised by the interconnection line from the Northern Area to the Southern Area via the Central Area. Additionally, 230 kV transmission lines have been adapted for the domestic power supply system due to the increase in power demand and power development in the Northern Area. Also, a 230 kV transmission line between Vientiane, Luang Prabang, and Namo substations has started operation. Furthermore, the national control centre in Vientiane operates the domestic power system in the Lao PDR and collaborates with the Khon Kaen substation in Thailand.

The 500 kV transmission line between Na Bong S/S and Udon 3 S/S in Thailand currently operates at 230 kV and imports power only from Nam Ngum 2 power station (hereinafter referred to as 'P/S') to the Electricity Generating Authority of Thailand (EGAT). Although the Nam Ngum 2 P/S company owns this transmission line, the power generated at the Nam Ngiep 1 power plant was also connected to this line in 2019. To interconnect with neighbouring countries, there are 500 kV and 230 kV transmission lines for direct export of power from IPPs and a 115 kV transmission lines between the EDL and EGAT grids. In addition, the Lao PDR and neighbouring countries trade power by supplying from the domestic power grid and 35 kV and 22 kV distribution lines, which are adopted in areas that are not serviced by the domestic power grid and are more than 115 kV transmission line, such as areas located near the national border.

Figure 2-16 shows the power system and interconnection lines, including projects under construction, in the Lao PDR as of December 2019. In addition, Table 2-3 shows the EDL's transmission line and substation facilities.

Figure 2-16 Power Grid Map of the Lao PDR



Source: MEM data.

Table 2-3 EDL's Transmission Line and Substation Facilities (as of 2020)

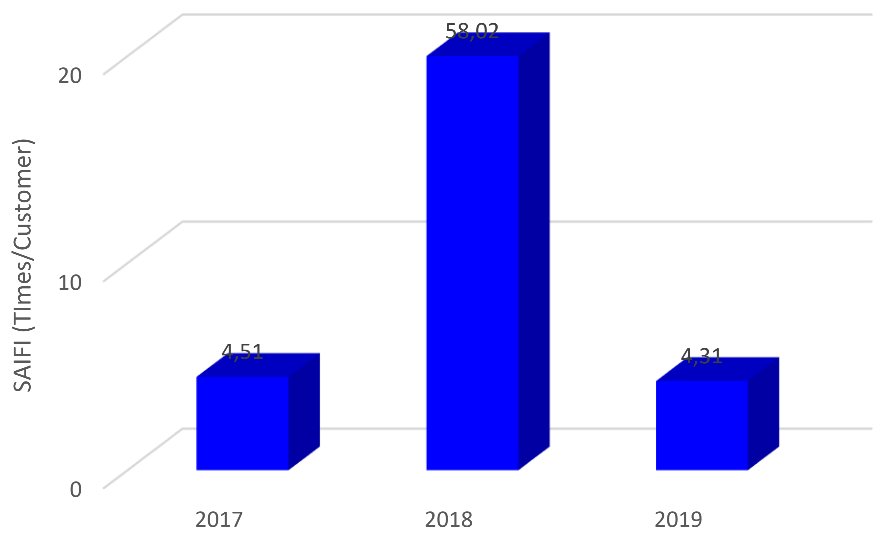
Regional	230 kV and 115 kV substation		230 kV and 115 kV transmission line	
	Number	TR Capacity (MVA)	Circuit number	Length (cct km)
Northern	40	3,240	107	4,982
Central 1	10	1,372	28	773
Central 2	14	826	40	2680
Southern	10	510	26	1387
Whole country	74	5,948	201	9,822

Source: MEM data, modified by the author.

2.2.5 Power system reliability

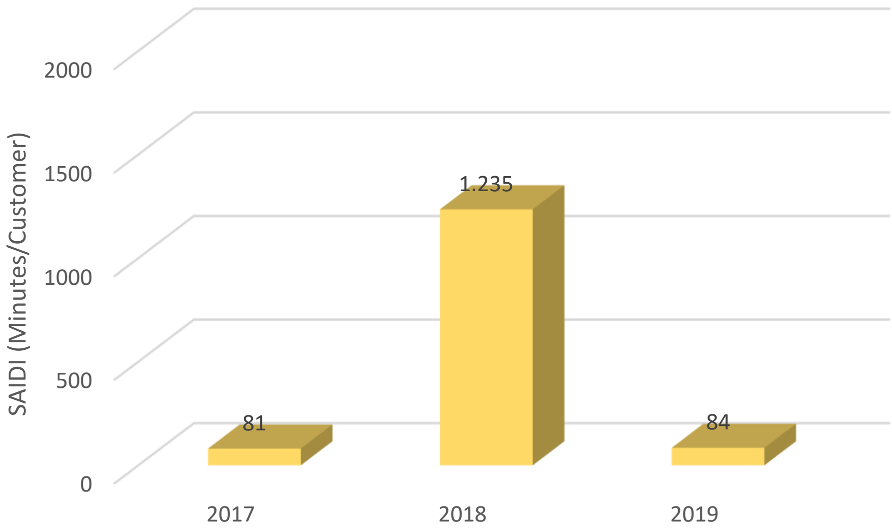
Figures 2-15 and 2-16 show changes in the SAIFI and SAIDI of the Lao PDR, respectively. The SAIFI in 2017 was 4.51 times; that of 2019 was 4.31 times and remained at almost the same level. On the other hand, the SAIDI in 2017 was 81 minutes, and that in 2019 was 84 minutes. It also stayed at nearly the same level. However, both the SAIFI and SAIDI skyrocketed in 2018. The SAIFI was 58.03 times, which was about 13 times higher than in 2017. The SAIDI was also 1,235 minutes, about 15 times higher than in 2017. The power outage in 2018 was thought to be more damaging than that in 2017. Although the SAIDI and SAIFI in 2017 and 2019 were lower than in developed countries, they are considered relatively high than other developing countries (ERIA, 2020).

Figure 2-17 Change in SAIFI of the Lao PDR



Source: MEM data, modified by the author.

Figure 2-18 Change in SAIDI of the Lao PDR



Source: MEM data, modified by the author.

2.2.6 Overview of the power development plan

MEM is responsible for general contracting in the power sector, and EDL is responsible for power purchase agreements for domestic power. The provincial or city government approves power generation projects whose general capacity is under 5 MW. The regional government handles those whose general capacity is under 0.1 MW with technical approval from regional technical departments.

According to JICA (2020b), MEM published the PDP in 2017. In this plan, approximately 14 GW will be exported, while 17 GW will be used domestically. Since the current total capacity is about 7 GW, the Lao PDR will have about 4.6 times the capacity in 2030. The reason for such a huge power generation plan was that the government did not manage it based on the overall supply and demand when it issued licences for power plants. Each power generation company planned it individually. The government also views such an excessive power supply plan as a problem. Considering the sluggish demand in the Lao PDR and the prospect of exporting electricity to Thailand, in March 2019, the Prime Minister, through the secretariat, directed the ministers of planning and investment, energy and mines, natural resources and environment, the mayors, and the prefectural governors to review the power supply plan.

On account of such a situation, in March 2019, the Prime Minister's office announced to the chief of each department concerned that the government would suspend or stop for 2 years the development of projects that are not economically sound for capacities less than 5 MW and renewable energy projects.

In April 2019, the Energy Promotion and Development and Ethnic Group Development Plan, both under MEM, and the EDL submitted the domestic generation plan up to 2030 to the ministry. In the new plan, no more than five new projects are to be developed until 2030 aside from those already under way to minimise surplus electricity. The total capacity for domestic use in 2030 is expected to be 6 GW, approximately one-third of the previous plan (JICA, 2020b).

Per the PDP, the total installed capacity will increase to 13,952 MW by 2030, including the existing generation capacity (as of 2020) of 10,091 MW (Table 2-4). It will be about 1.4 times the total installed capacity in 2020.

Table 2-4 Power Development Plan in the Lao PDR (as of 2019)

Year	Region	Total Capacity [MW]	Capacity [MW]	
			Domestic	Export
2025	Total	13,952	5,845	8,107
	North	8,290	3,916	4,374
	Central 1	651	651	0
	Central 2	2,729	497	2,232
	South	2,282	781	1,501
2030	Total	13,952	5,575	8,377
	North	8,290	3,496	4,374
	Central 1	651	651	0
	Central 2	2,729	497	2,232
	South	2,282	931	1,501

Source: JICA (2020b), modified by the author.

2.1 Myanmar

2.3.1 Organisation of the electricity sector

2.3.1.1 *The Policy of the Ministry of Electricity and Energy*

The Ministry of Electricity and Energy (MoEE) was organised on 1 April 2016 by merging the Ministry of Electric Power and the Ministry of Energy. To efficiently apply all possible opportunities for Myanmar's electricity and energy sector, the MoEE is developing a draft policy called the Myanmar Electricity and Energy Policy.

The draft states that the following measures should be taken during extraction and utilisation of natural resources to fulfil the country's energy needs:

- Minimise the environmental impacts
- Include sustainable utilisation plans for future generations
- Invite local and foreign investments
- Endorse and implement corporate social responsibility activities
- Develop and implement prioritised plans to use electricity and energy systematically and effectively

Under the market-oriented economy, the following are the objectives for defining electricity and energy pricing:

- Set fair and stable prices for electricity and energy consumers
- Ensure fair benefits to both producers and distributors
- Develop and enforce electricity and energy standards and specifications of the country based on international standards and specifications

- Encourage more cooperation with local foreign private partners following the State's economic policies

The objectives for exploring and utilising new renewable energy resources are as follows:

- Improve research and development programmes and awareness-raising activities
- Promote private sector participation by making laws and regulations
- Develop short-term and long-term plans
- Facilitate the operation of power plants by using locally available energy sources such as hydropower and renewable and thermal energy to provide a full and stable domestic electricity supply
- Develop and implement short-term and long-term plans to use liquefied natural gas, liquefied petroleum gas, coal, and other fuel energy sources
- Expand regional power trading when the domestic supply of electricity and energy is sufficient
- Cooperate with neighbouring countries to implement international power grid network and oil and gas pipeline network
- Implement modern petrochemical complexes in cooperation with local and foreign partners, which can produce petroleum and petrochemical products according to international standards and specifications, in line with economic policy, to set short-term and long-term plans to export.

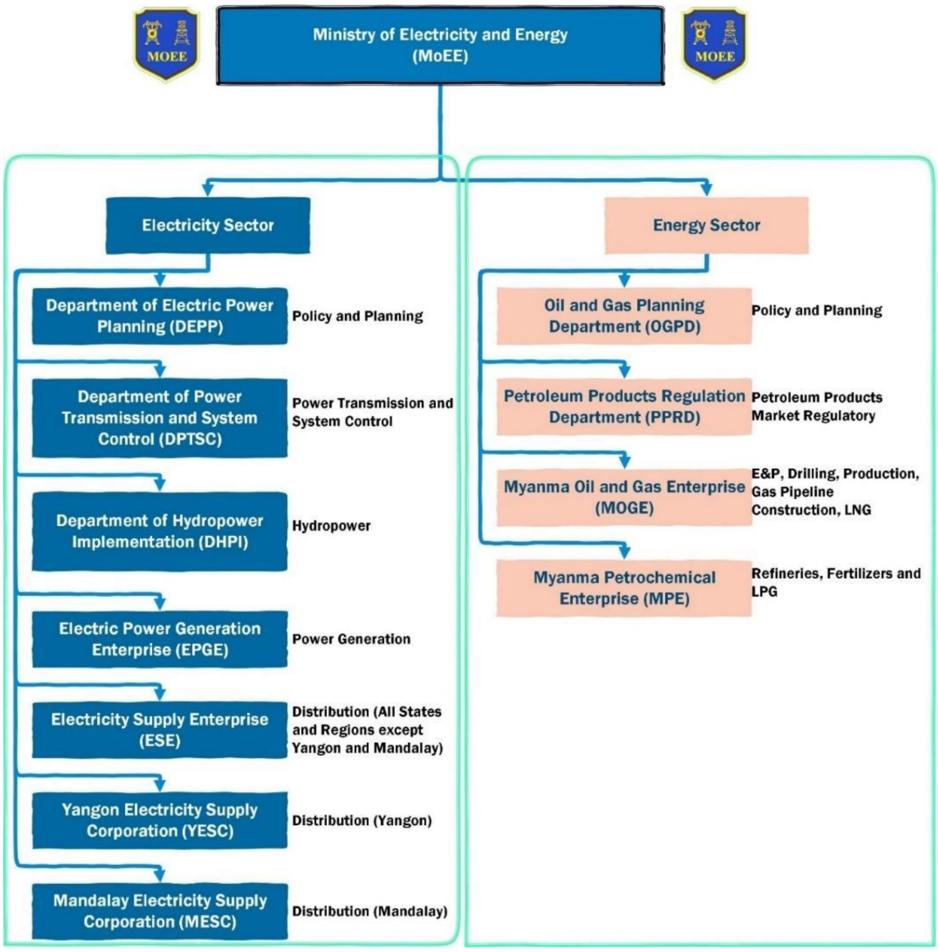
As for energy security, the MoEE will carry out long-term plans to increase reserved energy and formulate a plan to use civilian nuclear energy in line with ASEAN Standards.

Moreover, the MoEE has developed the following policies and plans: National Energy Policy, Electricity Sector Policy, Oil and Gas Sector Policy, Myanmar Energy Master Plan, National Electricity Master Plan, and National Electrification Plan. These were formulated by different international organisations such as the World Bank, JICA, and ADB and should be reviewed and revised to be in line with the current situation, national development plan, and government policy.

2.3.1.2 *Organisational structure*

The MoEE comprises five departments, four enterprises, and two corporations. There are three departments, two enterprises, and two corporations under the electricity sector; and two departments and two enterprises under the energy sector. Figure 2-19 shows the organisational structure of Myanmar's Ministry of Electricity and Energy.

Figure 2-19 Organisation of the Ministry of Electricity and Energy, Myanmar



Source: Authors, adapted from MoEE.

2.3.1.3 *Electricity sector*

The Department of Electric Power Planning (DEPP) is responsible for planning new power projects (thermal, hydro, and renewable); and coordinating with development partners, international organisations, and regional and international countries to develop, generate, transmit, and distribute electricity. DEPP is also responsible for drafting and modernising electricity laws, rules, regulations, and grid codes.

The Department of Power Transmission and System Control plans, implements new transmission lines and substations, and takes charge of the operation and maintenance (O&M) of the Myanmar power system.

The Department of Hydropower Implementation is responsible for planning, designing, and constructing state-owned hydropower plants.

The Electric Power Generation Enterprise plans the local and international tender invitation process on power generation. In addition, it is responsible for the O&M of existing thermal, hydro, and renewable power plants.

The Electricity Supply Enterprise distributes electricity in all states and regions: the Yangon Electricity Supply Corporation distributes in the Yangon Region, and the Mandalay Electricity Supply Corporation is for the Mandalay Region.

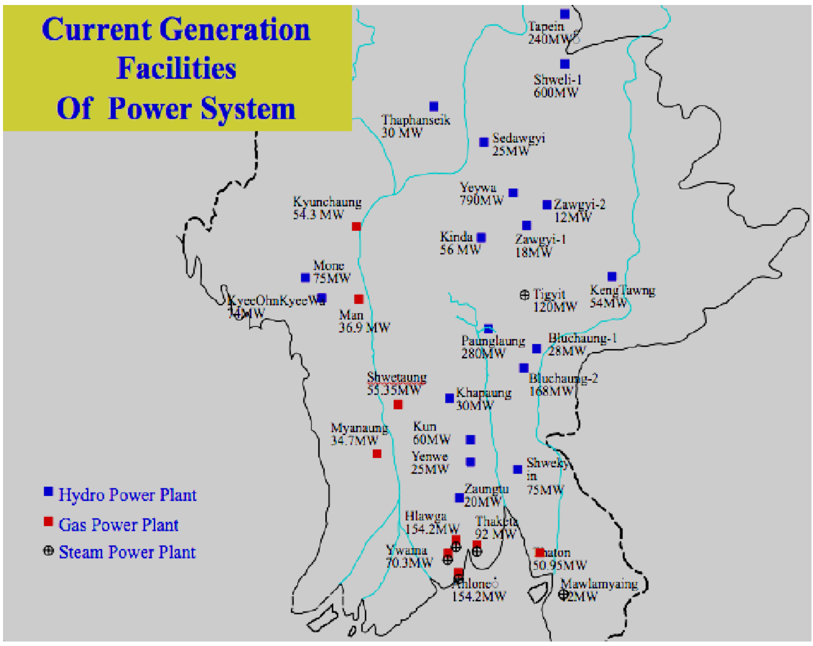
2.3.1.4 *Energy sector*

Two departments and two enterprises oversee the energy sector. The Oil and Gas Planning Department plans oil- and gas-related projects. The Petroleum Products Regulation Department, formerly the Myanmar Petroleum Products Enterprise, regulates the petroleum products market in Myanmar. The Myanmar Oil and Gas Enterprise is responsible for exploiting, midstreaming, and distributing oil and gas. The Myanmar Petrochemical Enterprise runs refineries, fertiliser factories, and the liquefied petroleum gas industry.

2.3.2 Power generation

The total installed power generation capacity of Myanmar is 6,749.9 MW for all power sources, including 3,225 MW for hydropower stations; 3,363.9 MW for gas-fired power plants; 120 MW for coal-fired power plants; and 40 MW for solar farms. In addition, there are some oil fuel self-contained units with a total installed capacity of 101 MW and 33 local small-scale hydropower projects with a total installed capacity of 37,374 MW. Both are mainly used in off-grid regions. Under the Ministry of Agriculture, Livestock, and Irrigation, the Department of Rural Development operates and manages small-scale solar firms, not considered in this study. The primary source of Myanmar's power plants is hydropower, followed by natural gas. The following figure shows the location of Myanmar's main power plants.

Figure 2-20 Power Generation Facilities in the Myanmar Power System



Source: MoEE data.

2.3.2.1 Hydropower

As of August 2020, the total installed capacity of Myanmar's hydropower stations, including 28 hydropower stations, is 3,225 MW. Table 2-5 shows the installed capacity of each hydropower station.

Table 2-5 Installed Capacity of Hydropower Plants in Myanmar

	Power Plant Name	Installed capacity (MW)	Commissioning Year
1	Baluchaung-2	168	1960/74
2	Kinda	56	1985
3	Sedawgyi	25	1989
4	Baluchaung-1	28	1992
5	Zawgyi Dam	18	1995
6	Zaungtu	20	2000
7	Zawgyi Dam 2	12	2000
8	Thapanzeik	30	2002
9	Mone	75	2004
10	Paung Laung	280	2005
11	Yenwe	25	2007
12	Kabaung	30	2008
13	Kengtawng	54	2009
14	Shweli-1	600	2009
15	Yeywa	790	2010
16	Dapein-1	240	2011
17	Shwegyin	75	2011
18	KyeeonKyeewa	74	2012
19	Kun	60	2012
20	Thauk Ye Khat-2	120	2013
21	Nancho	40	2014
22	Phyu Chaung	40	2014
23	Baluchaung - 3	52	2014
24	Chipwinge	99	2014
25	Upper Paunglaung	140	2014
26	Myitthar	40	2017
27	Myoe Gyi	30	2015
28	Yazagyo	4	2018
Total		**3,225**	

Source: MoEE data, modified by the author.

2.3.2.2 Gas power plants

So far, the total installed capacity of gas power plants in Myanmar has reached 3,363.9 MW. Table 2-6 shows the existing gas power plants.

Table 2-6 Installed Capacity of Gas Power Plants in Myanmar

Power Plant Name	Installed capacity (MW)	Commissioning Year
Kyun Chaung	54	1974
Man	37	1980
Shwe Taung	55	1984
Myan Aung	18	1984
Myan Aung 2	16	1975
Thaton (WB)	119	2018
Hlawga	99.9	1996
Ywama	37	1980
Ywama (NiDo)	24	2004
Ywama (240)	240	2014
Ahlone	99.9	1995
Thaketa	57	1990
Thilawa	50	2016
Hlawga	54	2013
Ywama (NEDO)	9	2014
Ahlone	54	2014
Toyo Thai	106	2015
Myanmar Lighting	78	2016
Thaketa	35	2018
Thaketa (UREC)	106	2018
Sembcorp (Myingyan)	225	2018
V power (KP)	90	2015-2016
V power (Myingyan)	90	2019
V power (Thaketa)	400	2020
V power (Thilawa)	350	2020
V power (Kyun Chaung)	22.3	2020
MCM (Shwe Taung)	39.2	2020
Total	3,363.9	

Source: MoEE data, modified by the author.

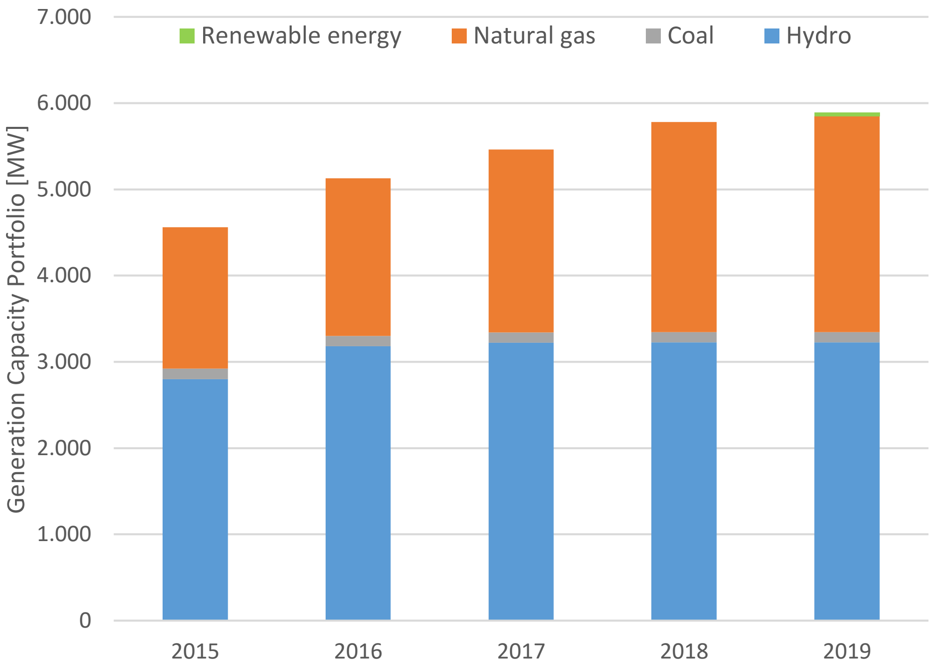
2.3.2.3 *Others*

The other power generation plants in Myanmar are the 120 MW coal-fired thermal power plant in Tigyit commissioned in 2005 and the 40 MW solar farm in Minbu commissioned in 2018.

2.3.2.4 *Installed capacity*

In recent years, the gas-fired power generation in Myanmar has developed rapidly, and its proportion in total installed capacity has increased year by year. In 2015, gas-fired power generation accounted for 35.9%, while hydropower accounted for 61.4%. In 2019, gas-fired power generation accounts for 42.5%, hydropower accounts for 54.7%, and the others are around 2.7%. In the future, the portion of the generation mix of renewable energy and thermal energy will be added because of ongoing tender and notices to proceed projects. The change in installed capacity in Myanmar is shown in Figure 2-21.

Figure 2-21 Change in Installed Capacity in Myanmar



Source: MoEE data, modified by the author.

2.3.2.5 *Unit generation*

According to the latest statistics, the total electricity generation of Myanmar in 2019 was 22,973 GWh, with an average growth rate of 12% from 2017 to 2019; the maximum load is 3,798 MW with an average growth rate of 15% from 2017 to 2019. Table 2-7 shows the change in the total generation from 2015 to 2019.

Table 2-7 Electricity Generation (GWh)

Month / Year	2015	2016	2017	2018	2019
January	1,142	1,252	1,467	1,621	1,781
February	1,053	1,243	1,377	1,521	1,702
March	1,304	1,513	1,591	1,837	2,016
April	1,238	1,429	1,519	1,791	2,007
May	1,390	1,507	1,760	1,919	1,992
June	1,311	1,410	1,641	1,771	1,900
July	1,307	1,479	1,643	1,885	1,938
August	1,326	1,488	1,717	1,881	1,933
September	1,325	1,493	1,712	1,893	1,918
October	1,366	1,537	1,714	1,931	2,048
November	1,316	1,434	1,661	1,820	1,932
December	1,311	1,493	1,617	1,816	1,806
Total	15,389	17,278	19,419	21,686	22,973

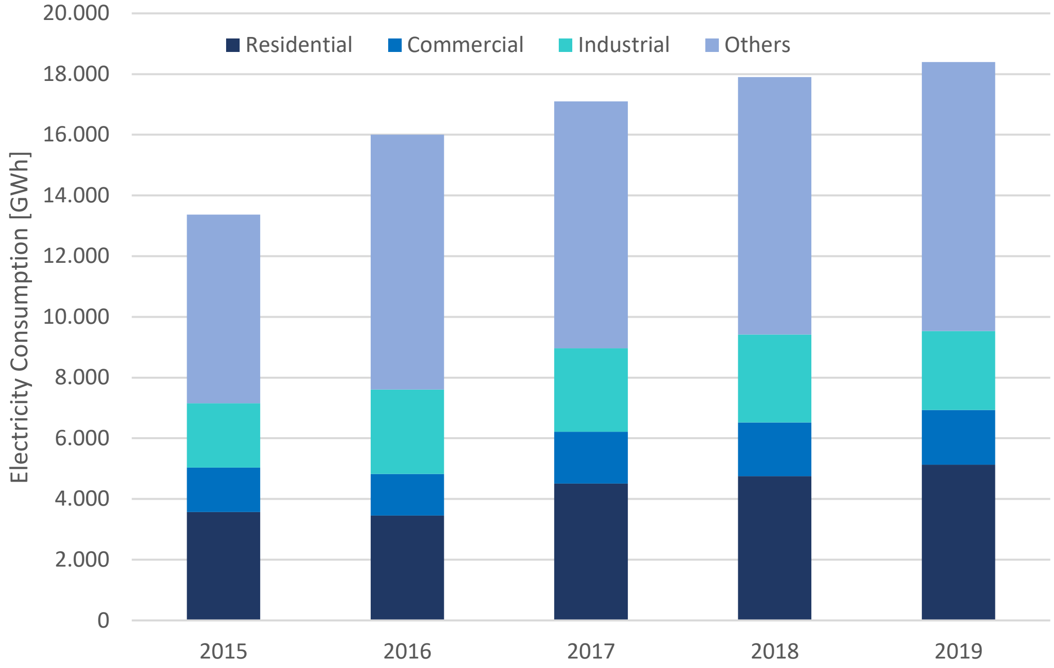
Source: MoEE data, modified by the author.

2.3.3 Power demand

2.3.3.1 *Electricity consumption*

According to MoEE's statistics, 50% of total households had access to grid electricity in 2019. Four sectors consume electricity: residential for household use, industrial for powering industries, commercial for business or bulk use, and others for street lighting and public use. The proportion of these contribution sectors are residential 31.50%, industrial 21.50%, commercial 12.99%, and others 34.02% from 2015 to 2019.

Figure 2-22 Changes in Electricity Consumption in Myanmar

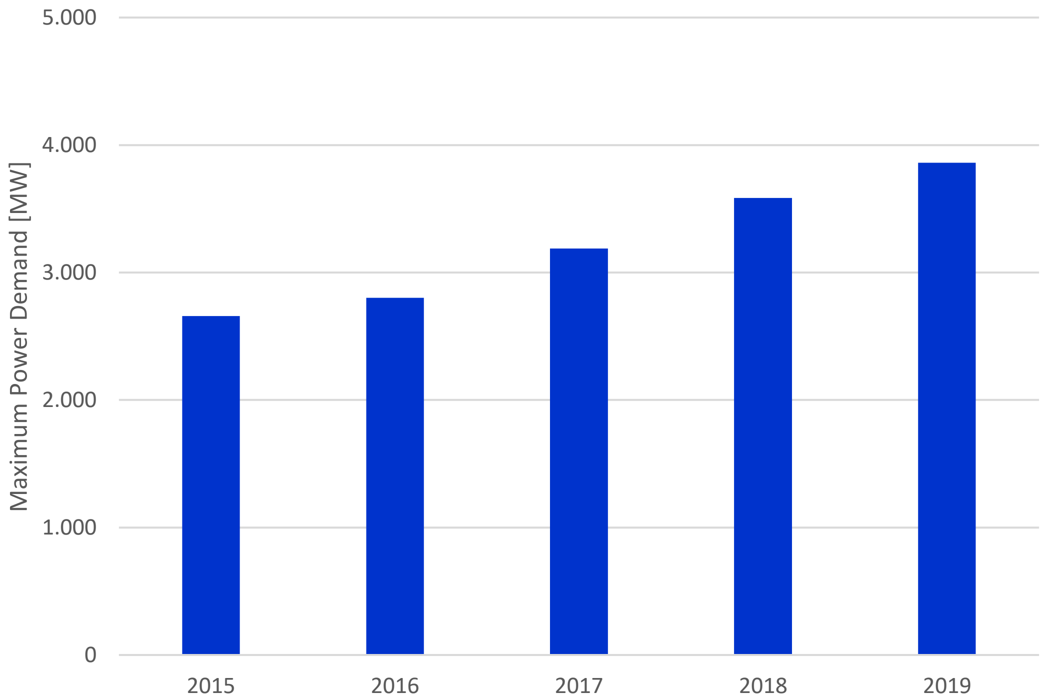


Source: MoEE data, modified by the author.

2.3.3.2 *Maximum demand*

The maximum demand in Myanmar was 2,659 MW in 2015; it steadily increased to 3,862 MW in 2019, with a growth rate of 45.3% (Figure 2-23).

Figure 2-23 Change in Maximum Demand in Myanmar



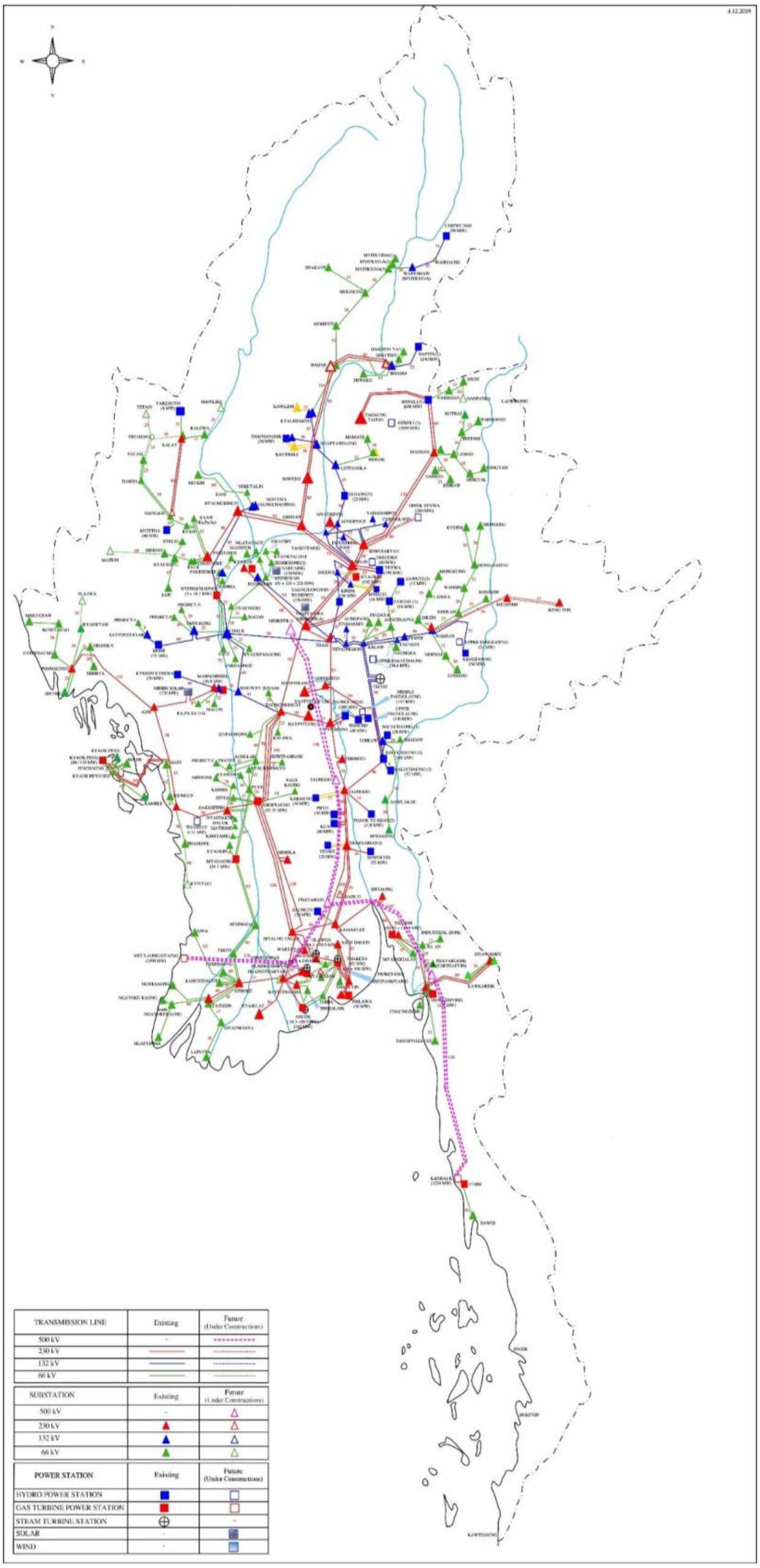
Source: MoEE data, modified by the author.

2.3.4 Overview of the transmission network

The power grid in Myanmar comprises national interconnected power grids (main grid) and isolated power grids in remote areas. Figure 2-24 shows Myanmar's power grid map.

The national transmission line mileage in Myanmar reached 15,319 km as of 2019, with primary voltage levels of 230 kV, 132 kV, and 66 kV. The transmission line is concentrated on the two major load centres, Yangon City and Mandalay City, and extends to surrounding cities. The transmission line covers most states and regions in the centre of Myanmar and some areas in Kachin State in the north, Shan State in the east, and Mon State and Kayin State in the south. In addition, isolated grids are used to supply power to most border and coastal regions. The existing 33 kV, 66 kV, 132 kV, and 230 kV transmission systems in Myanmar are concentrated around the main load centres and transmit electric energy to the load centre from power-gathering places located further north and south.

Figure 2-24 Power Grid Map in Myanmar



Source: Authors.

Table 2-8 Power Transmission Facilities in Myanmar

Voltage Class (kV)	Power Transmission Line		Substation	
	Quantity	Length (km)	Quantity	Capacity (MVA)
230	69	4,767	45	7,716
132	42	2,191	22	2,141
66	307	8,361	357	5,991
Total	418	15,319	424	15,848

Source: MoEE data, modified by the author.

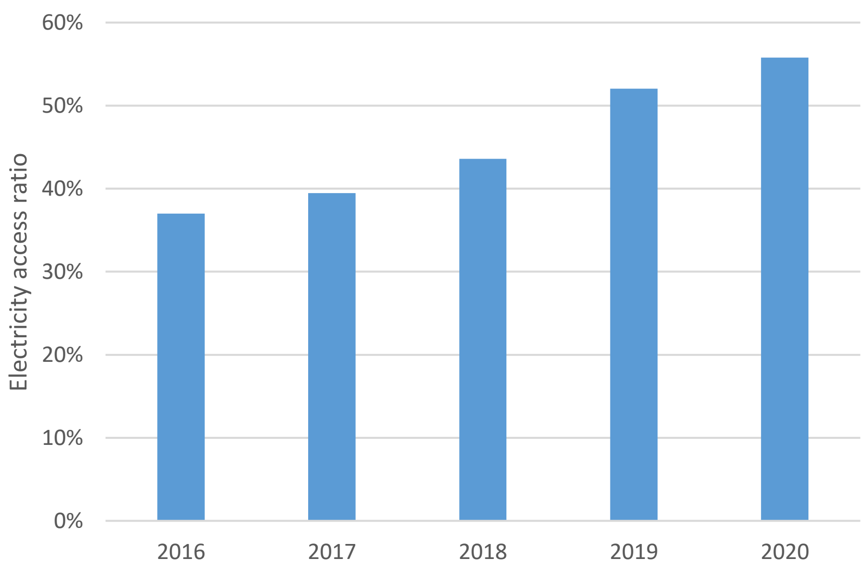
2.3.5 Power system reliability

In Myanmar, the statistics and indices for power system quality and reliability are yet to be fully developed.

2.3.6 Electricity access

The electricity access ratio in Myanmar is the lowest in ASEAN. Nevertheless, the country has been actively developing power infrastructure in recent years, and the electricity access ratio has been gradually increasing. Figure 2-25 shows the change in the electricity access ratio. First, the electricity access ratio was 37%, and then it steadily increased to 50% in 2019. By August 2020, it reached 55.8%. The Myanmar government aims for an electricity access ratio of 100% in 2030, and the progress of electricity access seems to be going well. However, the electrification rate is still low. Therefore, similar to Cambodia, this study also analyses the impact of electricity access on GDP in Myanmar.

Figure 2-25 Change in Electricity Access Ratio in Myanmar



Source: MoEE data, modified by the author.

2.3.7 Overview of the power development plan

2.3.7.1 *Hydropower*

Eight hydropower projects are presently undergoing preliminary work and construction in Myanmar, with a total installed capacity of 1,692 MW (Table 2-9). Only one project is progressing smoothly and is expected to be completed and be operational in 2019. The rest of the projects are progressing very slowly due to several reasons, and may be operational in 2025. Thus, by 2030, Myanmar's hydropower capacity will reach 4,947 MW.

Myanmar has initially identified more than 40 candidate hydropower plant lists with a total installed capacity of more than 30 GW as a long-term candidate for power supply construction.

Table 2-9 Hydropower Projects in Myanmar

Name of Hydropower Project	Installed capacity (MW)	Expected Commissioning Date
Upper Nanhtwan	3.2	2019
Shweli(3)	1050	2025
Deedok	66	2025
Upper Yeywa	280	2025
Middle Paunglaung	100	2025
Upper Kengtawng	51	2025
Upper Baluchaung	30.4	2025
Thahtay	111	2025

Source: MoEE data, modified by the author.

2.3.7.2 *Gas power plants*

Two gas-fired power plants in Myanmar are undergoing preliminary work and construction, with a total installed capacity of 335 MW (Table 2-10). Considering the commissioning and commercial operation of tendering thermal power plants in 2021, the generating capacity of gas-fired power projects in Myanmar will reach around 4,700 MW by 2021.

Table 2-10 Gas Power Plant under Construction in Myanmar

Power Plant Name	Installed Capacity (MW)	Expected Commissioning Date
Kyauk Phyu	135	2021
Kanbauk (UPA)	200	2025

Source: MoEE data, modified by the author.

To alleviate the severe power shortage in Myanmar, the MoEE passed four natural gas and liquefied gas power plant projects and issued notices to proceed on 30 January 2018. Other natural gas and liquefied gas power plant projects are planned to be developed by 2030, with a total installed capacity of around 4,000 MW.

2.3.7.3 *Solar power plants (photovoltaic: PV)*

Solar power plant projects, with a total installed capacity of over 1,000 MW in 30 locations connected with the grid, were invited in international competitive bidding for these power plants to operate at the beginning of the dry season in 2021. By 2030, the total installed capacity of solar power plants will reach 2,000 MW.

2.3.7.4 *Coal-fired power plants*

Most of the planned coal-fired power projects in Myanmar are build-operate-transfer projects, with seven memoranda of understanding and five memoranda of agreement in a semi-stagnating state. Due to environmental protection and other factors, the construction is seriously impeded; therefore, these projects are suspended for the time being. However, developing coal-fired power plants are expected soon to meet the country's electricity demand.

2.2 Thailand

2.4.1 Organisation of the electricity sector

2.4.1.1 *National energy policy*

To cope with the changes in economic and infrastructure development and the ASEAN Economic Community, the Ministry of Energy of Thailand (MoEN) developed the Thailand Integrated Energy Blueprint (Figure 2-26) as follows:

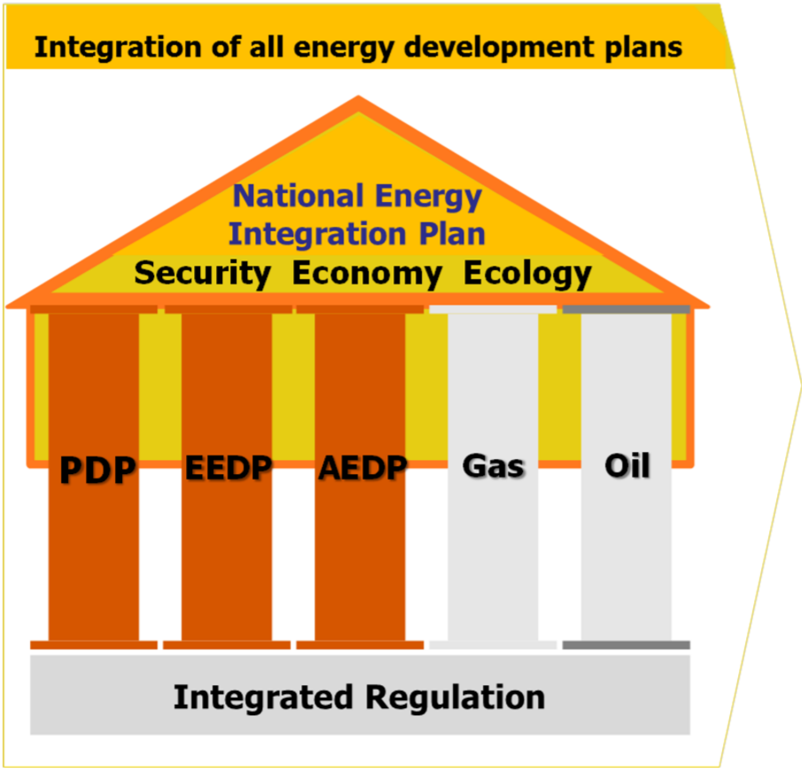
1) Thailand Power Development Plan (PDP)
2) Energy Efficiency Development Plan
3) Alternative Energy Development Plan
4) Natural Gas Supply Plan, and
5) Petroleum Management Plan

The new PDP, called the 'Thailand Power Development Plan 2018–2037 (PDP2018)', focuses on:

- Security - Enhancing the security of electricity generation, transmission, and distribution systems in each area to meet the electricity demand and support economic and social development
- Economy - Maintaining and appropriate costs in electricity generation and promoting low-cost electricity generation to relieve the burden of electricity users and not to pose obstacles to the economic and social development of the country in the long run
- Ecology - Reducing environmental impact by promoting electricity generation from renewable energy and increasing the efficiency of the power system on the supply and demand sides.

PDP2018 focuses on increasing the security of the electricity system by power development and improvement of the transmission system to increase the capability of interregional transmission. The 20-year PDP is divided into 5-year phases for flexibility in operation and investment facilitation, which will respond efficiently to socio-economic conditions and environmental protection.

Figure 2-26 Thailand Integrated Energy Blueprint

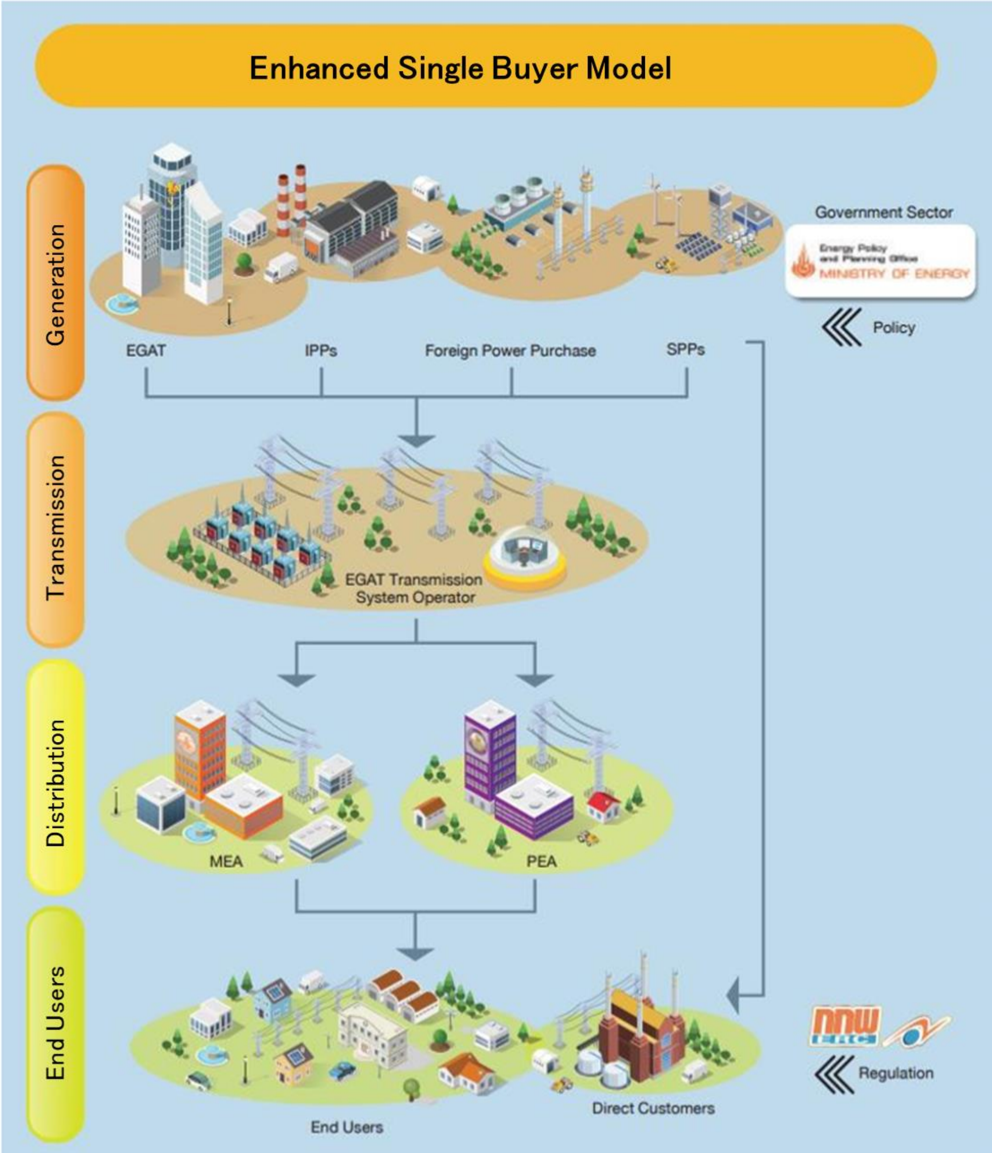


AEDP = Alternative Energy Development Plan, EEDP = Energy Efficiency Development Plan, PDP = Power Development Plan.
Source: MoEN (2016).

2.4.1.2 *Overview of the electricity market structure*

Thailand has adopted the Enhanced Single Buyer Model, authorising EGAT to take charge of the dominant electricity supply and be the sole buyer of electricity. Figure 2-27 shows the structure of Thailand's electricity supply industry. EGAT also serves as the system operator for the National Control Centre, which efficiently controls the dispatch of power plants, electricity generation, and transmission nationwide. In addition, the Energy Policy and Planning Office, Ministry of Energy, is responsible for national energy policies and plans. At the same time, the Energy Regulatory Commission regulates energy industry operations, including electricity prices. Meanwhile, policies are launched to promote private sector participation in Thailand's power market, including IPPs, small power producers (SPPs), and very small power producers (VSPPs), to buy power from renewable energy.

Figure 2-27 Structure of Thailand's Electricity Supply Industry



EGAT = Electricity Generating Authority of Thailand; EPPO = Energy Policy and Planning Office, Ministry of Energy; ERC = Energy Regulatory Committee; IPP = independent power producers (>90 MW); MEA = Metropolitan Electricity Authority; PEA = Provincial Electricity Authority; SPP = small power producer (10–90 MW); VSPP = very small power producer (<10 MW).
Source: EGAT (2020).

2.4.1.3 *Laws and governmental regulations for power companies*

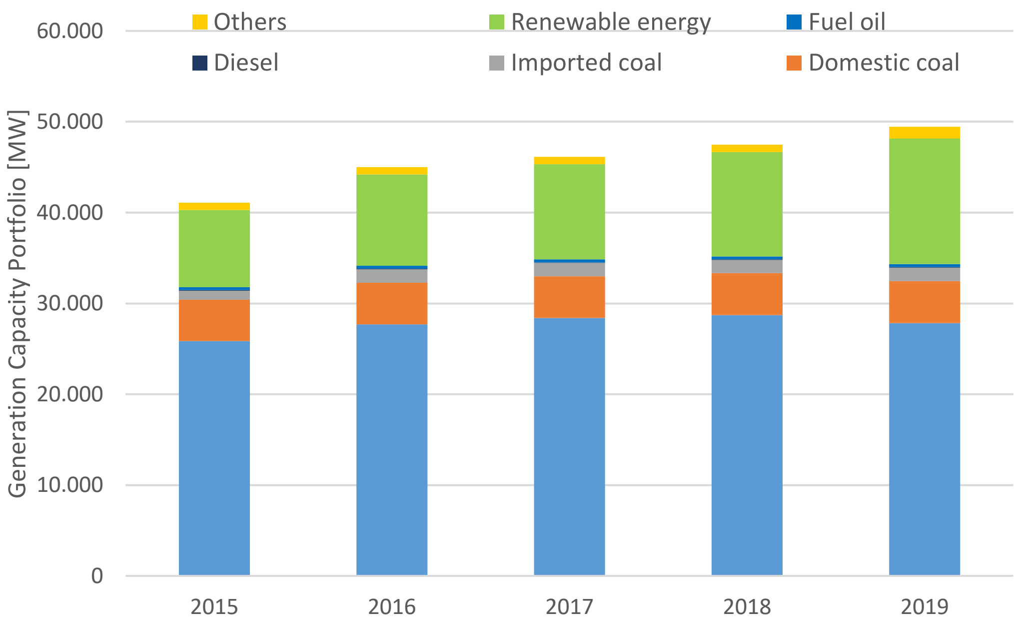
There is a collection of significant Thai legislation concerning the electricity supply industry. For instance, the EGAT Act, Metropolitan Electricity Authority (MEA) Act, and the Provincial Electricity Authority Act provide for the establishment, objectives, authority, and functions of the three principal power utilities. In addition, supplementary and subsequent regulations were developed and amended occasionally to coincide with contemporary social and economic situations, such as those for the SPPs and very small power producers. Lately, the Energy Regulatory Commission Act, which plays a vital role in the balance between energy consumers' rights and suppliers' power, was released in 2007.

Apart from these are laws conforming to international standards and regulations, such as the Factory Act and the National Environmental Quality Act.

2.4.2 Power generation

As of December 2015, the total installed capacity in Thailand was 41,098 MW. It gradually increased from 2015 and reached 49,462 MW in 2019. The installed capacity growth rate for the 5 years from 2015 to 2019 was approximately 20.4%. Generation in Thailand relies on natural gas as the main fuel. The generation capacity of natural gas accounted for 56.4% in 2019. Next to natural gas was renewable energy (hydro, wind, solar, geothermal, and biomass), which accounted for 28.0% in 2019. The generation capacity portfolio in Thailand is shown in Figure 2-28.

Figure 2-28 Generation Capacity Portfolio in Thailand

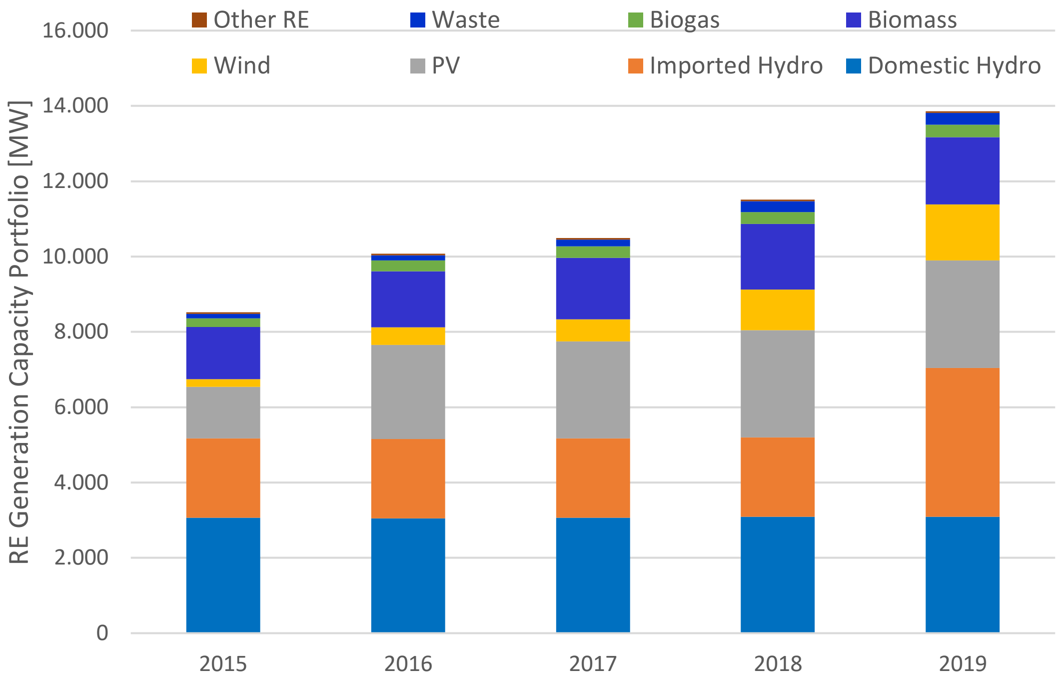


Source: EGAT data, modified by the author.

The generation of renewable energy skyrocketed in Thailand in 2015–2019. Figure 2-29 shows the generation capacity portfolio. The total installed renewable energy capacity was 8,522 MW in 2015 and reached 13,855 MW in 2019. The growth rate of renewable energy generation from 2015 to 2019 was 62.6%. Hydropower generation, including import, accounted for 50.8% in 2019. Next to hydropower was PV, accounting for 20.6%, and wind, accounting for 10.7%.

PV and wind power generation capacities were 1,367 MW and 202 MW, respectively, in 2015. Then PV and wind power skyrocketed and reached 2,854 MW and 1,486 MW in 2019. Thus, from 2015 to 2019, PV increased about 2.1 times, and wind power increased about 7.3 times in Thailand.

Figure 2-29 Renewable Energy Generation Capacity Portfolio in Thailand

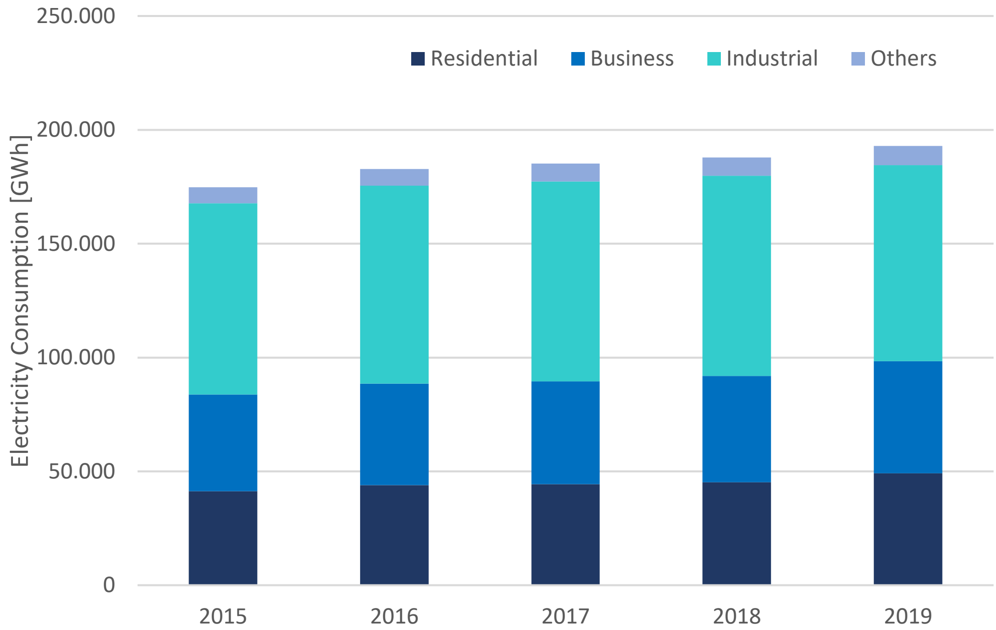


PV = photovoltaic, RE = renewable energy.
Source: EGAT data, modified by the author.

2.4.3 Power demand

Figure 2-30 shows the changes in electricity consumption in Thailand. The electricity consumption in 2015 was 174,833 GWh. It steadily increased from 2015 and reached 192,960 GWh in 2019. As a result, the electricity consumption growth rate from 2015 to 2019 was approximately 14.9%.

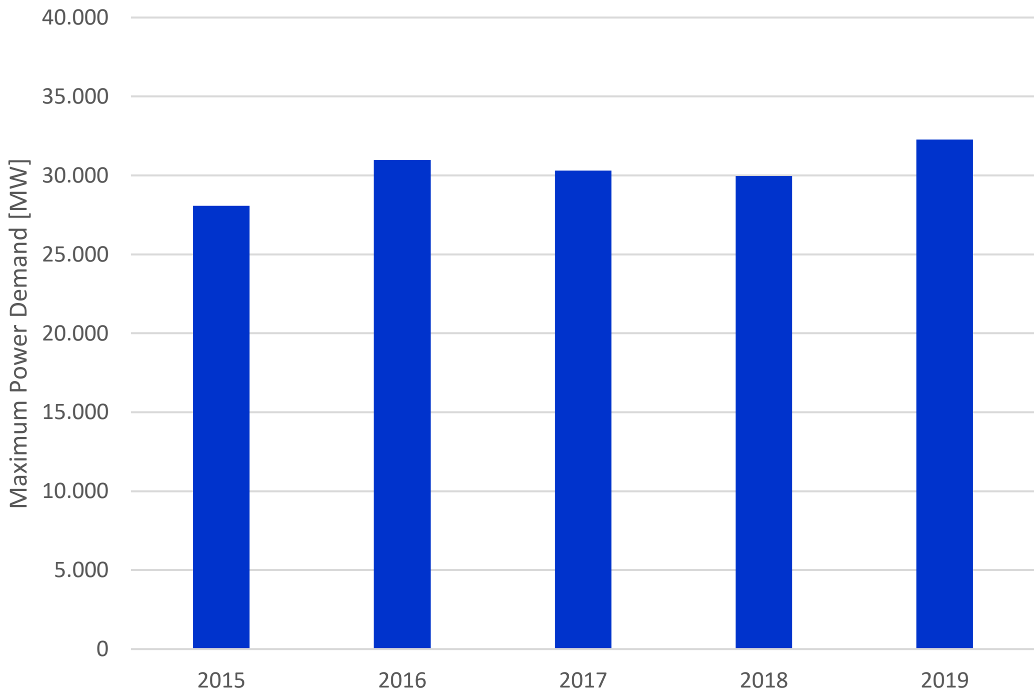
Figure 2-30 Changes in Electricity Consumption in Thailand



Source: EGAT data, modified by the author.

Figure 2-31 shows the changes in maximum demand in Thailand. The maximum power demand in 2015 was 28,082 MW. It steadily increased from 2015, slightly dipping in 2018, and reached 32,273 MW in 2019. Thus, the demand growth rate from 2015 to 2019 was approximately 14.9%.

Figure 2-31 Changes in Maximum Demand in Thailand



Source: EGAT data, modified by the author.

2.4.4 Overview of the transmission network

2.4.4.1 Transmission System Development Plan

As the state enterprise, EGAT solely owns the transmission system, including the 500 kV, 230 kV, and 115 kV transmission lines, as well as the high voltage direct current (HVDC) power exchange (300 kV HVDC link) between Thailand (EGAT) and Malaysia (Tenaga Nasional Berhad) in the southern part of Thailand.

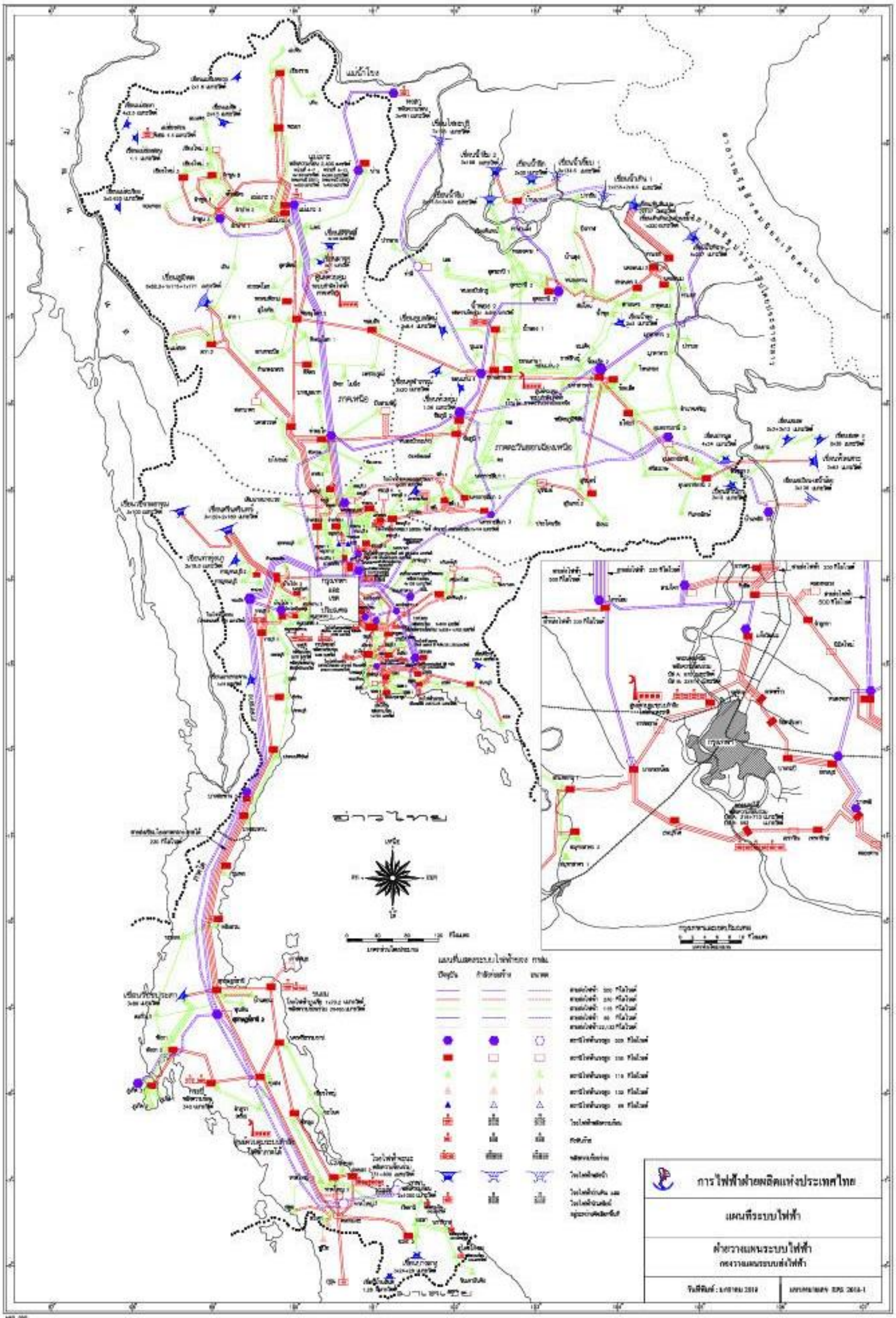
Additionally, to meet the increasing electricity demand, secure the system, and replenish the ageing power equipment, EGAT implements power plant development projects and transmission investment projects to fulfil the system requirements. The line length and number of substations at each voltage level are shown in Table 2-11.

Table 2-11 Line Length and Number of Substations at Each Voltage Level

Voltage Level [kV]	Line Length [Circuit-Kilometers]	Number of Substations
500	6,902.182	22
300	23.066	-
230	15,340.318	82
115	14,185.837	125
Total	36,451.403	229

Source: EGAT data, modified by the author.

Figure 2-32 Power Grid Map of Thailand

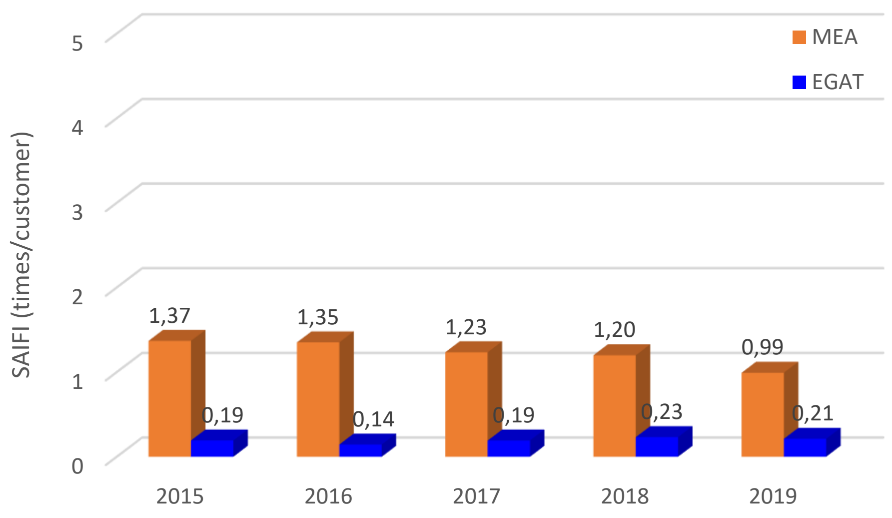


Source: EGAT (2018).

2.4.5 Power system reliability

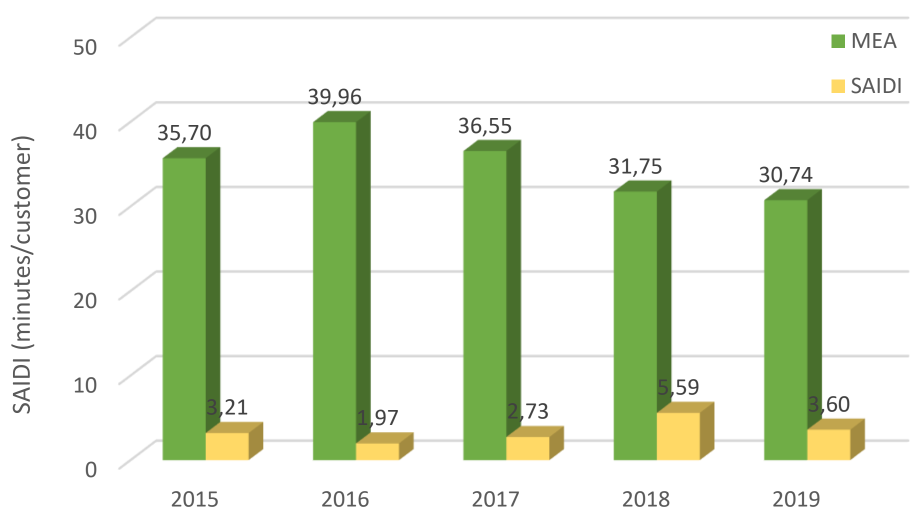
Figures 2-33 and 2-44 show the changes in SAIFI and SAIDI of Thailand, respectively. The SAIFI of EGAT and MEA in 2015 were 0.19 and 1.37 times. MEA's SAIFI steadily decreased from 2015 and was 0.99 times in 2019, about two-thirds of 2015. EGAT's SAIFI remained at about the same level. The SAIDIs of EGAT and MEA in 2015 were 3.21 and 35.70 minutes. MEA's SAIDI rose in 2016 but steadily decreased and was 30.74 minutes in 2019. On the other hand, EGAT's SAIDI changed between 2 and 6 minutes after 2015. From these data, power system reliability in Thailand is sufficiently high compared to developed countries (ERIA, 2019).

Figure 2-33 Change in SAIFI of Thailand



MEA = Metropolitan Electricity Authority, SAIFI = System Average Interruption Frequency Index.
Source: EGAT, MEA data, modified by the author.

Figure 2-34 Change in SAIDI of Thailand



MEA = Metropolitan Electricity Authority, SAIDI = System Average Interruption Duration Index.
Source: EGAT, MEA data, modified by the author.

2.4.6 Overview of Power Development Plan 2018–2037 (PDP 2018)

2.4.6.1 *Frameworks and directions of Thailand's PDP2018*

Thailand's PDP2018 focuses on three pillars:

1) Energy security

- ❖ Emphasising power system security, including generation, transmission, and distribution in each area to accommodate the increasing power demand to support economic and population growth and urbanisation regionally and nationally, as indicated in the National Economic and Social Development Plan
- ❖ Having adequate power plants for energy security to cope with an energy crisis

2) Economy

- ❖ Maintaining an appropriate power generation cost, prioritising the lowest generation to reduce the burden of power consumers and not hinder the country's economic and social development in the long run
- ❖ Managing electricity production cost-efficiently to reflect the actual cost of electricity generation

3) Ecology

- ❖ Promoting microgrids in remote areas, industrial estates, or special economic zones, in line with the power demand in each area, to optimise the use of local resources and reduce the investment in the transmission system
- ❖ Enhancing energy efficiency in the power system in both generation and consumption and introducing demand response to increase the potential of reducing peak demand to cope with an energy crisis, deferring the construction of new power plants, and saving from power imports
- ❖ Developing smart grids to facilitate decentralised generation and encourage more efficient energy use

Therefore, the key principles of Thailand's PDP2018 are as follows:

1) Formulating guidelines on reliable capacity allocation to serve power demand

- ❖ Allocating fossil fuel–based power plants
- ❖ Supporting power plants under the government's promotion policy, for example, committed power purchase from neighbouring countries
- ❖ Tracking the Paris Agreement adopted at COP21 by promoting renewable energy and energy efficiency
- ❖ Considering the economic concept of competitiveness and the change in innovation disruptions

2) Allocating fossil fuel–based power plants and main power plants in each region by considering power plants under the government's promotion policy
   a) Optimising the use of potential fuel sources and existing infrastructure in each region to reduce any further investments
   b) Alleviating the burden of a long-term commitment of the main power plant by considering the risk of disruptive technology
   c) Maintaining the generation capacity in the primary grid and increasing generation capacity from the main power plant in metropolitan areas to reduce dependence on power generation from other regions
3) Proposing a framework for reliable capacity allocation
   a) Constructing new fossil fuel–based power plants and ensuring committed power purchase from neighbouring countries
   b) Promoting renewable energy and energy efficiency programmes

4) Generating power for own use and/or direct sale - Determining the framework for power generation for own use and/or direct sale is connected to three utility systems (independent power supply), showing a significantly growing trend amongst power producers and consumers classified into three categories:
   a) SPP direct customers in industrial estates
   b) Business people, who invest in independent rooftop solar to generate electricity for their use (do not sell electricity to the grid)
   c) Power producers in the industry sector, who generate electricity for their use, for instance, agriculture and industry

The aforementioned framework for power generation for own use or direct sale was forecasted based on historical trends. However, regarding power generation for own use or direct sale in the future, the government will allow the market mechanism to determine which power producers and consumers will decide on the actual price. This change will affect the overall electricity demand.

2.4.6.2 *Guidelines of power plant allocation*

Main power plants were allocated in each region to maintain the security of the power system, considering the optimal use of potential fuel sources and existing infrastructure to minimise any further investments. Furthermore, power generation from new renewable technologies and risks of disruptive technologies were considered to avoid duplication of investments between the main power plant and renewable energy, alleviating the burden of electricity cost on consumers. Additionally, the generation capacity of primary power generation sources was retained. In contrast, there were new generation additions in metropolitan areas to reduce dependence on the power supply from other regions, primarily focusing on self-adequacy.

2.4.6.3 *Summary of PDP2018*

Thus, per Thailand's PDP2018, the total contracted capacity will increase to 77,211 MW by 2037, including the existing generation capacity (as of December 2017) of 46,090 MW; the new generation capacity of 56,431 MW; and the retiring generation capacity of 25,310 MW.

Table 2-12 Generation Capacity in 2018–2037

	Generation Capacity [MW]
Existing generation capacity as of December 2017	46,090
New generation capacity during year 2018-2037	56,431
Retiring generation capacity during year 2018-2037	-25,310
Total contracted capacity in 2037	**77,211**

Source: MoEN (2018).

Table 2-13 New Generation Capacity in 2018–2037

Type	Generation Capacity [MW]
Renewable energy	20,766
Pumped storage hydro power plant	500
Cogeneration power plant	2,112
Combined cycle power plant	13,156
Thermal power plant (Coal/Lignite)	1,740
Power purchase from neighbouring countries	5,857
New/Replacement power plant	8,300
Energy efficiency programs	4,000
Total	56,431

Source: MoEN (2018).

2.3 Viet Nam

2.5.1 **Organisation of the electricity sector**

2.5.5.1 *Government agency of the electricity sector*

Viet Nam's Ministry of Industry and Trade (MOIT) is responsible for electricity and energy. It formulates energy policies and plans. Three organisations are under MOIT: Institute of Energy, Electricity Regulatory Authority of Viet Nam (ERAV), and Electricity & Renewable Energy Authority (EREA).

1) Ministry of Industry and Trade

MOIT was established in 2007 through the merging of the Ministry of Trade and the Ministry of Industry. MOIT formulates, implements, and supervises laws and regulations, strategic and master plans for industries under its jurisdiction, and licences related to regulatory and investment projects. The ministry also formulates energy policies and plans, and approves electricity prices.

2) Institute of Energy

The Institute of Energy, an organisation directly under MOIT, is a research institute specialising in energy field research analysis and policy formulation. It is also in charge of formulating and revising the PDP, the power master plan, and forecasting long-term demand. Various drafts prepared in the institute are submitted to MOIT for its approval.

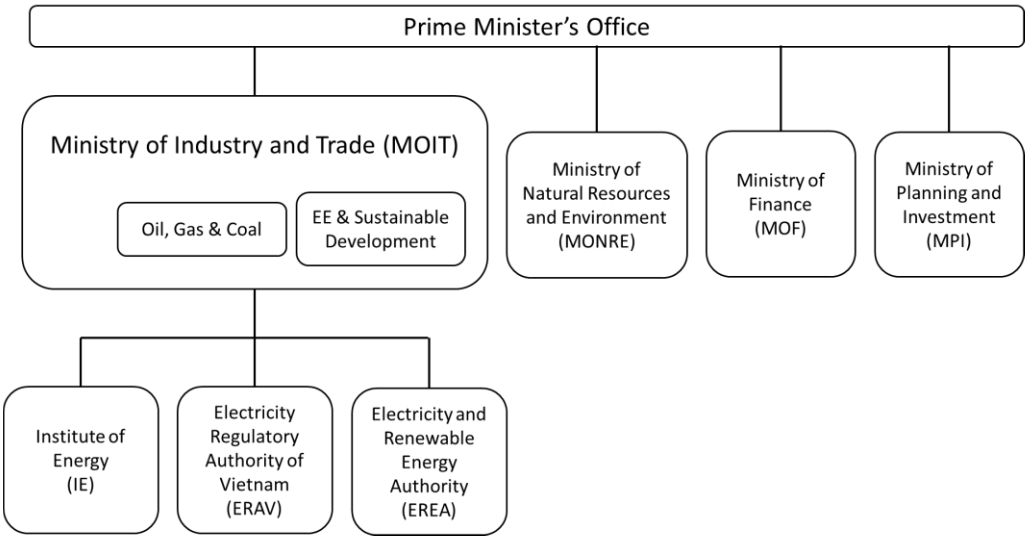
3) Electricity Regulatory Authority of Viet Nam

ERAV, also under the direct control of MOIT, is in charge of formulating and implementing regulations on electricity. The authority's primary functions are issuing electricity business licences, setting electricity prices, and maintaining and monitoring the electricity market. Since it is an internal organisation of MOIT, the latter approves various regulations and electricity prices.

4) Electricity and Renewable Energy Authority

EREA, also under MOIT, formulates policies, systems, and regulations related to renewable energy, and judges businesses for renewable energy power generation such as PV and wind power. EREA is also in charge of formulating the feed-in tariff system for renewable energy. In addition, MOIT approves various systems developed by EREA.

Figure 2-35 Organisational Structure of Government and Regulatory Bodies in the Electricity Sector



Source: Authors.

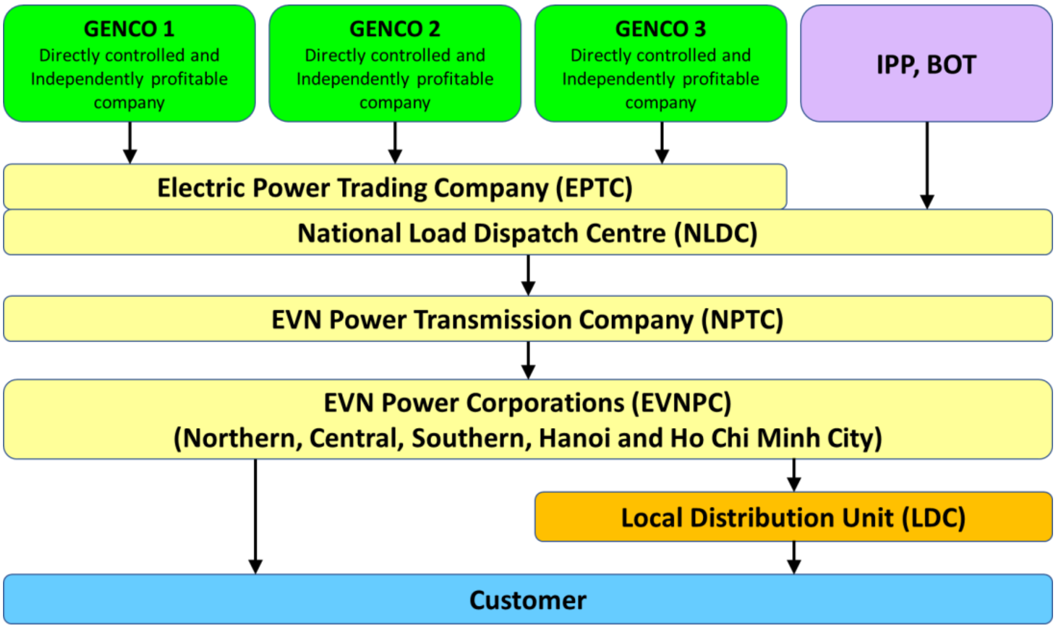
2.5.5.2 *Electric power utility*

The current electric power business in Viet Nam is divided into power generation, power system operation, transmission, distribution, and retail. Viet Nam Electricity (EVN) and its subsidiaries operate each electric power business. On the other hand, the power generation business is open to companies other than the EVN.

Electricity sector reform in Viet Nam began in 2005 following the promulgation of the Electricity Law of 2004 (No. 28/2004/QH11). The sector reform aimed to (i) meet the significant growth in power demand against the backdrop of economic growth and (ii) optimise electricity prices to appropriately allocate the necessary funds for maintaining and expanding the power grid.

In line with the progress of power sector reforms, the EVN integrated four regional transmission companies into one transmission company called the National Power Transmission Cooperation (NPT) in 2008. In the same year, the Electric Power Trading Company was established under the EVN as a single buyer in the electric power market. Then, the EVN was legally separated from the traditional vertically integrated company and was transformed into a holding company in 2009. In 2010, 11 regional power distribution companies were reorganised into five EVN subsidiaries. In 2012, three power generation companies (GENCO 1, 2, 3) were established.

Figure 2-36 Electricity Business Structure in Viet Nam

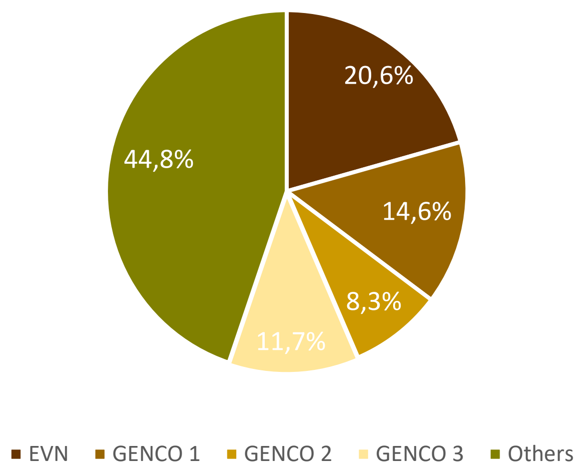


BOT = build-operate-transfer, GENCO – generation company, IPP = independent power producer.
Source: JEPIC, https://www.jepic.or.jp/data/asia06vtnm.html (accessed 8 February 2021).

1) Power generation company

Power generation companies in Viet Nam are broadly divided into the EVN, EVN subsidiaries, IPPs, and build-operate-transfer. GENCO 1, 2, and 3 spun off from the EVN in 2012 as an independently profitable company with 100% EVN. GENCO is assigned power plants owned by the EVN, except for those critical for energy policy. According to the EVN, the ratio of installed power generation capacity owned by the EVN Group is about 55% of Viet Nam's total (20.6% under direct control, 34.6% of GENCO), and about 45% of power plants of other companies such as IPPs. The installed capacity portfolio by company is shown in Figure 2-37.

Figure 2-37 Installed Capacity Portfolio, by Company (as of 2019)



EVN = Viet Nam Electricity, GENCO = generation company.
Source: EVN data, modified by the author.

2) Transmission company

The NPT is a 100% EVN independent profit company established in April 2008. It exclusively operates the power grid throughout Viet Nam. The NPT consists of four power transmission companies (PTCs) and three project management boards (PMBs), and supervises, operates, and maintains 220 kV–500 kV transmission networks. The Institute of Energy formulates the transmission development plan as part of the PDP. On the other hand, the corporate planning department of the EVNNPT reviews the reinforcement plan of 220 kV or more networks every year in cooperation with EVN's corporate planning department. Three NPT PMBs (Northern PMB, Central PMB, and Southern PMB) manage the construction work. The four NPT PTCs operate and maintain transmission equipment owned and operated by regional power companies.

3) Distribution and retail company

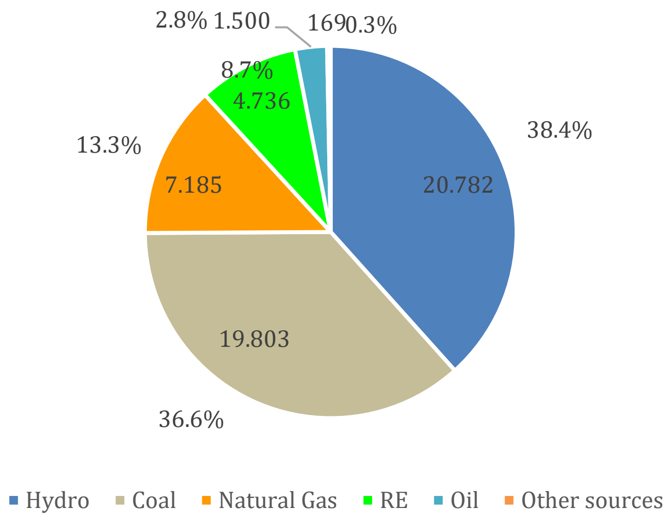
Power Corporation is an independently profitable company with 100% EVN, and is divided into five companies by operation and region. Its main business is planning and O&M of transmission and distribution equipment at 110 kV or less and electricity charge collection.

2.5.1 Power generation

As of 2019, the total installed capacity in Viet Nam was 54,175 MW. Figure 2-38 shows the country's installed capacity portfolio. Generation in Viet Nam relies on hydropower and coal-fired thermal power. The installed capacity of hydropower accounted for 38.4%. Next to hydropower was coal-fired, accounting for 36.6%.

The total installed capacity of renewable energy, including hydropower, was 25,518 MW, which accounted for 47.1%

Figure 2-38 Installed Capacity Portfolio in Viet Nam (as of 2019)

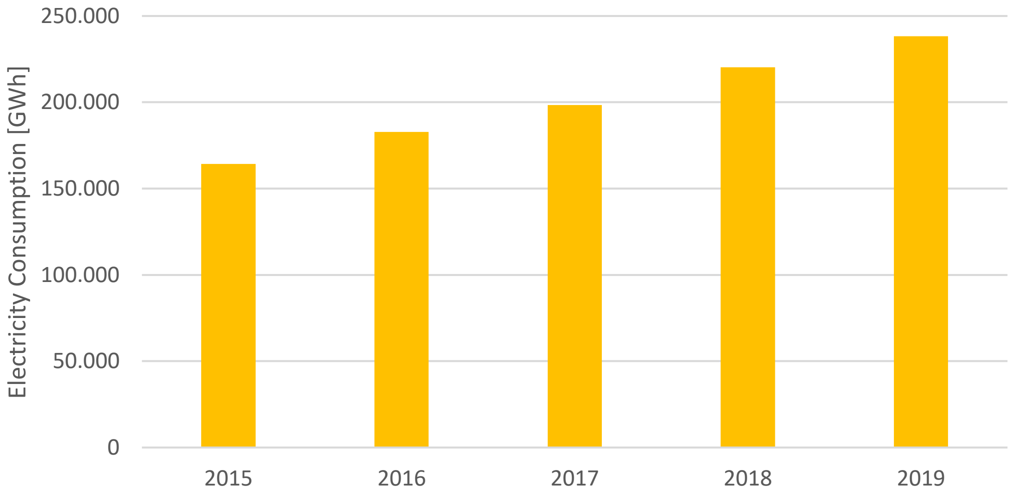


RE = renewable energy.
Source: EVN data, modified by the author.

2.5.2 Power demand

Figure 2-39 shows the changes in Viet Nam's electricity consumption, which was about 165,000 GWh in 2015. However, it steadily increased from 2015 and reached nearly 240,000 GWh in 2019. Thus, the electricity consumption growth rate from 2015 to 2019 was approximately 45.0%.

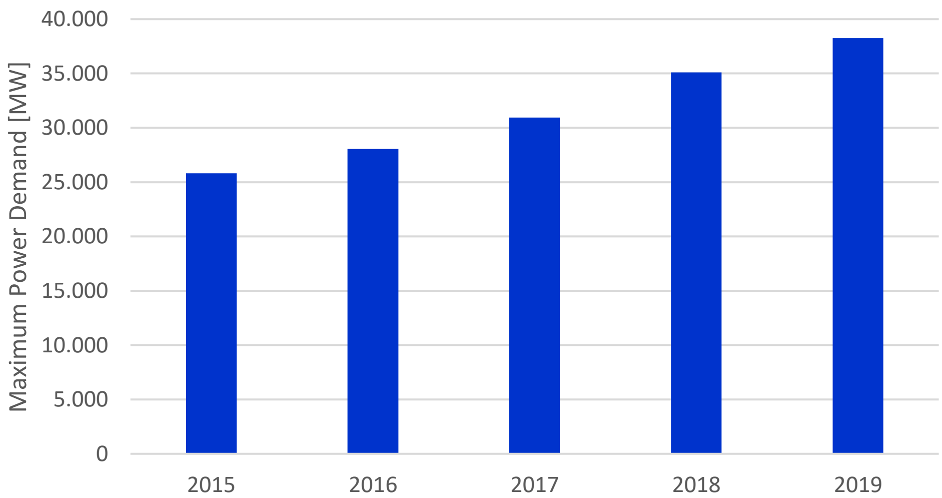
Figure 2-39 Changes in Electricity Consumption of Viet Nam



Source: EVN data, modified by the author.

Figure 2-40 shows the changes in maximum demand of the country, which in 2015 was 25,809 MW. It steadily increased from 2015 and reached 38,249 MW in 2019. The demand growth rate from 2015 to 2019 was approximately 48.2%.

Figure 2-40 Changes in Maximum Demand in Viet Nam



Source: EVN data, modified by the author.

2.5.3 Overview of the transmission network

The power system in Viet Nam has a 500 kV transmission system network from north to south due to the country's geographical characteristics. It operates at 500 kV, 220 kV, 110 kV, and medium and low voltage. The 500 kV and 220 kV networks are bulk power systems operated and maintained by the EVNNPT. Since hydropower stations are located in the northern and central parts of Viet Nam, the power flow of the 500 kV transmission network differs greatly between the wet season, when the hydropower output is large, and the dry season, when it is low. On the other hand, the distribution system, operated and maintained by five EVNPCs – Northern Power Corporation, Central Power Corporation, Southern Power Corporation, Hanoi Power Corporation, and Ho Chi Minh City Power Corporation – comprises 110 kV or less networks.

Figure 2-41 shows Viet Nam's power grid map. In addition, Tables 2-14 and 2-15 show the outline of the power system equipment owned by EVNNPT and EVNPCs.

Table 2-14 Outline of Power System Equipment Owned by EVNNPT

Item	Unit	Quantity
500 kV transmission lines	km	7,516
220 kV transmission lines	km	17,360
500 kV transformers	MVA	33,300
220 kV transformers	MVA	52,688

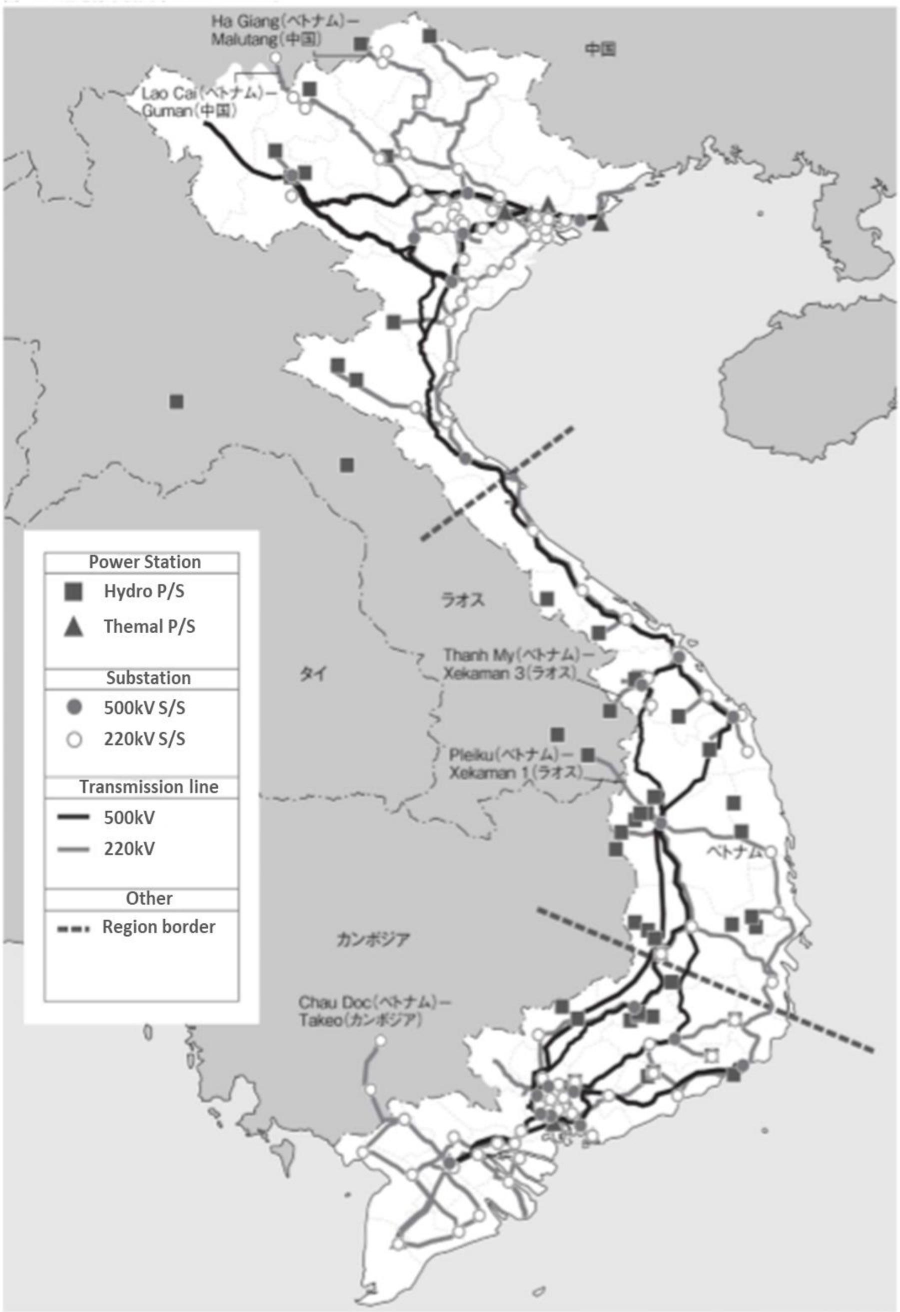
Source: EVN data, modified by the author.

Table 2-15 Outline of Power System Equipment Owned by EVNPC

Item	Unit	Quantity
220 kV distribution lines	km	110
110 kV distribution lines	km	19,628
Medium and low voltage distribution lines	km	491,777
220 kV transformers	MVA	4,250
110 kV transformers	MVA	53,415
Medium and low voltage transformers	MVA	48,147

Source: EVN data, modified by the author.

Figure 2-41 Power Grid Map of Viet Nam, at 500 kV and 220 kV (as of 2016)

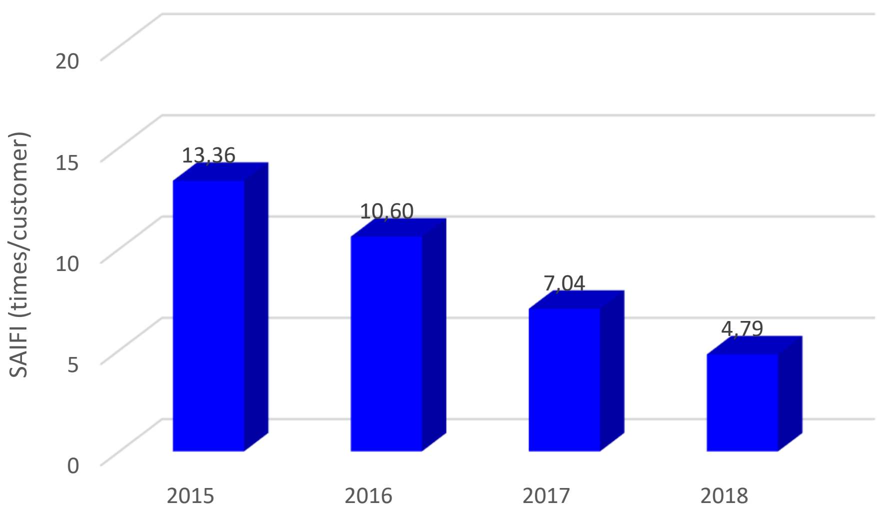


Source: JEPIC (2019).

2.5.4 Power system reliability

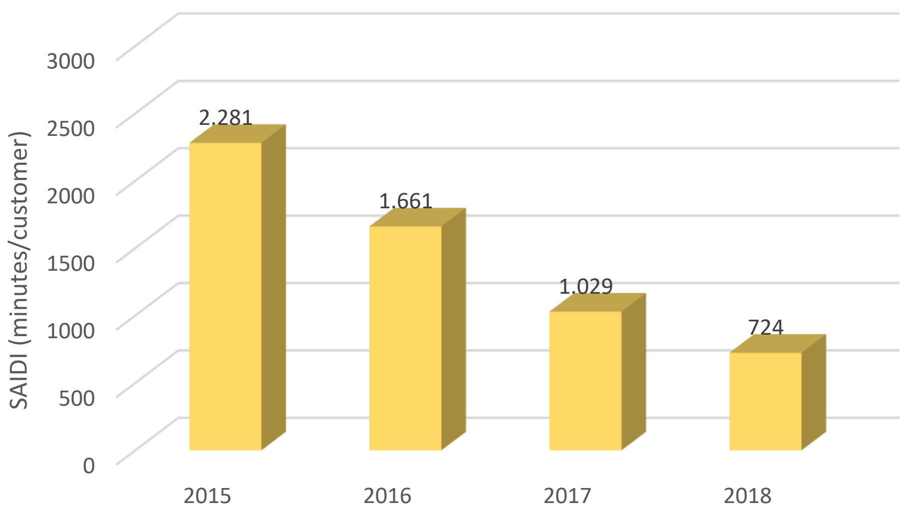
Figures 2-42 and 2-43 show changes in the country's SAIFI and SAIDI, respectively. The SAIFI in 2015 was 13.36 times. It steadily decreased from 2015 and was 4.79 times in 2018, about one-third of 2015. The SAIDI in 2015 was 2,281 minutes, steadily declined from 2015 and was 724 minutes in 2018, also about one-third of 2015. However, the SAIFI and SAIDI were still low than those of developing countries (ERIA, 2020).

Figure 2-42 Change in Viet Nam's SAIFI



SAIFI = System Average Interruption Frequency Index.
Source: EVN data, modified by the author.

Figure 2-43 Change in Viet Nam's SAIDI



SAIDI = System Average Interruption Duration Index.
Source: EVN data, modified by the author.

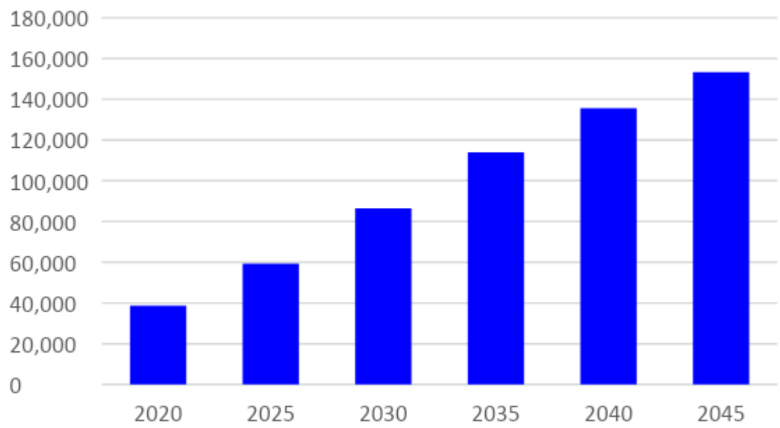
2.5.5 Overview of the power development plan

MOIT has been formulating the PDPs for many years. The latest version is PDP7 rev. The Prime Minister approved the adjustment of the National Power Development Master Plan for the Period 2011–2020 with the Vision to 2030. It strongly emphasised renewable energy development and power market liberalisation (ERIA, 2017c).

Now, MOIT is formulating the draft version of PDP8. According to Baker McKenzie[1], MOIT released the draft proposal for the national PDP for 2021–2030, with a vision to 2045 ("Draft PDP8") for public comments in February 2021. This is the third version of the draft.

The maximum power demand forecast of PDP8 is shown in Figure 2-44. The maximum power demand was 38,706 MW in 2020. It will gradually increase and reach 86,493 MW in 2030 and 135,596 MW in 2040.

Figure 2-44 Maximum Power Demand Forecast of PDP8



Source: Baker McKenzie, modified by the author.

Table 2-16 shows the proposed installed capacity of PDP8. From the breakdown of each power generation type, the capacity of all types will increase. On the other hand, as for the ratio of total capacity, coal and solar power will decrease, and gas and wind power will increase. Regarding thermal power, coal-fired is currently the mainstream, but gas will be the mainstream in the future. Since solar capacity skyrocketed in recent years and it was already 16,640 MW in 2020, the ratio of the total installed capacity will decrease in the future. In addition, the increase in wind power is particularly remarkable. In 2040, the ratio to total installed capacity will exceed hydropower and solar power and will be the third after thermal power. This also suggests that the wind power market in Viet Nam is huge.

❖ **Coal-fired thermal power plants**

The installed capacity of coal-fired power in 2020 was 20,431 MW, 29.5% of the total installed capacity. It will gradually rise and reach 37,323 MW in 2030 and 48,383 MW in 2040. However, the ratio of coal-fired thermal power will gradually decline to 27.1% in 2030 and 20.7% in 2040.

---

[1] Baker McKenzie is a multinational law firm headquartered in Chicago, Illinois. Founded in 1949 as Baker & McKenzie, it has 77 offices in 46 countries, and over 6,000 lawyers worldwide. It is one of the largest law firms in the world by headcount and revenue.

❖ **Gas-to-power**

The installed capacity of gas thermal in 2020 was 9,030 MW, 13.0% of the total installed capacity. It will gradually increase and reach 28,871 MW in 2030 and 55,704 MW in 2040. The ratio of gas will also gradually rise to 21.0% in 2030 and 23.8% in 2040.

❖ **Hydropower**

The installed capacity of hydropower in 2020 was 20,685 MW, 29.9% of the total installed capacity. It will gradually increase and reach 25,992 MW in 2030 and 55,704 MW in 2040. However, the ratio of hydropower will gradually decrease to 18.9% in 2030 and 13.4% in 2040.

❖ **Wind power**

The installed capacity of hydropower in 2020 was 630, 0.9% of the total installed capacity. It will skyrocket and reach 18,010 MW in 2030 and 45,910 MW in 2040. The ratio of wind power will also rise to 13.1% in 2030 and 19.6% in 2040.

❖ **Solar power**

The installed capacity of solar power in 2020 was 16,640, 24% of the total installed capacity. It will gradually increase and reach 18,640 MW in 2030 and 42,340 MW in 2040. However, the ratio of solar power will decrease to 13.5% in 2030 and 18.1% in 2040.

.

Table 2-16 Proposed Installed Capacity of PDP8

Source	2020		2025		2030		2035		2040		2045	
	Capacity [MW]	Ratio	Capacity [MW]	Ratio	Capacity [MW]	Ratio	Capacity [MW]	Ratio	Capacity [MW]	Ratio	Capacity [MW]	Ratio
Coal-fired thermal power	20,431	29.5%	29,523	28.9%	37,323	27.1%	43,843	23.0%	48,383	20.7%	49,918	18.0%
Gas-to-power and oil/diesel - fired thermal power	9,030	13.0%	14,055	13.8%	28,871	21.0%	45,019	23.6%	55,704	23.8%	66,504	24.0%
Hydropower + pumped storage hydropower (including small-scale hydropower)	20,685	29.9%	24,497	24.0%	25,992	18.9%	29,592	15.5%	31,292	13.4%	33,492	12.1%
Wind power	630	0.9%	11,320	11.1%	18,010	13.1%	32,110	16.9%	45,910	19.6%	60,610	21.9%
Solar power	16,640	24.0%	17,240	16.9%	18,640	13.5%	30,290	15.9%	42,340	18.1%	55,090	19.9%
Biomass and other renewable power	570	0.8%	2,050	2.0%	3,150	2.3%	3,860	2.0%	4,510	1.9%	5,310	1.9%
Power import	1,272	1.8%	3,508	3.4%	5,677	4.1%	5,677	3.0%	5,677	2.4%	5,677	2.1%
Total	**69,258**	**100%**	**102,193**	**100%**	**137,663**	**100%**	**190,391**	**100%**	**233,816**	**100%**	**276,601**	**100%**

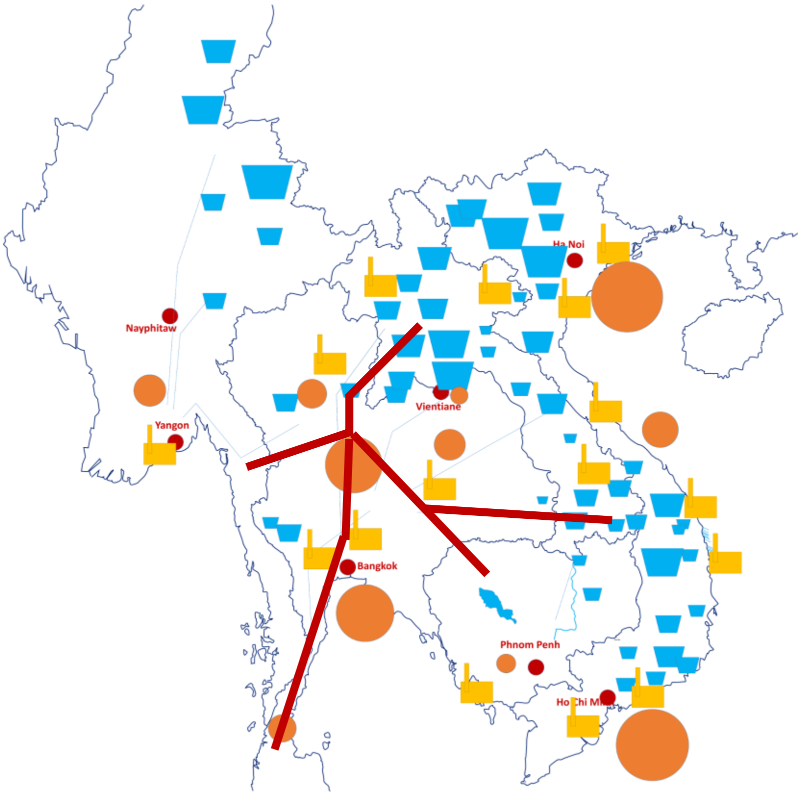
Source: Baker McKenzie, modified by the author.

Chapter 3

Cooperative Operation of Hydropower and Thermal Power in ACMECS Countries

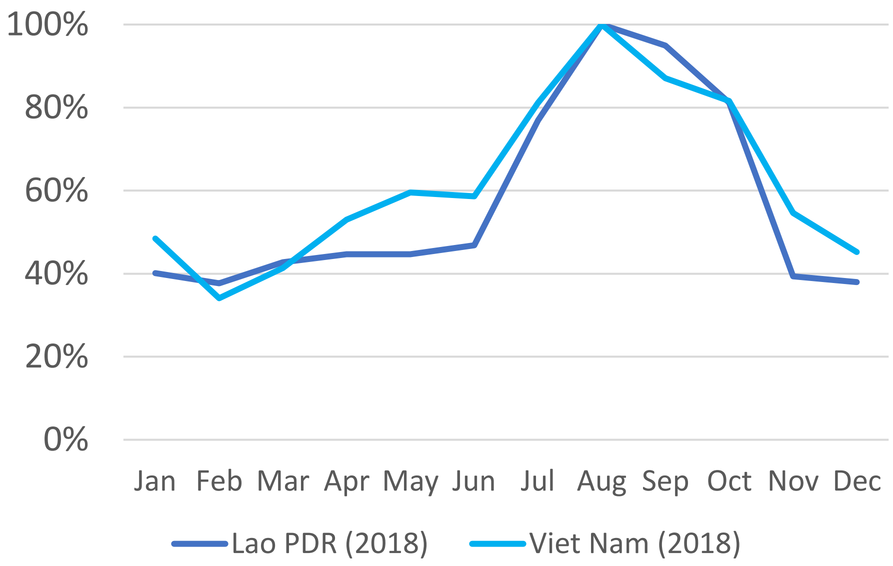
Hydropower plants in the Indochina Peninsula are concentrated in northern Myanmar, the Lao PDR, and Viet Nam. In the Indochina Peninsula, the amount of available electric power energy of hydropower plants during the dry season drops to about 40% of the rainy season. Thus, although reservoir-based hydropower plants are many, the number of plants that can adjust their power output over the year is limited. As a result, the difference in the amount of electric power generated between the rainy and dry seasons is large. The following graph shows monthly trends in electric power energy that hydropower plants in the Lao PDR and Viet Nam can generate.

Figure 3-1 Distribution of Hydropower and Thermal Power Plants and Demand in the Indochina Peninsula



Source: Authors.

Figure 3-2 Monthly Changes in the Amount of Energy that Hydropower Plants in the Lao PDR and Viet Nam Can Generate (2018)



Source: Authors.

On the other hand, there is not much difference between the wet and dry seasons in the electric power demand in the Indochina Peninsula. The total energy generated by hydropower and thermal power plants does not differ significantly between the wet and dry seasons. Therefore, it is necessary to increase the energy generated by hydropower plants and reduce the energy generated by thermal power plants during the rainy season. During the dry season, the amount of energy generated by thermal power plants should be increased. For this reason, ACMECS countries need the coordinated operation of hydropower and thermal power plants using wide-area interconnections.

The locations of hydropower plants in ACMECS countries will be concentrated in the Lao PDR, northern Myanmar, and Viet Nam. The construction of 500 kV interconnections in Thailand will enable the hydropower transmission from the Lao PDR to Cambodia, southern Myanmar, Thailand, and Malaysia, thus contributing to the efficient power generation in the Indochina Peninsula. In this study, we examined the cost of the new 500 kV interconnections connecting the Lao PDR, Myanmar, Thailand, and Viet Nam and the savings in thermal power generation in Myanmar, Thailand, and Viet Nam.

Chapter 4

Existing Cross-Border Interconnections in ACMECS Countries

4.1 Types of Cross-Border Interconnections

Generally, cross-border interconnections are broadly categorised into four types:

1) Cross-border interconnection between main lines (system–to–system AC)
2) DC linkage (system–to–system DC)
3) Cross-border interconnection of generators isolated from the main system (G–to–System)
4) Cross-border interconnections supplying only demand areas isolated from the main system (system–to–L)

The following describes the characteristics of each type.

1) Cross-border interconnection between main lines

This is a mode in which the main systems are interconnected directly by alternating current (AC) and synchronised as an AC system with the same power frequency. It is necessary to balance the output from all the generators synchronised with the grid and the total value of all the loads to maintain the power system frequency. At the same time, the power flow of the cross-border interconnection lines should always be controlled at an appropriate value.

The main power system is planned in such a way as to avoid large power supply interruptions in the domestic power supply system even when severe faults occur, such as a fault on the route of transmission lines with double circuits, because the main system supplies the domestic power demand. To realise this, the plan is structured to have sufficient power generation capacity to automatically control the power supply and demand balance via power generators synchronously connected to the interconnection when the power flow in the interconnection shuts down.

When the interconnection line is connected to the power system via one route with double circuits and the one route fails, the power flow in the interconnection line instantaneously drops out from the system, the power supply and demand balance of the system collapses, and the system frequency fluctuates wildly.

To keep the frequency at the permissible value, it is necessary to adjust the power supply and demand balance via automatic adjustment of the output by the generator’s governor, disconnection of the generator, or an emergency response such as load shedding, .

However, maintaining the supply and demand balance will be difficult if the power system has less margin for adjustment. In the worst case, the system frequency can exceed the allowable value, causing a large-scale power supply interruption in the overall system.

To avoid this and maintain the frequency at an allowable value via power output adjustment, disconnection of the synchronously connected power generators, or partial load shutdown even when one route with double circuits fails, it is necessary to limit the power flow of the line. The power system should also have sufficient controllable capacity for synchronous power generation facilities.

2) DC linkage (system–to–system DC)

Cross-border Interconnection can be carried out via direct current (DC) power transmission lines with an AC/DC converting station or AC/AC converting stations at both ends. The power flow in the connecting line can be maintained at a specific value. The power flow in the cross-border interconnection line can also be specified regardless of the balance between the power generation amount in the system and the demand for electric power. This specified value can easily be changed. For this reason, the influence on the frequency of the neighbouring countries is small, and these countries can follow the frequency control methods by controlling generator outputs. However, the disadvantage is that the costs of AC/DC converter stations are high, and the converter temporarily stops due to instantaneous voltage drop in the case of a fault at an AC transmission line.

In DC interconnection, the converter controls the power flow in the cross-border interconnection line. As a result, the generators are not synchronised with the power system of the neighbouring country. Therefore, the degree of restriction in the generators' specification by the grid code of the neighbouring country is small.

However, the generators should control the power output and maintain the frequency according to the power flow of the cross-border interconnection line. In addition, to operate the DC transmission line stably, power system stability should be maintained to prevent interaction between AC and DC. Therefore, it is necessary to make the short-circuit capacity (inverse number of the system capacity) at the interconnection point on the AC system sufficiently large relative to the capacity of the interconnection line. However, stability can be maintained if self-excited[2] converters are adopted. For this reason, to adopt DC linkage in a power system whose capacity is small, and when it is difficult to adjust the frequency in the system itself, synchronising the system with that of neighbouring countries with larger capacities is desirable.

3) Cross-border interconnection of generators isolated from the main system (G–to–system)

The transmission lines operated by the export IPPs as export-exclusive interconnections are operated as interconnections of generators isolated from the main system. A group of generators directly connected to a neighbouring country's system by a dedicated transmission line drops out of the grid in the event of a one-route accident on the dedicated transmission line. However, if the system capacity of the neighbouring country is sufficiently large, it is possible to maintain the correct frequency using synchronous generators within the neighbouring country. In addition, the dropout of the generator group will not affect the power supply of its own country. For this reason, with respect to a power plant or a group of power stations independent from the main system, the generator group is permitted to fall off during a one-route accident on the interconnection line. Of course, the power flow in the interconnection line needs to be made small enough for the other countries.

So far, we have described the types of cross-border interconnections. For example, for an AC interconnection, the generators are synchronised with the power system of the neighbouring country. For this reason, as described above, cooperation on the grid codes for interconnected systems is necessary. Also, the specifications of the generators and protection relay devices' installation must

[2] In these machines, instead of a separate voltage source, the field winding is connected across the main voltage terminals.

satisfy the requirements of neighbouring countries' grid codes. In addition, the generators follow the power dispatching orders from the neighbouring country. Alternatively, the home country must control the power flow in the cross-border interconnection properly and in cooperation with the power dispatching orders from the neighbouring country.

4.2 Existing Cross-Border Interconnections in ACMECS Countries

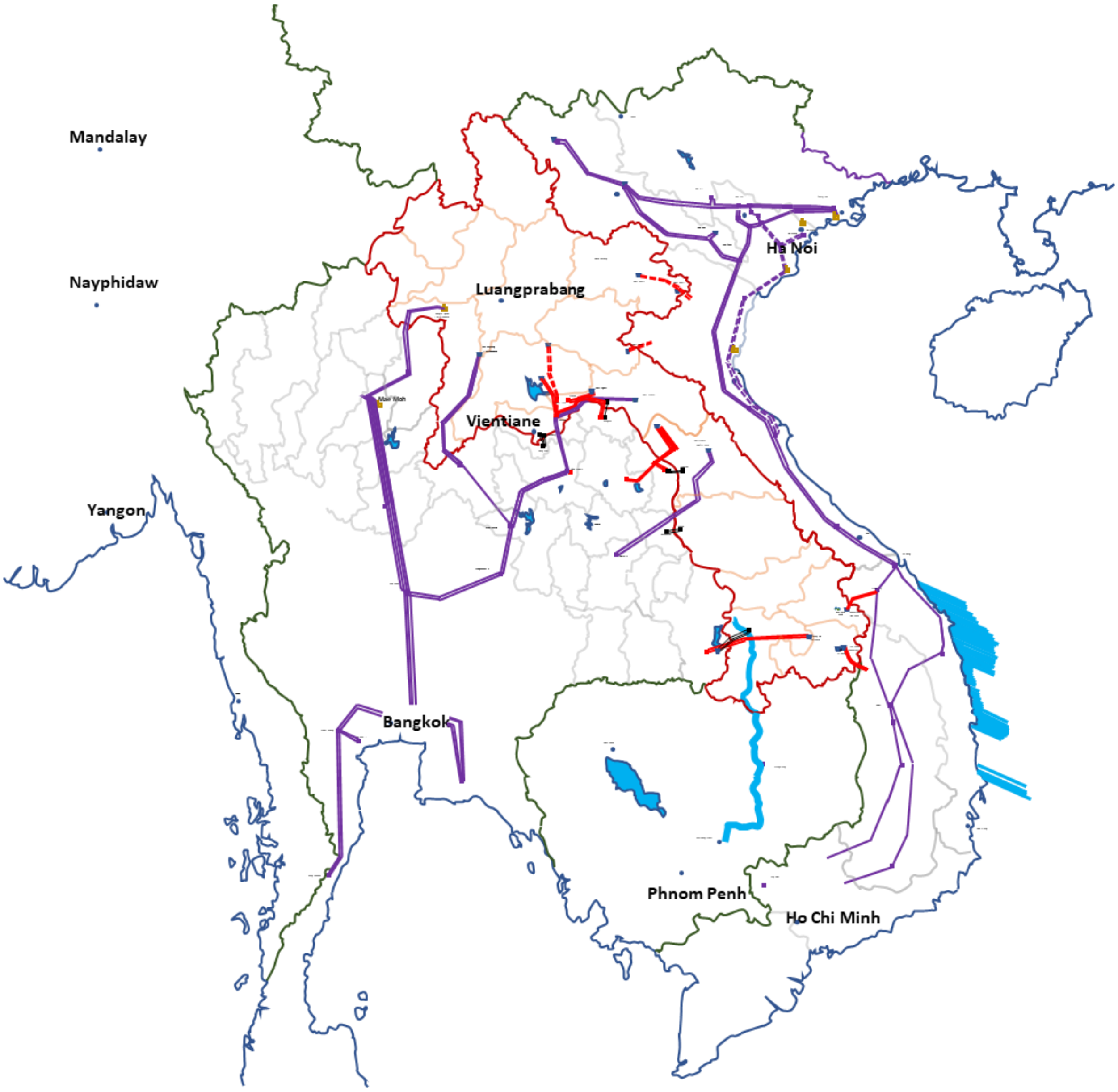
ACMECS already has many cross-border interconnections. However, many of them are transmission lines with low voltage levels. Table 4-1 shows the existing cross-border interconnections with voltage levels greater than 220 kV; Figure 4-1 depicts these cross-border interconnections.

Table 4-1 Existing Cross-Border Interconnections in ACMECS, at 220 kV or More

Country (From)	Country (To)	Section	Voltage [kV]	No. Circuits	Length [km]
Lao PDR	Thailand	Nam Theun 2 (HPP) - Roi Et 2	500	2	304
Lao PDR	Thailand	Nam Ngum 2 - Na Bong – UdonThani 3	500	2	187
Lao PDR	Thailand	Hongsa (TPP) - Nan - Mae Moh 3	500	2	325
Lao PDR	Thailand	HoouayHo (HPP) – UbonRachaThani 2	230	2	230
Lao PDR	Thailand	Theun Hinboun (HPP) - Ban Veun SwS - Nakhon Phanon 2	230	2	176
Lao PDR	Viet Nam	Xekaman 3 HPP - Thanh My	220	2	111
Lao PDR	Viet Nam	Xekaman 1 HPP (Hatxan) - Pleiku	220	2	115
Viet Nam	Cambodia	Chou Doc - Takeo - Phnom Penh	220/230	2	120

Source: World Bank (2019), JICA (2020b), MEM, MME data, modified by the author.

Figure 4-1 Existing Cross-Border Interconnectors and Main 500 kV Transmission Lines in ACMECS

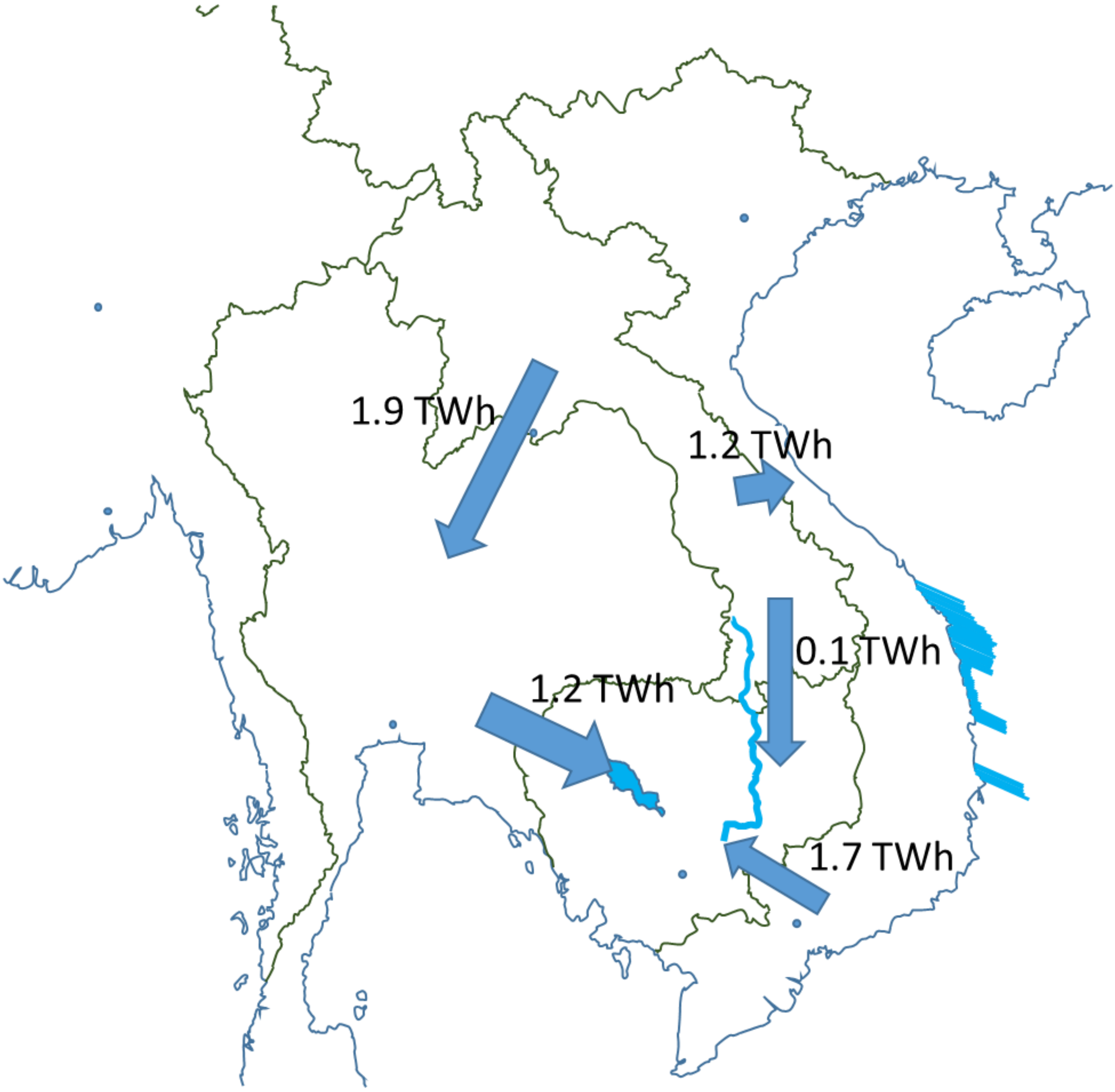


Source: Authors.

4.3 Current Power Exchange amongst ACMECS Countries

The overview of the current power exchange in ACMECS is shown in Figure 4-2. As of 2019, the Lao PDR exported 1.9 TWh of electricity to Thailand, 1.2 TWh of electricity to Viet Nam, and 0.1 TWh of electricity to Cambodia. Thailand exported 1.2 TWh of electricity to Cambodia, and Viet Nam exported 1.7 TWh of electricity to Cambodia. Figure 4-2 shows that the Lao PDR plays a central role in electricity exports in ACMECS countries.

Figure 4-2 Overview of Current Power Exchange in ACMECS (as of 2019)



Source: EGAT, EVN, MME data, modified by the author.

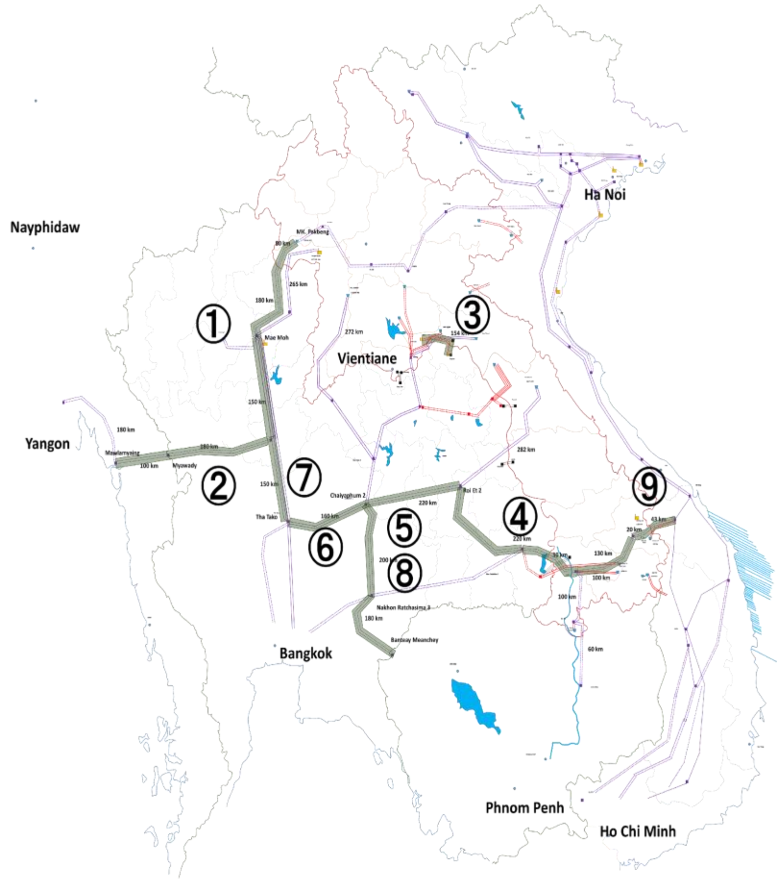
Chapter 5

Candidate Cross-Border Interconnections for the Transmission Highway in ACMECS

5.1 Summary of Candidate Interconnections

Figure 5.1 shows the locations of the interconnections assumed to be newly constructed. Table 5.1 shows their voltages and distances.

Figure 5-1 Candidate Cross-Border Interconnections for the Transmission Highway



Source: Authors.

Table 5-1 Sections of Interconnections Assuming New Construction

Section.		Voltage (kV)	No. Circuits	Length (km)
(1)	MK. Pakbeng – (Mae Moh–Tha Tako)	500 kV	2	415
(2)	(Mae Moh–Tha Tako) – Mawlamyaing	500 kV	2	280
(3)	Vientiane–Bunkan	230 kV	2	58
(4)	Xekong–Roi Et	500 kV	2	368
(5)	Roi Et–Chaiyaphum	500 kV	2	230
(6)	Chaiyaphum–Tha Tako	500 kV	2	160
(7)	Tha Tako – (Mae Moh–Tha Tako)	500 kV	2	150
(8)	Chaiyaphum–Banteay Meanchey	500 kV	2	380
(9)	Thanh My–Xekong	500 kV	2	108

Source: Authors.

5.2 Surge Impedance Loading (SIL)

To assess the 'loadability' of transmission lines, engineers generally use the concept of surge impedance loading (SIL). SIL is generally accepted in the industry as a convenient reference to estimate loading limits on transmission lines. Equation (1) expresses the formulation of SIL.

$$SIL = \frac{kV^2 \times 10^3}{Z_0} MW \quad (1)$$

Where:

SIL: surge impedance loading

kV: voltage of transmission line

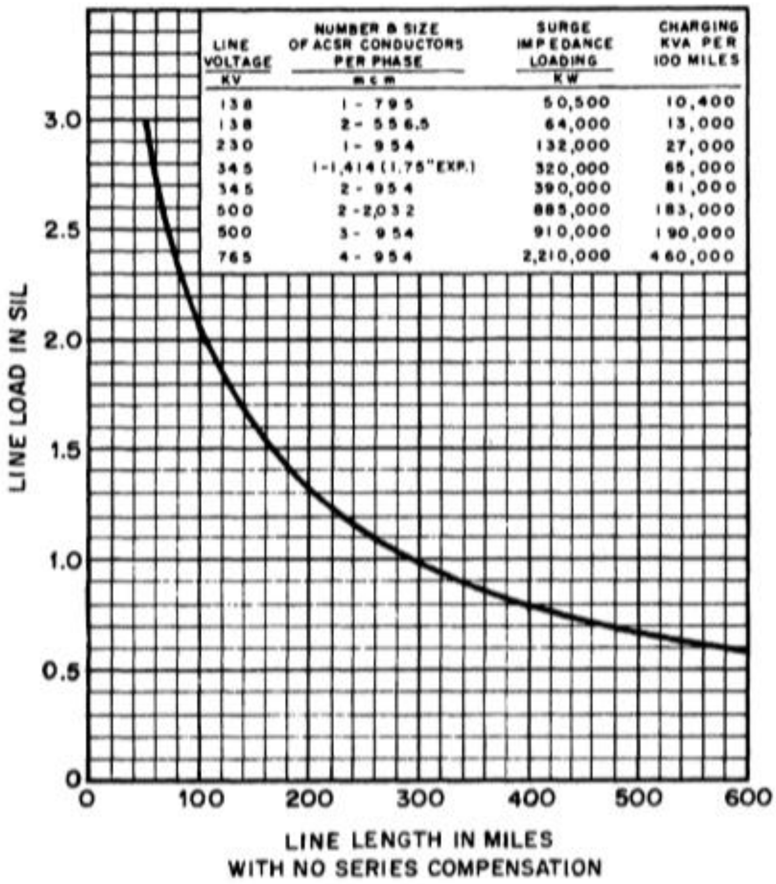
Z_0: surge impedance

SIL depends on the voltage of the transmission line. In other words, since the surge impedance is almost constant once the number of conductors is determined, the transmitted power can be obtained regardless of the voltage.

The SIL curve is shown in Figure 5-2. This figure means that when SIL is 1 and the length of the transmission is 300 miles (480 km), the loadabilities of the transmission line are 910 MW/cct at 500 kV and 132 MW/cct at 230 kV, respectively. Also, when SIL is 1, the transmission lines of that length operate with very little or no reactive power supplied from either end, owing to the equalisation of stored inductive and capacitive energy that oscillates between the magnetic and electric fields of the transmission line. However, suppose the power flow becomes a heavily loaded condition, the reactive power consumption increases, and the power system voltage drops. Therefore, the reactive power should be compensated to maintain the power system voltage.

Based on the above, this study assumes that the transmission line capacities are about 1,000 MW/cct at 500 kV and about 150 MW/cct at 230 kV, respectively. When converted into the annual capacity, it is about 8.8 TWh/year at 500 kV and 1.3 TWh/cct at 230 kV.

Figure 5-2 Curve of Surge Impedance Loading



Source: Dunlop, Gutman, and Marchenko (1979).

5.3 Assumptions for Estimating the Construction Cost of Candidate Cross-Border Interconnections

The interconnections are assumed to be 500 kV except for (3) Vientiane–Bunkan of 230 kV double circuits per route (Table 5-1). The costs of substations are assumed to prepare switchyard facilities for double circuit transmission lines. Table 5-2 shows the set unit costs.

Table 5-2 Unit Prices for Transmission Lines and Substation Switchyard Facilities

Type	Unit Price [million US$]
500 kV Transmission Line	0.62
500 kV Substation 2 bays	6.2
230 kV Transmission Line	0.31
230 kV Substation 2 bays	3.0

Source: Authors.

The cost estimate for each section of the interconnections is shown in Table 5-3.

Table 5-3 Costs of Each Section of Interconnections

		Length km	S/S m.US$	T/L m.US$	Total m.US$
1	**500 kV MK. Pakbeng - (Mae Moh - Tha Tako)**				
	MK. Pakbeng		6.2		6.2
		95		58.9	58.9
	Border		12.4		12.4
		170		105.4	105.4
	Mae Moh		12.4		12.4
		150		93	93
	(Mae Moh - Tha Tako)		6.2		6.2
	Total	415	37.2	257.3	294.5
2	**500 kV (Mae Moh - Tha Tako) - Myanmar**				
			6.2		6.2
		180		111.6	111.6
	Myawady		12.4		12.4
		100		62	62
	Mawlamyaing		6.2		6.2
	Total	280	24.8	173.6	198.4
3	**230 kV Vientiane - Bunkan**				
	Thabok		3		3
		58.03		17.99	17.9893
	Bungkan		3		3
	Total	58.0	6.0	17.99	24.0
4	**500 kV Xekong - Roi Et**				
	Xekong		6.2		6.2
		128		79.36	79.36
	Lak25		12.4		12.4
		60		37.2	37.2
	Ubon Ratchathani		12.4		12.4
		180		111.6	111.6
	Roi Et		6.2		6.2
	Total	**368**	**37.2**	**228.2**	**265.36**

		Length km	S/S m.US$	T/L m.US$	Total m.US$
5	**500 kV Roi Et - Chaiyaphum**				
	Roi Et		6.2		6.2
		230		142.6	142.6
	Chaiyaphum		6.2		6.2
	Total	230	12.4	142.6	155
6	**500 kV Chaiyaphum - Tha Tako**				
	Chaiyaphum		6.2		6.2
		160		99.2	99.2
	Tha Tako		6.2		6.2
	Total	160	12.4	99.2	111.6
7	**500 kV Tha Tako - (Mae Moh - Tha Tako)**				
	Tha Tako		6.2		6.2
		150		93	93
	Middle between Mae Mo & Tha Tako		6.2		6.2
	Total	150	12.4	93	105.4
8	**500 kV Chaiyaphum - Banteay Meanchey**				
	Chaiyaphum		6.2		6.2
		200		124	124
	Nakhon Ratchasima		12.4		
		180		111.6	111.6
	Banteay Meanchey		6.2		6.2
	Total	380	24.8	235.6	248
9	**500 kV Thanh My - Xekong**				
	Thanh My		6.2		6.2
		43		26.66	26.66
	Monsoon Wind Farm		12.4		12.4
		65		40.3	40.3
	Xekong		6.2		6.2
	Total	**108**	**24.8**	**66.96**	**91.76**
	Transmission Highway total				
	Including Thailand domestic				1,494.0
	Without Thailand domestic				1,122.0

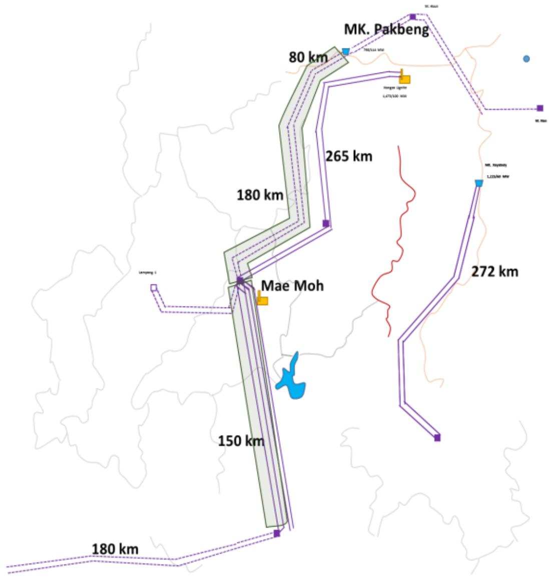
Source: Authors.

5.4 Overview of Each Transmission Line Route

5.4.1 **Route (1): 500 kV MK. Pakbeng – (Mae Moh–Tha Tako)**

MK. Pakbeng in the Lao PDR is a planned IPP and, although not a definite project, is a strong candidate for export to Thailand. MK. Pakbeng will likely be connected to EGAT's Mae Moh substation by a 500 kV export-dedicated transmission line. Four 500 kV circuits are currently operating from Mae Moh to Tha Tako. In this project plan, a new switching station from Mae Moh to Tha Tako and a new transmission line from the Mae Moh substation to this switching station are planned to be built. The power will flow from MK. Pakbeng to EGAT. In the rainy season, the surplus power from the Lao domestic grid will be added to MK. Pakbeng. During the dry season, the amount of electric power transmitted to Thailand will be less because the electric power will be supplied to the domestic grid of the Lao PDR.

Figure 5-3 500 kV MK. Pakbeng – (Mae Moh–Tha Tako)

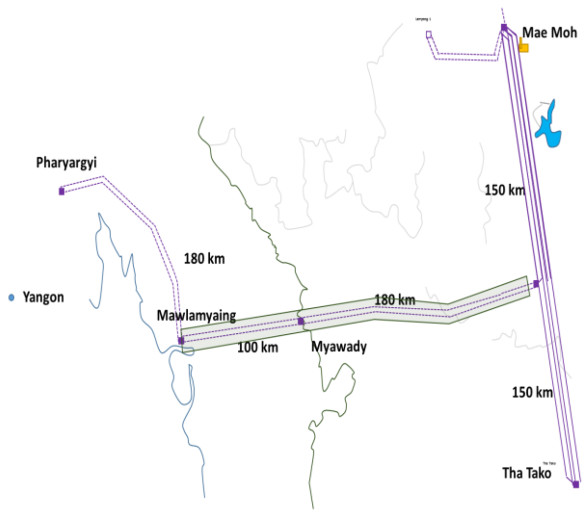


Source: Authors.

5.4.2 Route (2): 500 kV (Mae Moh–Tha Tako) – Mawlamyaing

This transmission line is an interconnection between the grids of EGAT and the Department of Power Transmission and System Control in Myanmar. A 230 kV transmission line was completed between Mawalamyaing and Myawaddy in Myanmar. This project assumes constructing a new 500 kV transmission line from the switching station on the route from Mae Moh to Tha Tako to Mawlamyaing via Myawaddy. The power will flow from Thailand to Myanmar.

Figure 5-4 500 kV (Mae Moh–Tha Tako) – Mawlamyaing

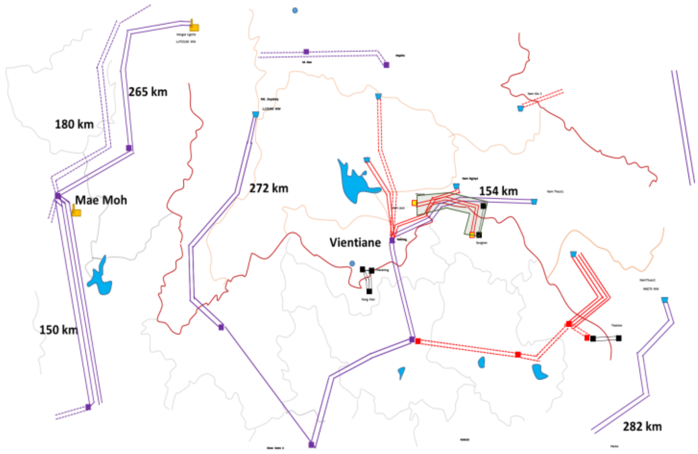


Source: Authors.

5.4.3 Route (3): 230 kV Vientiane–Bunkan

This transmission line is a 230 kV interconnection between the systems of the EDL and EGAT. Currently, a 115 kV single circuit line operates from EDL's 115 kV Pakxan substation near Vientiane to the Bungkan substation in the EGAT system. In recent years, the power plant capacity of the EDL system increased, leading to a rise in the power flow of this interconnection. The project involves constructing a new 230 kV interconnected transmission line along the route of this transmission line. The power will flow from the Lao PDR to Thailand during the rainy season and from Thailand to the Lao PDR during the dry season.

Figure 5-5 230 kV Vientiane–Bunkan

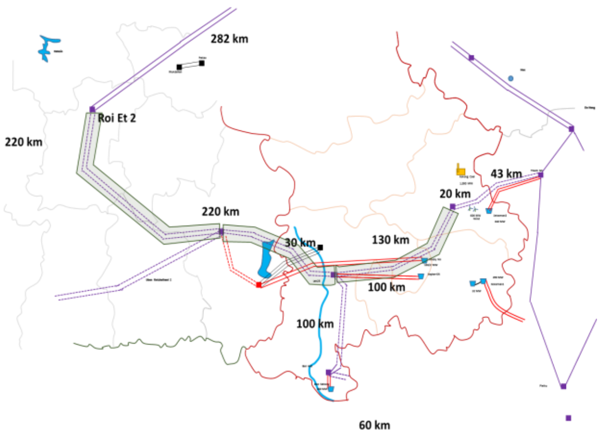


Source: Authors.

5.4.4 Route (4): 500 kV Xekong–Roi Et

Xepian–Xenamnoi's IPP is constructing a 500 kV Lak 25 substation in Champasak province, Lao PDR, and a 500 kV transmission line from Lak 25 to EGAT's Ubon substation. In addition, the transmission lines assumed for the project are those from Xekong province to Lak 25 in the Lao PDR and between Ubon and Loi Et. Thus, the transmission power will flow from the Lao PDR to Thailand.

Figure 5-6 500 kV Xekong–Roi Et

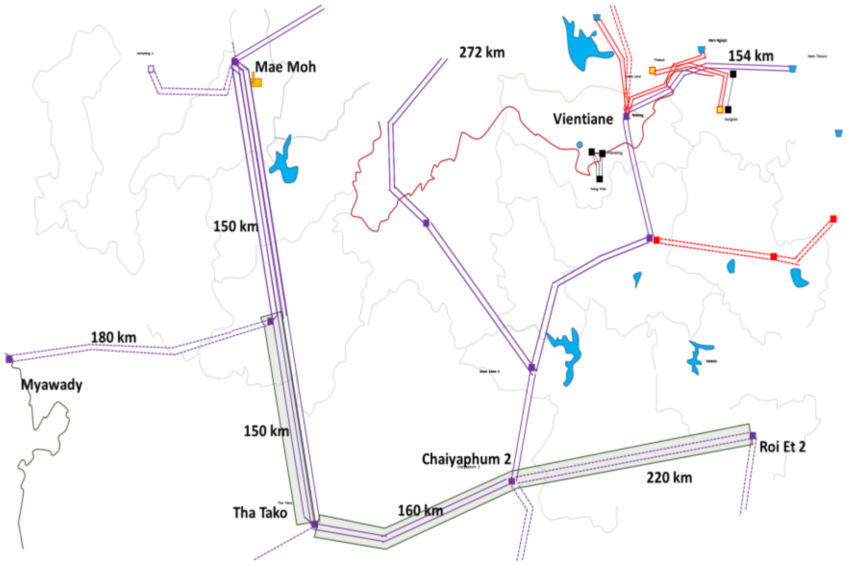


Source: Authors.

5.4.5 Route (5): 500 kV Roi Et–Chaiyaphum, Route (6): 500 kV Chaiyaphum–Tha Tako, Route (7): 500 kV Tha Tako – (Mae Moh–Tha Tako)

Routes (5), (6), and (7) in Table 5-1 are 500 kV transmission lines for transmitting power from the Lao PDR received in eastern Thailand to central and western Thailand. Some existing 500 kV lines were already constructed. And depending on the amount of the power flow, the existing lines could be used for the project.

Figure 5-7 500 kV Roi Et–Chaiyaphum–Tha Tako – (Mae Moh–Tha Tako)

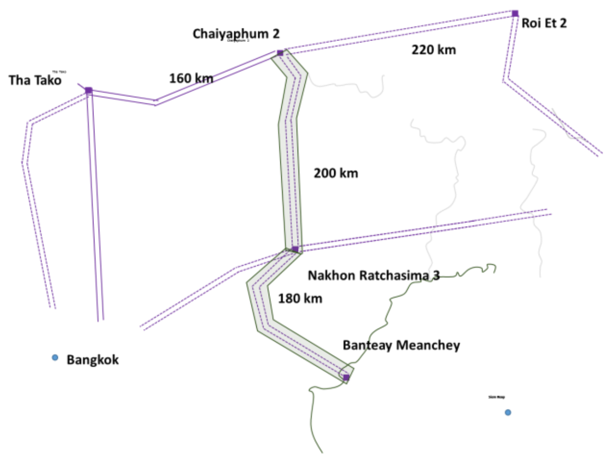


Source: Authors.

5.4.6 Route (8): 500 kV Chaiyaphum–Banteay Meanchey

A 115 kV line connects Thailand and Cambodia. The new interconnection is assumed to be between the Cambodian border point of 115 kV interconnection and Nakhon Ratchasima. The transmission line between Chaiyaphum and Nakhon Ratchashima in Thailand is also a transmission line for the project. The power will flow from Thailand to Cambodia.

Figure 5-8 500 kV Chaiyaphum–Banteay Meanchey

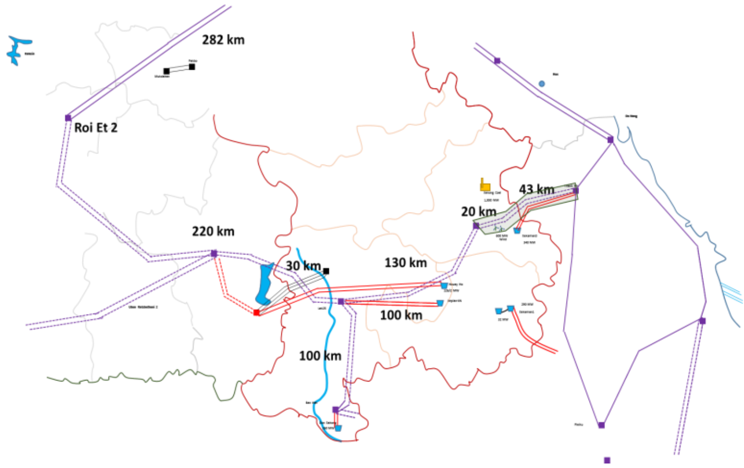


Source: Authors.

5.4.7 Route (9): 500 kV Thanh My–Xekong

There is a plan for a wind farm in Xekong province, Lao PDR. Our project assumes that the transmission line will consist of double circuits from the wind farm to the Thanh My substation in Viet Nam. The power will be transmitted to Viet Nam in addition to power from neighbouring domestic power plants on the domestic grid of the Lao PDR. The power will flow from the Lao PDR to Viet Nam.

Figure 5-9 500 kV Thanh My–Xekong



Source: Authors.

Chapter 6

Power Exchange through the Transmission Highway

6.1 Exported Power Generation from the Lao PDR through the Transmission Highway

6.1.1 Power generation in the Lao PDR exported through candidate cross-border interconnections

The electric energy to be transmitted from the Lao PDR through the new interconnections is from the increase in energy export volume from the domestic power grid and new export-dedicated IPPs of the country. In addition, the rise in energy import from Thailand into the domestic power grid of the Lao PDR during the dry season is also expected.

6.1.2 Increase in export from the domestic power system of the Lao PDR

During the rainy season, the power generators in the domestic power grid of the Lao PDR produce a surplus of electric power. However, the capacity of the interconnections with Thailand is insufficient to transmit all the surplus power. When interconnections (1) and (3) with Thailand (Table 5.1) operate, the interconnection capacity will expand, and the amount of surplus power exported to Thailand from domestic power supply generators will increase. This increase is calculated from Lao PDR's power supply and demand balance and factored into the rise in the country's hydropower generation. Interconnection line (4) will only transmit electricity from the export-dedicated IPPs.

During the dry season, the power output of hydropower plants in the domestic power grid of the Lao PDR declines, requiring imports from Thailand. Although building a new thermal power plant to secure electric power for the dry season is possible, the amount of electric power imported from Thailand through new interconnection lines in (1) and (4) is estimated to be the amount of electric power that can secure the power supply in the dry season.

Table 6-1 Increase in Imports from Thailand to the Domestic Power Grid of the Lao PDR (Annual) (Unit: GWh)

	2030	2035
Import from Thailand due to existing interconnected capacity	780	1,742
Imports from Thailand by expanding the interconnection (+1000MW*)	780	4,224
Increase in imports from Thailand	0	2,482

*MK. Pakbeng vacancy and the increase in interconnection capacity due to the linkage between the vicinity of 230 kV Vientiane and Thailand
Source: Authors.

6.1.3 New IPPs for exporting

Table 6-2 lists the export-dedicated IPPs in the Lao PDR to Thailand. Existing plants are (1), (2), (7), (8), and (14), and (13) Xepien–Xenamnoy hydropower plant is under construction in southern Lao PDR. The planned (9) MK. Pakbeng hydropower plant in the north and the hydropower plants in Sekong province in the south of (10) to (12) are expected to account for the increase in Lao's hydropower in 2030. IPPs (10) to (12) are expected to be transmitted to Thailand by the export-dedicated lines under construction at the (13) Xepien–Xenamnoy hydropower station.

Table 6-2 Export-dedicated IPPs in the Lao PDR to Thailand

Power Plant	MW	Type.	COD	Status	Remarks
Theun-Hinboun	440.0	Reservoir	1998	existing	existing export-dedicated line
Nam Theun 2	1,000.0	Reservoir	2009	existing	existing export-dedicated line
Nam Ngum 2	615.0	Reservoir	2010	existing	Existing export-dedicated lines (Nabong substation)
Nam Ngum 3	480.0	Reservoir	2020	under construction	Existing export-dedicated lines (Nabong substation)
Nam Ngiep 1	294.0	Reservoir	2019	existing	Existing export-dedicated lines (Nabong substation)
Nam Theun 1	520.0	Reservoir	2022	under construction	Existing export-dedicated lines (Nabong substation)
Hongsa Lignite (T)	1,778.0	Thermal	2015	existing	Existing export-dedicated line
MK. Xayaboury	1,225.0	Run of river	2019	existing	Existing export-dedicated line
MK. Pakbeng	798.0	Run of river			Planned export-dedicated lines (including part of Table 5-1 (1))
Sekong 5	330.0	Reservoir			
Xekong 4A	175.0	Reservoir			
Xekong 4B	165.0	Reservoir			
Xepien - Xenamnoy	370.0	Reservoir	2019	under construction	Export-dedicated lines under construction (including part of Table 5-1 (4))
Houay Ho	150.0	Reservoir			Existing export-dedicated line to be returned from IPP to Lao PDR with 2029 BOT deadline

BOT = build-operate-transfer
Source: Authors.

In addition to the above, the wind power station in Attapeu province, which was considered for Viet Nam, was expected to be used for wind farms.

6.1.4 IPPs in the Lao PDR for exporting to Thailand and Viet Nam

Table 6.3 shows the IPPs in the Lao PDR to be exported by candidate interconnections.

Table 6-3 IPPs in the Lao PDR Exported by Candidate Cross-Border Interconnections

Power Station	Rated Capacity [MW]	Annual Generation [GWh/year]
MK. Pakbeng	798	4,169
Sekong 5	330	1,613
Xekong 4A	175	781
Xekong 4B	165	749
Xepien - Xenamnoy (e) ***	370	1,794
Wind power in Attapeu	600	1,505
Total	**2,438**	**10,611**

*** Existing contracts
Source: Authors.

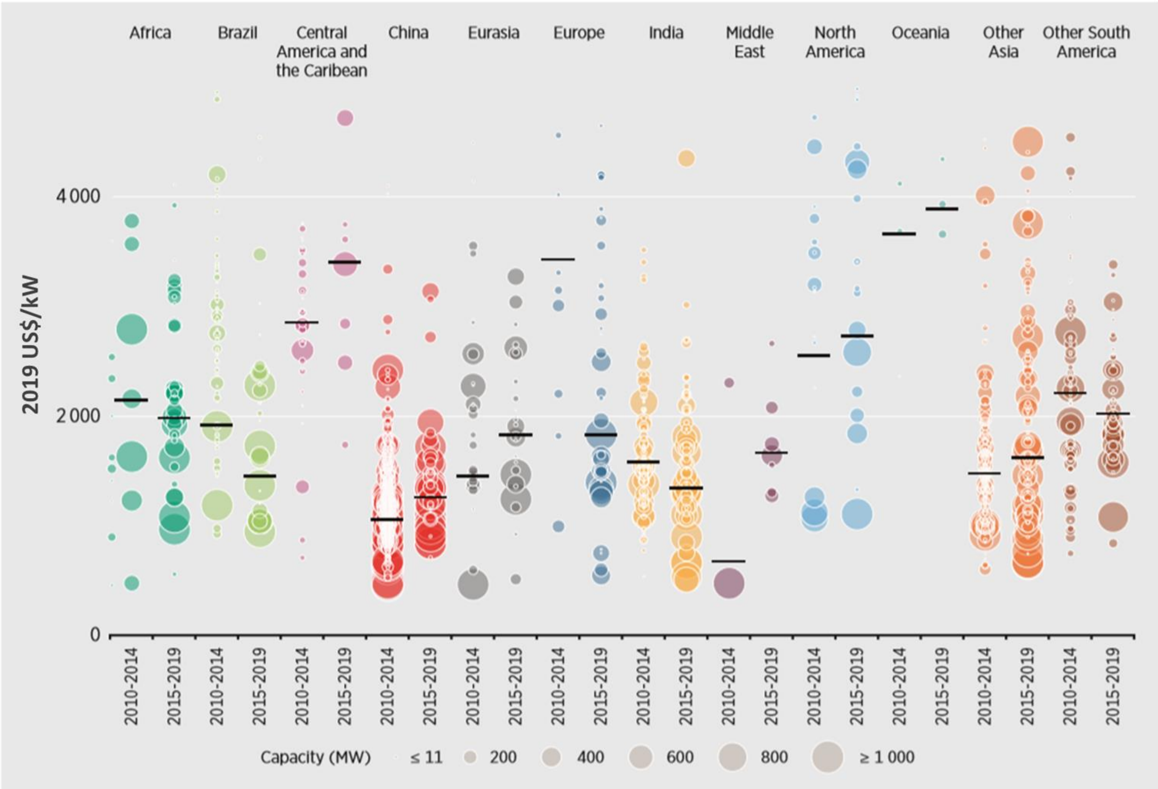
6.1.5 Assumptions for installation cost estimation of new power stations

According to IRENA (2019), the total installed cost varies from region to region. The total installed hydropower costs are highest in Oceania, Central America, and the Caribbean, while lowest in China and India (Figure 6-1). The IRENA study divided total installed costs in Asia amongst China, India, and others. Since the development of hydropower assumed in this survey is a plan in the Lao PDR to calculate the construction cost of the hydropower plant, this survey referred to the cost of China, which is US$1,264/kW.

On the other hand, the total installed costs for onshore wind are highest in Other Asia, Middle East and Africa, Europe, Central America and the Caribbean, South America (excluding Brazil), and Oceania. Brazil, China, and India have more mature markets and lower cost structures than their neighbours (Table 6-4). Similar to hydropower, to calculate the construction cost of the onshore wind power plant, this survey referred to the cost of China, which is US$1,223/kW.

Table 6-5 shows the cost estimate for each new power station. The total installation cost of new IPPs is US$4,016 million.

Figure 6-1 Total Installed Cost Ranges and Capacity Weighted Averages for Large Hydropower Projects, by Country and Region



Source: IRENA (2019).

Table 6-4 Total Installed Cost Ranges and Weighted Averages for Onshore Wind Projects, by Country and Region, 2010 and 2019

	2010			2019		
	5th percentile	Weighted average	95th percentile	5th percentile	Weighted average	95th percentile
	(2019 US$/kW)					
Africa	2,226	2,291	3,196	1,448	1,952	2,189
Other Asia	1,829	2,501	2,762	1,392	2,368	3,709
Central America and the Caribbean	2,497	2,664	2,787	1,737	1,737	1,737
Eurasia	2,284	2,432	2,501	1,277	1,633	2,035
Europe	1,575	2,405	3,602	1,071	1,800	2,233
North America	1,594	2,407	3,696	1,099	1,636	2,162
Oceania	2,993	3,501	3,882	1,157	1,555	1,788
Other South America	2,399	2,644	2,729	1,123	1,718	2,270
Brazil	2,252	2,539	2,603	1,224	1,559	2,061
China	1,173	1,491	2,038	1,115	1,223	1,340
India	1,013	1,412	1,941	1,039	1,055	1,082

Source: IRENA (2019).

Table 6-5 Installation Cost of New IPPs

Power Station	Rated Capacity [MW]	Installation cost [mil. US$]
MK. Pakbeng	798	1,009
Xekong 5	330	417
Xekong 4A	175	221
Xekong 4B	165	209
Xepien - Xenamnoy (e) ***	370	468
Wind power in Attapeu	600	734
Total	**2,438**	**3,057**

*** Existing contracts.
IPP = independent power producer.
Source: Authors.

6.2 Power Exchange Settings

Table 6-6 shows the power exchange settings for study analysis.

Table 6-6 Power Exchange Settings for Study Analysis (GWh/year)

Power Station and Power Exchange	2030	2035	Type	Power generation	Power receiving
Increase in exports from Lao PDR to Thailand	2,563	1,404	Hydropower	Lao PDR	Thailand
Increase in imports from Thailand to Lao PDR	0	2,482	Thermal power	Thailand	Lao PDR
MK. Pakbeng	4,169	4,169	Hydropower	Lao PDR	Thailand
Xekong 5	1,613	1,613	Hydropower	Lao PDR	Viet Nam
Xekong 4A	781	781	Hydropower	Lao PDR	Viet Nam
Xekong 4B	749	749	Hydropower	Lao PDR	Viet Nam
Xepien - Xenamnoy ***	1,794	1,794	Hydropower	Lao PDR	Thailand
Wind power in Attapeu	1,505	1,505	Wind power	Lao PDR	Viet Nam
Increase in export from Thailand to Myanmar	6,000	6,000	Import from Lao PDR	Thailand	Myanmar
Increase in export from Thailand to Cambodia	2,000	2,000	Import from Lao PDR	Thailand	Cambodia

*** Existing contracts.
Source: Authors.

Table 6-7 lists the power sources that will be transmitted by candidate cross-border interconnections.

Table 6-7 Power Sources for Candidate Cross-Border Interconnections

	Section.	Independent Power Plant (IPP)	Power Sources
(1)	MK. Pakbeng – (Mae Moh–Tha Tako)	MK. Pakbeng	(Rainy seasons) Increase in exports to Thailand from domestic power grid of Lao PDR x 1/2 (Dry seasons) Increase in imports to domestic power grid of Lao PDR Lao from Thailand x 1/2
(2)	(Mae Moh–Tha Tako) – Mawlamyaing		Export from Thailand to Myanmar
(3)	Vientiane–Bunkan		(Rainy seasons) Increase in exports to Thailand from domestic power grid of Lao PDR x 1/2 (Dry seasons) Increase in imports to domestic power grid of Lao PDR Lao from Thailand x 1/2
(4)	Xekong–Roi Et	Xepien–Xenamnoy	
(8)	Chaiyaphum–Banteay Meanchey		Export from Thailand to Cambodia
(9)	Thanh My–Xekong	Wind power in Attapeu, Xekong 5, 4A, 4B	

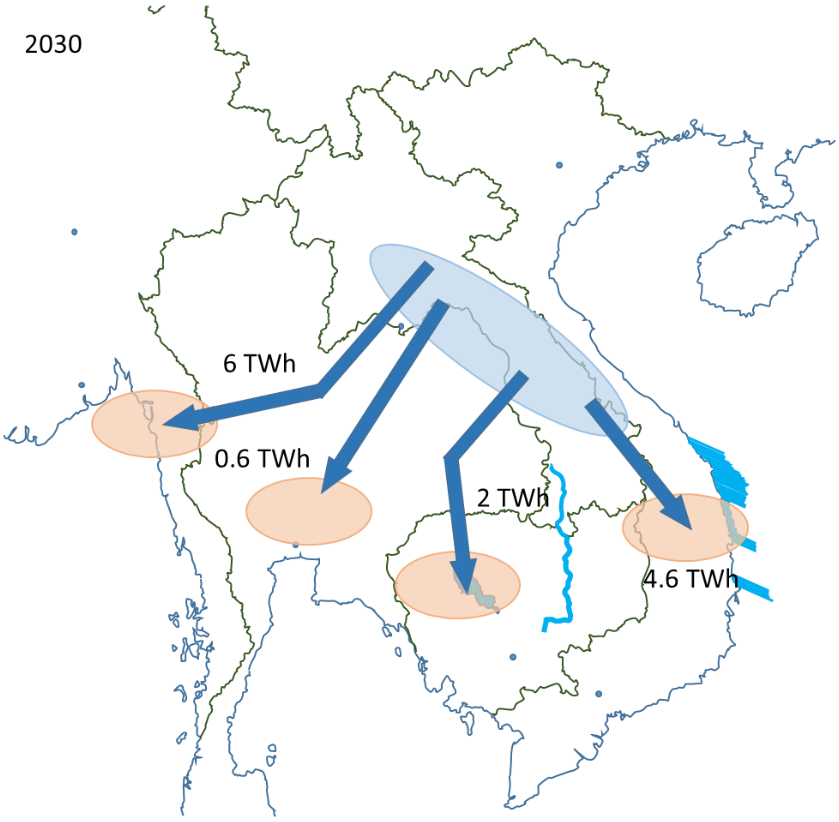
Source: Authors.

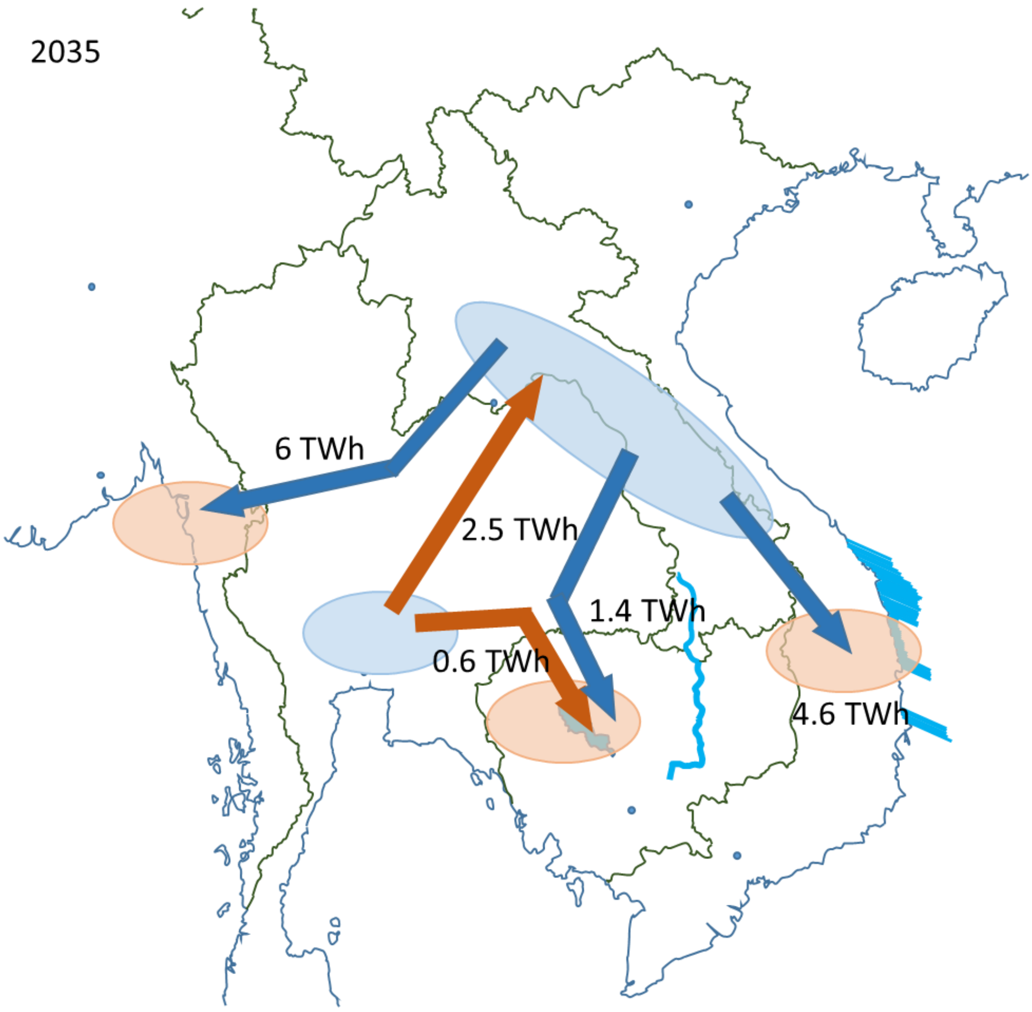
6.3 .Expected Power Trade

Figure 6-2 shows the expected power trade amongst ACMECS countries. The country with increased energy generated is the sending end of the flow, and the country with decreased energy generated is the receiving end of the flow. Here, the power flow assumptions did not include existing power trade but assumed the amount of power flow for which new power trades are expected.

The Lao PDR could export additional power energy to Cambodia, Myanmar, Thailand, and Viet Nam. The Lao PDR exports 6 TWh of power energy to Myanmar via Thailand, 0.6 TWh to Thailand, 2 TWh to Cambodia via Thailand, and 4.6 TWh to Viet Nam in 2030. The power demand in the Lao PDR increases, and power trade condition changes from 2030 to 2035. The Lao PDR exports 6 TWh of power energy to Myanmar via Thailand, 1.4 TWh to Cambodia via Thailand, and 4.6 TWh to Viet Nam, while Thailand exports 2.5 TWh to the Lao PDR and 0.6 TWh to Cambodia in 2035.

Figure 6-2 Expected Power Trade





Source: Authors.

6.4 Changes in the Amount of Power Generation in Each Country through the Transmission Highway

The changes in the amount of electricity generated in each country due to the power trade are compared with each country's supply and demand balance in the energy outlook (ERIA, 2019).

Some of the new hydropower plants shown in Table 6-2 already seem to be included in the 2030 and 2035 hydropower plants in the energy outlook (ERIA, 2019). Still, no breakdown is available, so the increase in the amount of energy generated by hydropower plants in the Lao PDR from the original figures is not known. However, changes in the amount of energy generated by thermal power plants in Cambodia, Myanmar, Thailand, and Viet Nam can be considered changes from the original figures.

In Cambodia, the power demands are about 20 TWh in 2030 and 27 TWh in 2035. According to discussions with the MME in working group meetings, the power imports account for less than 10% of power generation in terms of energy security. Thus, the electricity exports to Cambodia are assumed to be 2 TWh: 0.5 TWh of imported energy for reduced thermal power generation, and the remaining 1.5 TWh is supplied to domestic power demand to contribute to the electricity access in 2030. Then, half of the imported energy is for reduced thermal power generation, and the remaining half is used for electricity access in 2035.

In Myanmar, the power demand is about 36 TWh in 2030 and 46 TWh in 2035. Since the electricity access ratio is still low, this study set the amount of imported energy at 6 TWh, accounting for about 17% of total power demand in 2030 and about 13% in 2035. Half of the imported energy is used to reduce thermal power generation, and the remaining half is supplied to domestic power demand to contribute to electricity access.

Table 6-8 Energy Outlook and Changes in Power Generation by Using the Candidate Cross-Border Interconnections in Different Countries

	2030	Lao PDR	Thailand	Myanmar	Viet Nam	Cambodia
Primary energy supply (Import) (TWh)						
	Original	-35.14	61.91	0.00	5.97	1.82
	Scenario	-13.20	0.60	6.00	4.60	2.00
Final energy consumption						
Final energy consumption		7.11	273.88	36.29	374.95	19.73
				3.00		1.50
Total		42.32	237.18	40.33	398.90	19.05
Power generation output (TWh)						
Coal		20.71	38.11	14.54	253.42	6.87
				-3.00	-4.60	-0.50
				11.54	248.82	6.37
				-20.6%	-1.8%	-7.3%
Oil		0.00	0.62	0.00	0.00	0.00
Natural gas	Original	0.00	150.58	9.30	85.00	2.42
	Scenario		-2.60			
			147.98			
			-1.7%			
Hydro	Original	21.61	13.24	13.37	60.11	9.55
	Scenario	11.70				
Others		0.00	34.63	3.13	0.38	0.21
	Scenario	1.50				
Power generation input (MTOE)						
Coal	Original	5.09	9.18	3.29	59.21	1.64
	Scenario			-0.68	-1.07	-0.12
				2.61	58.14	1.52
				-20.6%	-1.8%	-7.3%
Oil		0.00	0.14	0.00	0.00	0.00
Natural gas	Original	0.00	27.01	2.00	14.28	0.43
	Scenario		-0.47			
			26.54			
			-1.7%			

	2035	Lao PDR	Thailand	Myanmar	Viet Nam	Cambodia
Primary energy supply (Import) (TWh)						
	Original	-33.50	88.93	0.00	5.97	1.82
	Scenario	-9.60	-3.10	6.00	4.60	2.00
Final energy						
Final energy consumption		8.71	312.15	45.67	441.53	26.79
				3.00		1.00
Total		42.32	251.27	50.48	469.84	26.57
Power generation output (TWh)						
Coal		20.71	49.01	17.91	313.14	9.82
	Original			-3.00	-4.60	-1.00
	Scenario			14.91	308.54	8.82
				-16.8%	-1.5%	-10.2%
Oil		0.00	1.80	0.00	0.00	0.00
Natural gas	Original	0.00	145.81	12.30	96.72	3.15
	Scenario		3.10			
			148.91			
			2.1%			
Hydro	Original	21.61	14.29	16.43	59.60	13.05
	Scenario	8.10				
Others	Original	0.00	40.35	3.84	0.37	0.56
	Scenario	1.50				
Power generation input (MTOE)						
Coal	Original	5.09	11.55	4.05	71.99	2.22
	Scenario			-0.68	-1.06	-0.23
				3.37	70.93	1.99
				-16.8%	-1.5%	-10.2%
Oil		0.00	0.40	0.00	0.00	0.00
Natural gas	Original	0.00	26.16	2.64	16.12	1.25
	Scenario		0.56			
			26.72			
			2.1%			

Source: ERIA (2019), modified by the author.

Table 6-9 shows the summary of changes in power generation by using the candidate cross-border interconnections in different countries under the above conditions, assuming the power trade of hydro and wind power generation in the Lao PDR.

Table 6-9 Summary of Changes in Power Generation by Using the Candidate Cross-Border Interconnections in Different Countries

	Countries	Energy outlook (TWh)	Fuel type	Changes (TWh)	Study case (TWh)	Change Ratios (%)
2030	Thailand	150.58	Natural gas	-2.6	147.98	-1.7
	Myanmar	14.54	Coal	-3	11.54	-20.6
	Viet Nam	253.42	Coal	-4.6	248.82	-1.8
	Cambodia	6.87	Coal	-0.5	6.37	-7.3
2035	Thailand	145.81	Natural gas	3.1	148.81	2.1
	Myanmar	17.91	Coal	-3	14.91	-16.8
	Viet Nam	313.14	Coal	-4.6	308.54	-1.5
	Cambodia	9.82	Coal	-1	8.82	-10.2

Source: Authors.

In Thailand and Viet Nam, the amount of energy generated by the original thermal power plants is large, and the change is only a small percentage. In Myanmar, the scale of demand is small, and the change is close to 20% of the total amount of energy generated by the coal-fired power plants in the country.

Chapter 7

Cost–Benefit Analysis of the Transmission Highway

This chapter calculates the economic and social benefits of the candidate cross-border interconnections proposed in the previous chapter.

7.1 Assumptions of Benefit Analysis

The study assumed the following in calculating the benefits of the candidate cross-border interconnections:

1) Power flow through candidate cross-border interconnections

- ❖ The amount of power flow is the main criterion for calculating benefits. The power flows of the candidate cross-border interconnections were based on the results from the previous chapter.
- ❖ The amount of electricity exports to Myanmar is 6 TWh/year, of which 50%, 3 TWh/year, was used for reduced thermal power generation, and the remaining 3 TWh/year was used for electricity access.
- ❖ The amount of electricity exports to Cambodia is 2 TWh/year. However, according to discussions with the MME during working group meetings, the power imports account for less than 10% of power generation in terms of energy security. Thus, 0.5 TWh/year of 2 TWh/year will be used to reduce thermal power generation, and the remaining 1.5 TWh/year will be used for electricity access before 2035. Then, 1.0 TWh/year of 2 TWh/year will be used for reduced thermal power generation, and the remaining 1.0 TWh/year will be used for electricity access after 2035.

2) Fuel cost reduction

- ❖ The unit fuel cost of natural gas was calculated by using the natural gas consumption and fuel utilisation cost in the EGAT *Annual Report 2018*. It uses the unit cost of US$8.33/MBTU (Mega British Thermal Unit).

Table 7-1 Unit Cost of Natural Gas

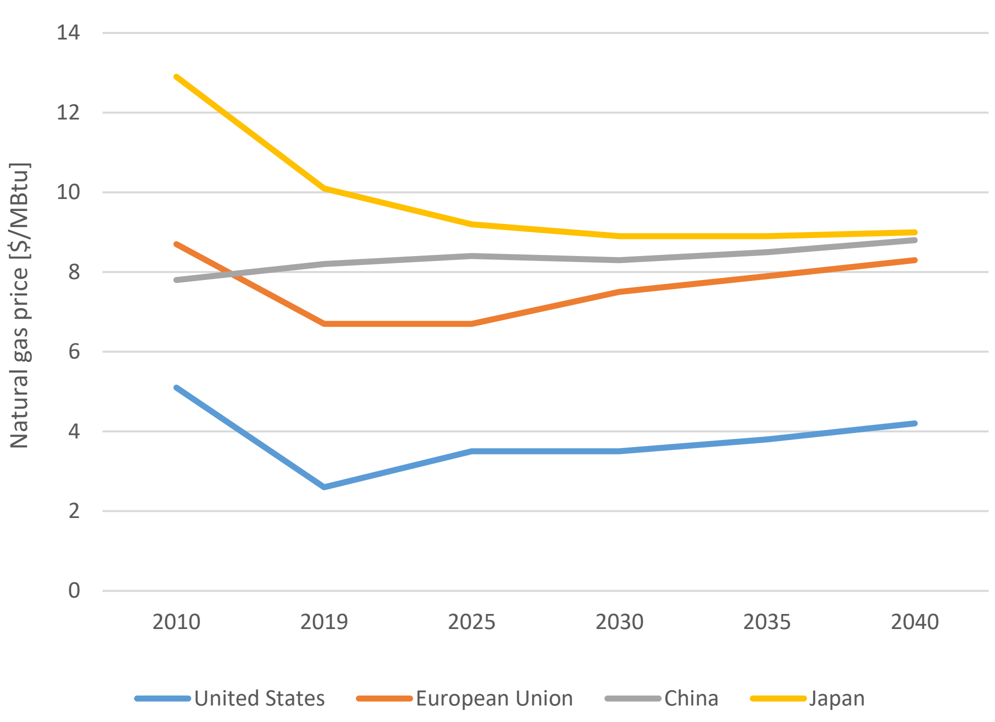
Fuel type	Fuel consumption (MBTU)	Fuel cost (million baht)	Unit cost (baht/MBTU)	Unit cost (US$/MBTU)
Natural gas	383.91	99,896.12	260.21	8.33

MBTU = Mega British Thermal Unit.
Source: EGAT (2018).

- ❖ The study used the Indonesian free-on-board (FOB) coal price of US$77.9/tonne, which is the average price in 2019, to calculate the fuel cost reduction of coal-fired power.

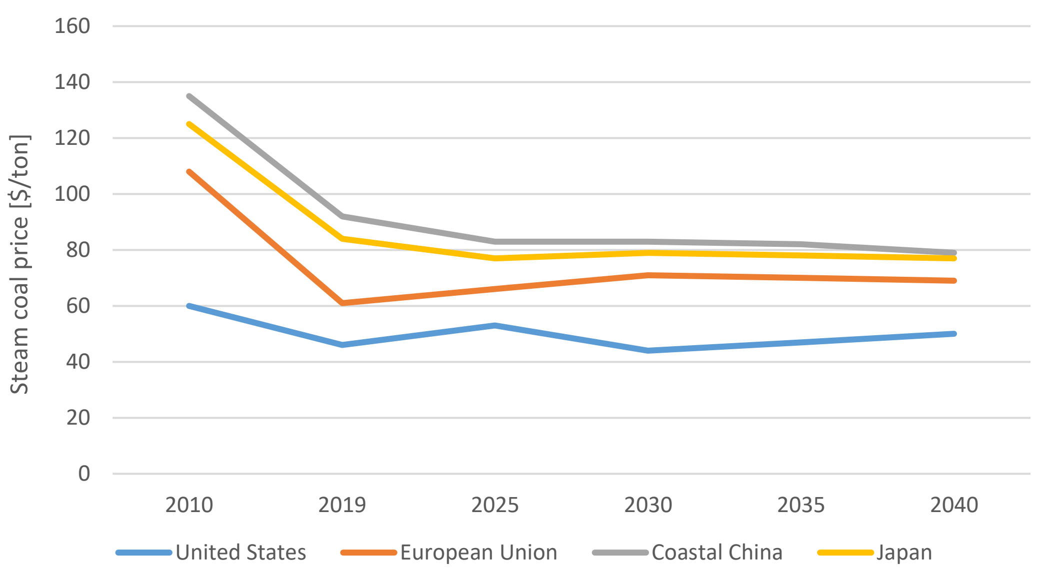
The future fuel unit cost was estimated based on future fuel prices described in the IEA's data (Figures 7-1 and 7-2). This study referred to the trend of China's future price scenario for the future price calculation.

Figure 7-1 Trend of Natural Gas Price



Source: IEA, Report Extract Macro Drivers, https://www.iea.org/reports/world-energy-model/macro-drivers (accessed 3 February 2021), modified by the author.

Figure 7-2 Trend of Coal Price



Source: IEA, Report Extract Macro Drivers, https://www.iea.org/reports/world-energy-model/macro-drivers (accessed 3 February 2021), modified by the author.

3) Reduction in new investment of thermal power plant

If thermal power generation can be reduced by importing electricity from neighbouring countries, new investment in thermal power plants can be reduced. This study analyses the decrease in new investment in thermal power plants due to power imports under the following conditions.

- **Table 7-2 assumes the installation cost of each type of thermal power plant.**

Table 7-2 Unit Installation Cost of Thermal Power Plant

Fuel type	Unit installation cost (US$/kW)
Coal (SC)	1,600
Natural gas (CCGT)	700

SC = supercritical, CCGT = combined cycle gas turbine.
Source: IEA (2015).

- **The assumptions of the capacity factor of each type of thermal power plant are shown in Table 7-3.**

Table 7-3 Capacity Factor of Each Type of Thermal Power Plant

Fuel type	Capacity Factor [%]
Coal	0.85
Natural gas (GT)	0.85

GT = gas turbine.
Source: Timilsina (2020).

4) CO_2 emission reduction and carbon pricing

Greenhouse gas (GHG) emissions, including CO_2, have become a global issue. To address this global challenge, 196 parties adopted the Paris Agreement at COP21 in 2015. The Paris Agreement is a legally binding international treaty on climate change. Its goal is to limit global warming to well below 2, preferably 1.5, degrees Celsius than pre-industrial levels. Countries aim to reach global peaking of GHG emissions as soon as possible to achieve a climate-neutral world by mid-century to achieve this long-term temperature goal.[3]

As of September 2017, all AMSs had signed and ratified the Paris Agreement, joining the global cooperative effort to mitigate and adapt to climate change. As the heart of the Paris Agreement, the nationally determined contributions (NDCs) chronicle the climate strategy of each party to the agreement in reducing GHG emissions, including associated policies, financial measures, and progress towards achieving the targets. Most AMSs have transformed their intended nationally determined contributions into NDCs by ratifying them (Yurnaidia et al., 2021).

[3] UNFCCC, The Paris Agreement, https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (accessed 12 January 2021).

At present, the proportion of 'energy-derived CO_2' emitted from fuel combustion and the use of supplied electricity and heat are high in many countries. As mentioned in the previous chapter, the ratios of thermal power to total installed capacity are the highest in all ACMECS countries except the Lao PDR. If Lao PDR's hydropower can be utilised through the Transmission Highway, it will be possible to reduce the amount of thermal power generation in each country, thus contributing to reduced CO_2 emissions. Therefore, this study analysed the CO_2 emission reduction by utilising the Transmission Highway.

CO_2 emissions from electricity generation vary by type of fuel/energy source and by type and efficiency of electric power plants. The amount of CO_2 produced per kWh during any time will vary according to the sources of electricity supplied to the electric power grid during that time. Therefore, electricity-related CO_2 emissions and CO_2 emission factors will change hourly, daily, monthly, and annually. The US Energy Information Administration (EIA) reported on US electric utility and independent power electricity generation and resulting CO_2 emissions by fuel in 2019 (Table 7-4). This study uses the emission factor of 1.0 × 10-4 metric tonnes CO_2/kWh for coal-fired thermal power and 0.41 × 10-4 metric tonnes CO_2/kWh for natural gas thermal power.[4]

Table 7-4 US Electric Utility and Independent Power Electricity Generation and Resulting CO_2 Emissions, by Fuel, in 2019

Fuel type	Electricity generation [GWh]	CO_2 emissions [million metric tons]	CO_2 emissions factor [metric tons CO_2/kWh]
Coal	947,891	952	1.00 x 10-3
Natural gas	1,358,047	560	0.41 x 10-3
Petroleum	15,471	15	0.97 x 10-3

Source: EIA data, modified by the author.

This study also analysed the benefits of 'carbon pricing', a market-based strategy for lowering GHG emissions. Its purpose is to set a monetary value on carbon emissions so that the costs of climate change impacts and opportunities for low-carbon energy options are better reflected in our production and consumption choices.

According to the World Bank (2021), 61 carbon pricing initiatives are now in place or scheduled for implementation. These comprise 31 emissions trading systems (ETSs) and 30 carbon taxes, covering 12 gigatons of CO_2 equivalent ($GtCO_2e$) or about 22% of global GHG emissions. In ACMECS countries, Thailand and Viet Nam are also considering ETS or carbon tax.

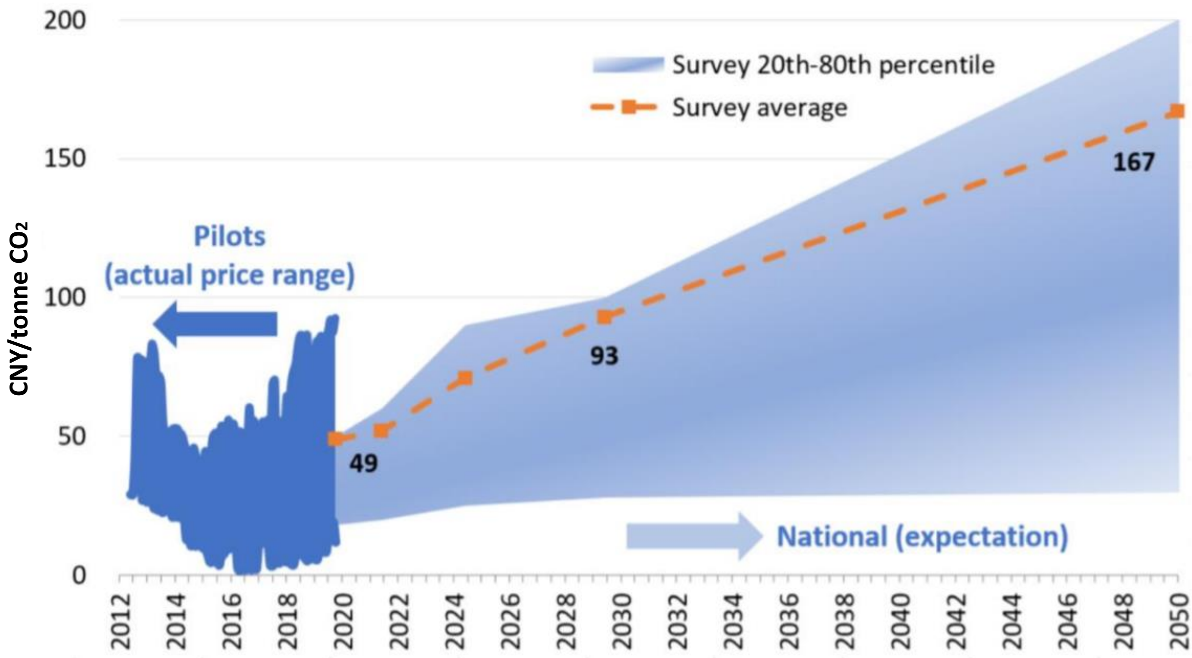
The High-Level Commission on Carbon Prices estimated that carbon prices of at least US$40–80/$tCO_2$ by 2020 and US$50–100/$tCO_2$ by 2030 are required to reduce emissions cost-effectively in line with the temperature goals of the Paris Agreement. However, as of today, less than 5% of GHG emissions currently covered by a carbon price are within this range, with about half of covered emissions priced

[4] EIA, https://www.eia.gov/tools/faqs/faq.php?id=74&t=11 (accessed 11 January 2021).

at less than US$10/t$CO_2$e. The International Monetary Fund calculates the global average carbon price to be only US$2/t$CO_2$. (World Bank, 2021)

The China Carbon Forum implemented the 2020 China Carbon Pricing Survey in July–August 2020, obtaining expectations about the future of carbon pricing in China from hundreds of stakeholders. They asked for stakeholders' carbon price expectations to mid-century to understand how carbon pricing may play a role in China's mid- to long-term decarbonisation strategy. According to this survey, the average price expectation in the national carbon market starts at CNY49/tonne in 2020, rising to CNY71/tonne in 2025, CNY93/tonne by 2030, and CNY167/tonne by 2050 (Figure 7-3). However, as in most carbon markets, the actual price levels remain highly uncertain, especially in the more distant future (Slater et al., 2020).

Figure 7-3 Range of Prices in the Pilot Systems to-date, and Estimated Prices in China



Source: Slater et al. (2020).

Since there are no carbon pricing initiatives in ACMECS countries, this study referred to this carbon pricing estimation in China to calculate the benefit of reduced CO_2 emissions. The carbon price converted by the average value of the Chinese yuan and the US dollar in 2020 (CNY1.0 = US$0.145) is shown in Table 7-5.

Table 7-5 Average Carbon Price Estimation in China

	Carbon price (CNY/tonne)	Carbon Price (US$/tonne)
2020	49	7.1
2025	71	10.3
2030	93	13.5
2050	167	24.2

Source: Slater et al. (2020), modified by the author.

5) Impact of electricity access on GDP in Myanmar and Cambodia

- This study referred to the following data from ERIA's *Energy Outlook* report (ERIA, 2019) to calculate the impact of electricity access on GDP in Myanmar and Cambodia.
  - GDP
  - GDP per capita
  - Electricity consumption
  - Population
- According to The Rockefeller Foundation[5], electricity access can increase household per capita income by 39% in Africa. Since the per capita income in Africa is the same as in Myanmar and Cambodia, this study uses this percentage to calculate the impact on GDP.
- Utilise 3 TWh/year out of 6 TWh/year of electricity exports to Myanmar for electricity access.
- Utilise 1.5 TWh/year before 2035 and 1 TWh/year out of 2 TWh/year after 2035 out of 2 TWh/year to Myanmar for electricity access.

6) Wheeling charge

Wheeling charge is the price power network users pay transmission asset owners and operators to use their assets (Energy & Environment, 2015). Generally, a power producer such as an IPP pays a usage fee to transmission asset owners and operators to supply electricity to the purchaser. The wheeling charges should reflect the full costs (fixed and variable) to the transmission owner to provide the necessary transmission infrastructure and services. This could include capital cost, asset depreciation, O&M costs, and any associated losses. In addition, the wheeling charge also needs to consider both the physical and commercial aspects of power transmission. Some key aspects to be considered in a basic arrangement are summarised as follows:

- amount of wheeling capacity
- time duration of the transmission
- grid or country entry and exit points
- metering of actual power flows
- agreed balancing procedures (to be used if a counterparty fails or is unable to honour the agreed transaction volumes)
- how to handle transmission losses
- an agreement on managing taxation of cross-border trades.

This methodology can cover both long-term bilateral trading agreements and short-term trading (IEA, 2019).

As mentioned, the wheeling charge depends on the conditions of each transmission line; thus, the wheeling charge should be fixed through careful discussion. JICA, in 2017, surveyed the South African Power Pool (SAPP). The study was conducted to follow up the 5th Tokyo International Conference on African Development. The study reviewed power system

[5]The Rockefeller Foundation, https://www.rockefellerfoundation.org/blog/access-to-electricity-is-critical-to-africas-growth/ (accessed 15 October 2020).

development plans, such as the existing master plans and relevant information, found and prioritised issues and projects comprehensively to realise a power pool as part of the strategic master plan formation for the Southern African region. According to this study, the wheeling charge for 92 routes of transmission lines in SAPP was listed, and the price range was 0.004–0.685 cents/kWh in 2016. The wheeling charge in SAPP was calculated based on:

- The available capacity calculation for power trade on all transmission systems in SAPP
- Usage charge calculation in each transmission facility with their book values
- Summation of charges on transmission facilities for all routes.

SAPP charges are very low because the book value of existing power transmission facilities is low. In other words, power transmission facilities are considerably old. Therefore, the wheeling charge may sharply rise in the future as new transmission lines are built (JICA, 2017).

This study analysed the income from wheeling charges through cost–benefit analysis. The unit price of wheeling charge should be set to calculate income. Since this study assumed the construction of new cross-border interconnections between ACMECS countries, it is appropriate to set the unit price of wheeling charge higher than the case of SAPP at least. Based on the above, this study roughly conducted a benefit analysis assuming a 1 cent/kWh unit price for all candidate cross-border interconnections. Since the distance and construction cost of the cross-border interconnections are different, the wheeling charges should be decided for each cross-border interconnection in actual operation.

7) Calculation Period

The calculation period was assumed to be 25 years, the same as the period for calculating the construction cost.

8) Net Present Value (NPV)

To account for the time value of money, the yearly net benefit was discounted and then summed to see how the present value of the benefit compares to the other. The formulation of NPV is expressed in Equation (2).

$$NPV = \sum_{n=0}^{N} \frac{B_n - C_n}{(1+r)^n} \qquad (2)$$

Where:

N: calculation period

n: point in time (n = 0 means present)

B: is benefits gained by cross-border interconnections

C: cost incurred by cross-border interconnections

r: discount rate

9) **Internal Rate of Return (IRR)**

The IRR is the discount rate that forces the expected cash flows to equal the initial cash flow. This is equivalent to forcing the NPV to equal zero. The IRR is an estimate of the project's rate of return. If this return exceeds the cost of funds used to finance the project, then the difference benefits the firm's stockholders. On the other hand, if the IRR is less than the cost of capital, stockholders must make up for the shortfall. .

To calculate the IRR, begin with Equation (2) for the NPV, replace *r* in the denominator with *IRR* and choose a value of *r* so that the NPV equals zero. This transforms Equation (2) into Equation (3), the one used to find the IRR (Brigham and Ehrhardt, 2010).

$$NPV = \sum_{n=0}^{N} \frac{CF}{(1+IRR)^n} = 0 \qquad (3)$$

Where:

CF: Cash flow

IRR: Internal rate of return

Based on the above assumptions, the benefits of each interconnection will be calculated in the following sections.

7.2 Fuel Cost Reduction of Thermal Power Plants

Many benefits can be obtained by power trade through cross-border interconnections. One of them is fuel cost reduction of the thermal power plant as an economic benefit. The summary of fuel cost reduction is shown in Table 7-6. The results of fuel cost reductions for 25 years are US$1,569 million in Thailand; US$2,614 million in Viet Nam; US$1,667 million in Myanmar; and US$448 million in Cambodia. The total fuel cost reduction is expected to be US$6,298 million.

Table 7-6 Fuel Cost Reduction of Thermal Power Plant in Each Country

Country	Thermal power generation reduction (GWh)			Fuel type	Fuel Cost Reduction (mil. US$)		
	2030	2035	25 years		2030	2035	25 years
Thailand	-2,600	0	-26,000	Natural gas	156.0	0	1,569
Viet Nam	-4,600	-4,600	-115,000	Coal	107.9	104.9	2,614
Myanmar	-3,000	-3,000	-75,000	Coal	68.2	67.3	1,667
Cambodia	-500	-1000	-20,000	Coal	12.0	22.4	448
Total	**-10,700**	**-8,600**	**-236,000**		**344.0**	**194.6**	**6,298**

Source: Authors.

7.3 Reduction in New Investment of Thermal Power Plants

Power imports from neighbouring countries may reduce fuel costs of, and investment in, thermal power plants. Reduced new investment in thermal power plants also has economic benefits.

Table 7-7 summarises the reduction in the new investment of thermal power plants. In Thailand, the reduction in new generation capacity is 349 MW, about 0.6% of the total installed capacity in 2030, while that for natural gas power plants is about US$244 million. In Myanmar, the reduction in new generation capacity is 403 MW, about 3.4% of the total installed capacity in 2030. The reduction in new investment of coal power plants is about US$645 million. In Viet Nam, the reduction in new generation capacity is 618 MW, about 0.4% of the total installed capacity in 2030, while that for coal power plants is about US$989 million. In Cambodia, the reduction in new generation capacity is 134 MW, about 0.8% of the total installed capacity in 2030, and that for coal power plants is approximately US$215 million. The total capacity and total installation costs that can be reduced are 1,504 MW and US$2,093 million, respectively. Therefore, we can expect that power trade though transmission highway contributes to reduced new investment of thermal power plants.

Table 7-7 Reduction in New Investment of Thermal Power Plant

Country	Thermal power generation reduction (GWh)			Fuel type	Fuel Cost Reduction (mil. US$)		
	2030	2035	25 years		2030	2035	25 years
Thailand	-2,600	0	-26,000	Natural gas	156.0	0	1,569
Viet Nam	-4,600	-4,600	-115,000	Coal	107.9	104.9	2,614
Myanmar	-3,000	-3,000	-75,000	Coal	68.2	67.3	1,667
Cambodia	-500	-1000	-20,000	Coal	12.0	22.4	448
Total	**-10,700**	**-8,600**	**-236,000**		**344.0**	**194.6**	**6,298**

Source: Authors.

7.4 CO2 Emission Reduction and Carbon Pricing

CO_2 emission will decrease due to reduced thermal power generation. This result is calculated as a social benefit. The CO_2 emission reduction in each country is shown in Table 7-8. We expect that CO_2 emission reduction for 25 years are 3 Mt-C in Thailand, 31 Mt-C in Viet Nam, 21 Mt-C in Myanmar, and 5 Mt-C in Cambodia. The total CO_2 emission reduction is expected to be 60 Mt-C.

Table 7-8 CO_2 Emission Reduction in Each Country

Country	Thermal power generation reduction (GWh)			Fuel type	Fuel Cost Reduction (mil. US$)		
	2030	2035	25 years		2030	2035	25 years
Thailand	-2,600	0	-26,000	Natural gas	156.0	0	1,569
Viet Nam	-4,600	-4,600	-115,000	Coal	107.9	104.9	2,614
Myanmar	-3,000	-3,000	-75,000	Coal	68.2	67.3	1,667
Cambodia	-500	-1000	-20,000	Coal	12.0	22.4	448
Total	**-10,700**	**-8,600**	**-236,000**		**344.0**	**194.6**	**6,298**

Source: Authors.

Table 7-9 shows the benefits of carbon pricing in each country based on CO_2 emission reductions. We expect that the benefits of carbon pricing for 25 years to be US$46.2 million in Thailand; US$1,984.1 million in Viet Nam; US$1,294.1 million in Myanmar; and US$365.7 million in Cambodia. Thus, the total benefits of carbon pricing are expected to be US$3,690.2 million.

Here, to date, ACMECS countries have not yet introduced a carbon pricing incentive. However, this result shows the feasibility of introducing carbon pricing incentives to ACMECS countries. Therefore, we can expect the Transmission Highway to contribute greatly to global GHG emission issues.

Table 7-9 Benefits of Carbon Pricing

Country	Carbon price (million US$)		
	2030	2035	25 years
Thailand	3.9	0	46.2
Viet Nam	62.3	74.7	1,984.2
Myanmar	40.6	48.7	1,294.1
Cambodia	13.5	16.2	365.7
Total	**120.4**	**139.6**	**3,690.2**

Source: Authors.

7.5 Improvement of GDP

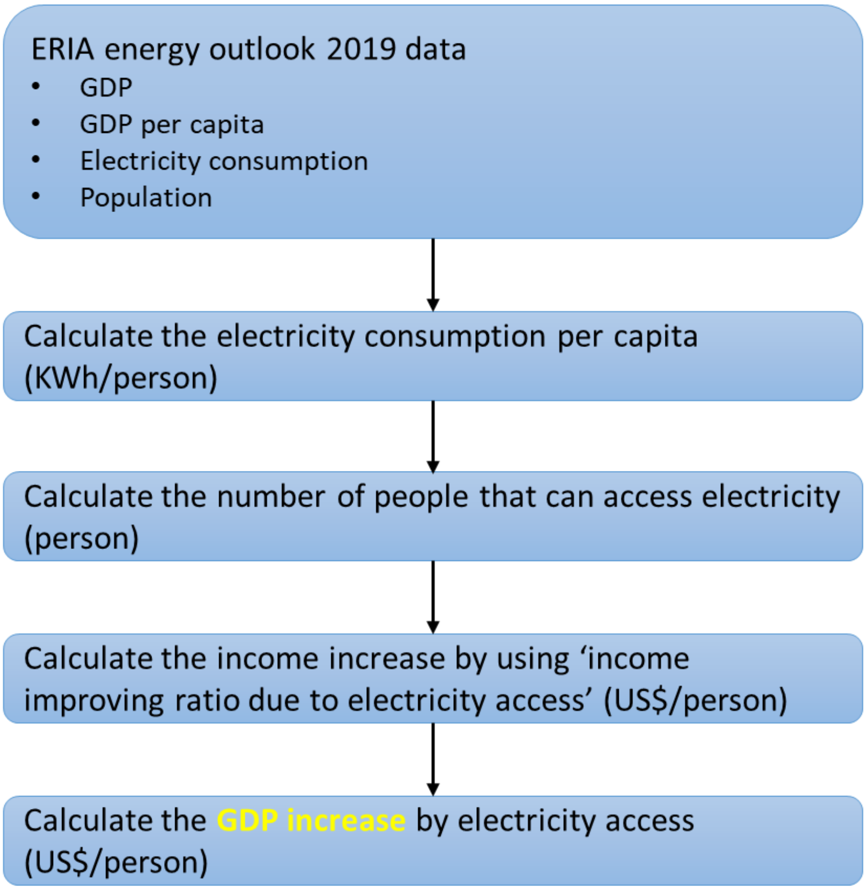
Electricity access results in many benefits. Businesses can operate at higher productivity levels; farmers can run cleaner irrigation systems and processing machines, improving their yields and, thus, their incomes.

This study referred to the following data from ERIA’s Energy Outlook report (ERIA, 2019). To calculate the impact on GDP:

- **GDP**
- **GDP per capita**
- **Electricity consumption**
- **Population**

Figure 7-4 shows the simple calculation flow of impact on GDP by electricity access.

Figure 7-4 Simple Calculation Flow of Impact on the GDP, by Electricity Access



Source: Authors.

7.5.1 Myanmar

Myanmar has achieved 50% of nationwide electricity access in 2019, however, electricity access level is still low. Table 7-10 shows the assumption of calculation data in Myanmar.

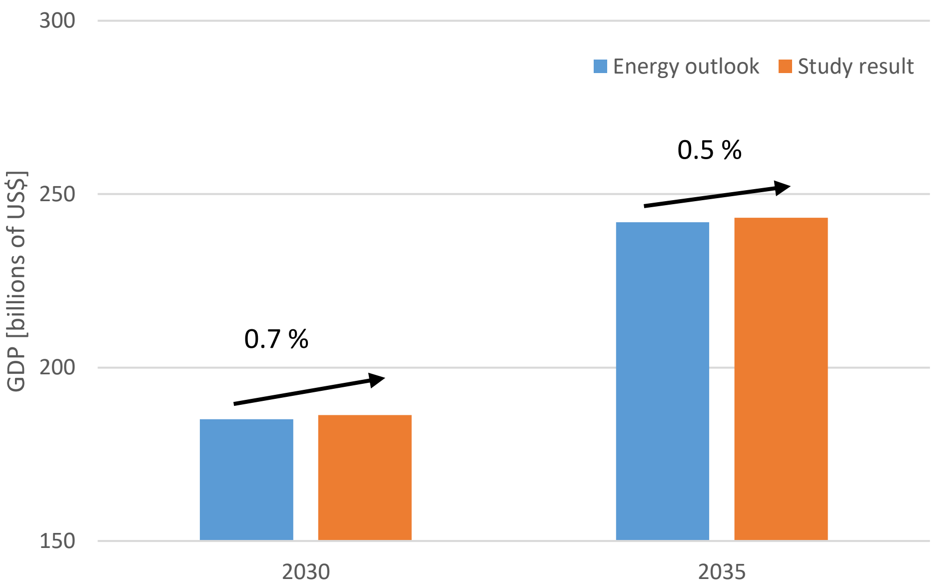
Table 7-10 Assumptions of Calculation Data in Myanmar

Item	2030	2035
GDP (billions of 2010 US dollars)	185	242
GDP per capita (thousands of 2010 USD/person)	3.12	3.96
Electricity Consumption (TWh)	36.29	45.67
Population (millions of people)	59.26	61.12
Imported electricity for electricity access (TWh)	3.0	3.0
Average number of people per household (people)	4.8	4.8
Income improving ratio per capita by electricity access	**8.1 %**	**8.1 %**

Source: Authors.

Based on the above calculation flow, GDP improvement through electricity access in Myanmar was calculated (Figure 7-5). Using electricity imports from Thailand for electricity access will improve GDP by 0.7% in 2030 and 0.5% in 2035, respectively (ERIA, 2019).

Figure 7-5 GDP Improvement in Myanmar, by Electricity Access



Source: Authors.

7.5.2 Cambodia

Electricity access in Cambodia was about 74.7% of villages and 58.2% of households in 2017, still low at those levels. Similar to Myanmar's calculation, data from ERIA's energy outlook report was used.

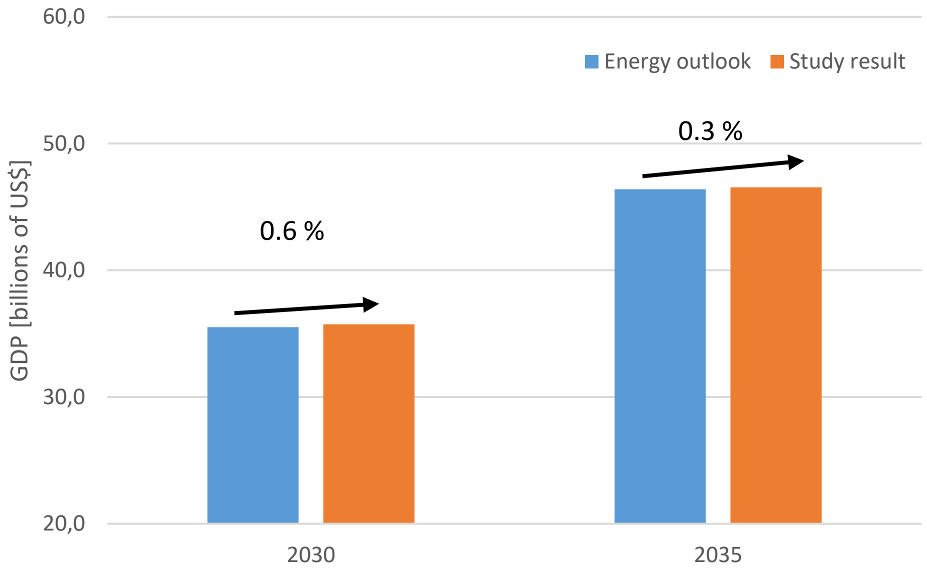
Table 7-11 Assumptions of Calculation Data in Cambodia

Item	2030	2035
GDP (billions of 2010 US dollars)	35.50	46.40
GDP per capita (thousands of 2010 USD/person)	1.83	2.22
Electricity Consumption (TWh)	19.73	26.79
Population (millions of people)	19.40	20.90
Imported electricity for electricity access (TWh)	1.5	1.0
Average number of people per household (people)	4.6	4.6
Income improving ratio per capita by electricity access	**8.5 %**	**8.5 %**

Source: Authors.

Based on the above calculation flow, GDP improvement through electricity access in Cambodia was calculated (Figure 7-6). Using electricity imports from the Lao PDR through Thailand to make electricity accessible will improve GDP by 0.6% in 2030 and 0.3% in 2035, respectively (ERIA, 2019).

Figure 7-6 GDP Improvement in Cambodia, by Electricity Access



Source: Authors.

7.6 Income from Wheeling Charge

The Income from the wheeling charge of each cross-border interconnection is shown in Table 7-12. This study assumes that the wheeling charges are the same for all candidate cross-border interconnections. Therefore, the larger the amount of power trade, the larger the income. The income from the wheeling charge for 25 years in each candidate cross-border interconnection ranged from US$446 million to US$1,500. The total income from the wheeling charge is expected to be US$5,545 million.

Table 7-12 Income from Wheeling Charge of Each Cross-Border Interconnection

Section	Amount of power exchange (GWh)			Income from wheeling charge (mil. US$)		
	2030	2035	25 years	2030	2035	25 years
(1) 500 kV MK. Pakbeng – (Mae Moh – Tha Tako)	5,450	6,112	148,828	54.5	61.1	1,488
(2) 500 kV (Mae Moh – Tha Tako) – Mawlamyaing	6,000	6,000	150,000	60.0	60.0	1,500
(3) 230 kV Laos Vientiane – Thailand Bunkan	1,281	1,943	44,603	12.8	19.4	446
(4) 500 kV Xekong – Roi Et	1,794	1,794	44,850	17.9	17.9	449
(8) 500 kV Chaiyaphum – Banteay Meanchey	2,000	2,000	50.000	46.5	46.5	500
(9) 500 kV Thanh My – Xekong	4,648	4,648	116,200	20.0	20.0	1,162
Total	**21,173**	**22,497**	**554,481**	**211.7**	**225.0**	**5,545**

Source: Authors.

7.7 Financial Indicators

The study analysed the benefits of the candidate transmission lines in the previous section. In this section, the study analyses the financial internal rate of return (FIRR), economic internal rate of return (EIRR), and the NPV of the Transmission Highway.

The assumptions used to calculate the FIRR, EIRR, and NPV for the Transmission Highway are as follows:.

1) FIRR

- ❖ The calculation period was set to 25 years
- ❖ The costs for FIRR calculation were assumed as follows:
  - The total construction cost of candidate cross-border interconnections (excluding the domestic transmission lines in Thailand)
  - O&M cost for each year is 3% of the total construction cost
- ❖ The benefits for FIRR calculation were assumed as follows:
  - Wheeling charge of candidate cross-border interconnections
- ❖ NPV was evaluated at 8% and 10% discount rate

2) EIRR

- ❖ The calculation period was set to 25 years
- ❖ The costs for EIRR calculation were assumed as follows:
  - The total construction cost of candidate cross-border interconnections (excluding the domestic transmission lines in Thailand)
  - The total construction cost of new power stations
  - O&M cost for each year is 3% of the total construction cost
- ❖ The benefits for EIRR calculation were assumed as follows:
  - Wheeling charge of candidate cross-border interconnections
  - Fuel cost reduction of thermal power plant
  - Reduction in new investments for thermal power
  - CO_2 emission reduction (carbon pricing)
- ❖ NPV was evaluated at 8% and 10% of the discount rate

The result of FIRR, 15.9%, is shown in Table 7-13. In the case of a discount rate of 8%, the estimated NPV for the Transmission Highway is US$859 million, with a payback period of 8.9 years. For a discount rate of 10%, the NPV is US$557 million with a payback period of 10.1 years.

Amongst the five ACMECS countries, Myanmar's long-term interest rate is as high as 9.5%, but FIRR is higher than that. In addition, the NPV is also positive (> 0). Therefore, the Transmission Highway has sufficient financial feasibility.

Table 7-13 FIRR of Transmission Highway

Financial indicators	
FIRR	15.9%
NPV (million US$) (Discount rate: 8%)	859
Payback period in years (Discount rate: 8%)	8.9 years
NPV (million US$) (Discount rate: 10%)	557
Payback period in years (Discount rate: 10%)	10.1 years

Source: Authors.

The EIRR is shown in Table 7-14. The EIRR is 13.9%. For a discount rate of 8%, the estimated NPV for the Transmission Highway is US$2,170 million, with a payback period of 9.9 years. For a discount rate of 10%, the NPV is US$1,249 million, with a payback period of 11.9 years.

According to ADB, the general criterion for accepting a project is achieving a positive economic net present value discounted at the minimum required EIRR or achieving the minimum required EIRR. ADB adopted 9% as the minimum required EIRR (ADB, 2017). The EIRR of the Transmission Highway is higher than 9% of the standard adopted by ADB; the NPV is also positive (> 0). Therefore, the Transmission Highway is also economically feasible.

Table 7-14 EIRR of Transmission Highway

Financial indicators	
EIRR	13.9%
NPV (million US$) (Discount rate: 8%)	2,170
Payback period in years (Discount rate: 8%)	9.9 years
NPV (million US$) (Discount rate: 10%)	1,249
Payback period in years (Discount rate: 10%)	11.9 years

Source: Authors.

Chapter 8

The Important Role of ACMECS in Multilateral Power Trade

This study analysed the benefits of the Transmission Highway in the ACMECS region and identified the cross-border interconnections that would lead to the greatest benefits in ACMECS. However, to maximise the Transmission Highway benefits, multilateral power trade should be realised in the ASEAN region.

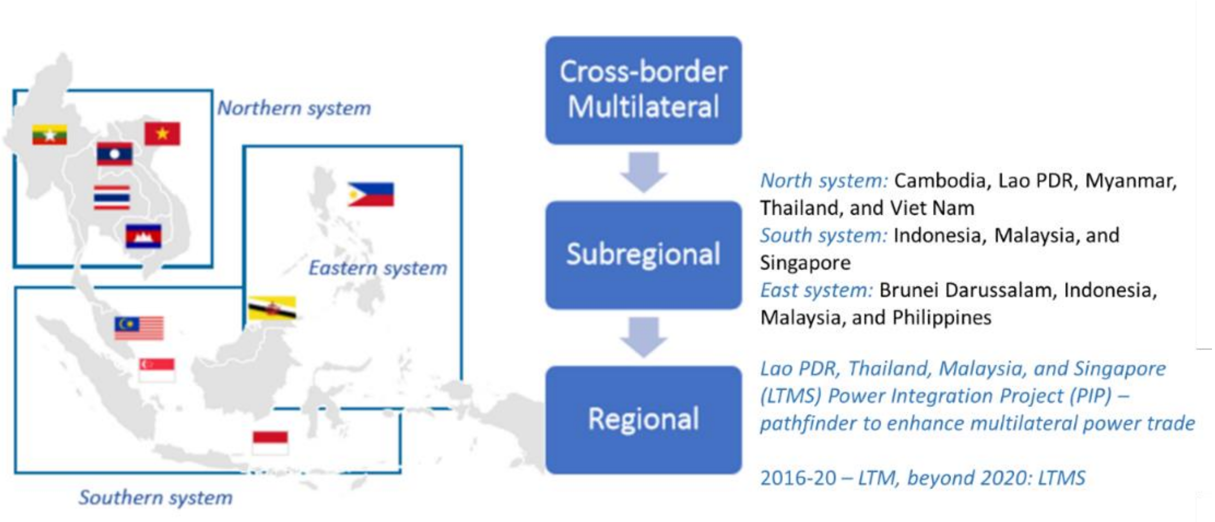
The AMSs have a long-standing goal of integrating their power systems via the common APG. There are numerous existing efforts to establish multilateral power trade amongst the AMSs as follows (IEA, 2019):

- ASEAN Power Grid (APG)
- Greater Mekong Subregion (GMS)
- Laos-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP)
- Brunei Darussalam-Indonesia-Malaysia-Philippines East ASEAN Growth Area (BIMP-EAGA) interconnectivity project

The APG and the GMS have had a lot of discussions over the years. The APG has been led by the Heads of ASEAN Power Utilities/Authorities (HAPUA), whose primary role is to ensure regional energy security by promoting efficient utilisation and sharing of resources. HAPUA has conducted several studies, the most representative of which is the 'ASEAN Interconnection Master Plan Study (AIMS)'. The AIMS focused on a comprehensive plan of regional cross-border interconnections linking AMS's power systems. The first study (AIMS I) was completed in 2003, and the second study (AIMS II), in 2010. The ASEAN Centre for Energy is currently conducting AIMS III.

The development of the APG so far has progressed only on a bilateral basis between neighbouring countries. However, the expectation has always been to move from bilateral interconnections to subregional power systems (focusing primarily on three subregions: Northern, Southern, and Eastern systems), and finally to a fully integrated regional system. The development of the full APG is critical for establishing full multilateral power trading amongst ASEAN countries, as trading cannot occur without sufficient supportive infrastructure (IEA, 2019).

Figure 8-1 Pathway to Establishing Multilateral Power Trade



Source: IEA (2019).

The GMS, established in 1992, involves six countries: five AMSs (Cambodia, Lao PDR, Myanmar, Thailand, and Viet Nam) and China. As mentioned in the previous chapter, the GMS countries are already interconnected and trade power bilaterally. The Regional Power Trade Coordination Committee (RPTCC) was established in 2002 to coordinate the implementation of regional power trade. To date, the RPTCC has held a lot of meetings. Some discussions and recommendations made in the context of the GMS through meetings are as follows:

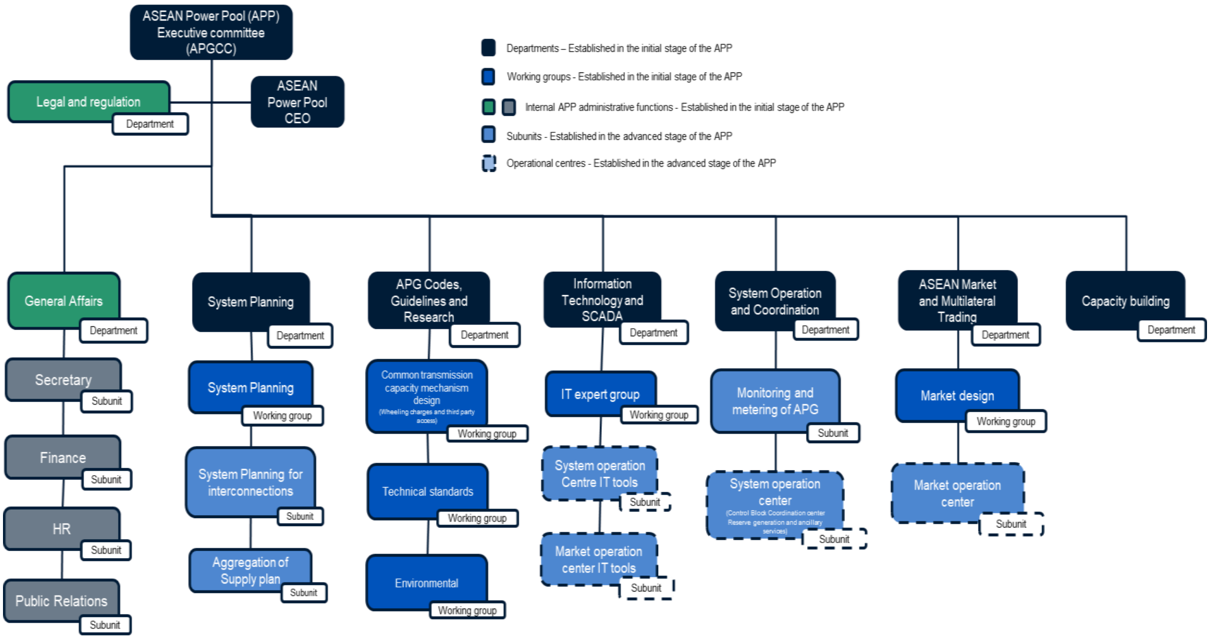
- A set of draft harmonised grid codes were developed.
- The Regional Power Coordinating Centre was proposed to be an advisory body on regulatory issues and not a regional regulator.

In the GMS, some AMSs have already been discussing harmonised grid codes and regional institutions. The GMS effort offers many important learning points for the APG. Most importantly, it offers a starting point for the AMSs from which to work, which could be beneficial in terms of accelerating the work within the ASEAN region (IEA, 2019).

One of the recent efforts is the LTMS-PIP, a pilot project of multilateral power trading in ASEAN. As a pilot project, the focus is primarily on identifying and resolving issues that could affect cross-border power trade amongst the AMSs more broadly. The LTMS-PIP started in January 2018. It is a multilateral trading arrangement that includes more than two countries. However, it is also a unidirectional trade, and so it is more limited than multilateral trading as defined by this study. However, certain key elements of the LTMS–PIP are very relevant to the broader goals of the APG. Two stand out in particular: the development of the wheeling charge and the underlying process for developing the LTMS–PIP in the first place (IEA, 2019).

The AMSs already have a lot of knowledge and experience through their existing efforts. Along with their efforts, several studies about multilateral power trade have been conducted. In collaboration with HAPUA, ERIA conducted two studies, 'Study on the Formation of the ASEAN Power Grid Transmission System Operator Institution (ATSO)' and 'Study on the Formation of the ASEAN Power Grid Generation and Transmission System Planning Institution (AGTP)' in 2017. These projects aim to help the AMSs achieve consensus on the principles, building blocks, and framework of an integrated regional electricity market. From the two projects, it was concluded that the AGTP and ATSO functions should be placed in the same organisation to secure a close relationship between planning and system operation. The most important outcome of this study is the proposal of establishing the new regional institution. After thorough discussions during the project workshops, the AMSs agreed this new institution to be named the ASEAN Power Pool (ERIA, 2017a and 2017b).

Figure 8-2 Proposed ASEAN Power Pool Organisational Chart



Source: ERIA (2017a).

In addition, the IEA conducted a feasibility study on 'Establishing Multilateral Power Trade in ASEAN'. This study identifies a set of minimum political, technical, and institutional requirements that the AMSs should meet to establish multilateral power trade in the ASEAN region.

At the 34th HAPUA council meeting held in 2018, the council recognised that the three studies done by ERIA, IEA, and the ASEAN Centre for Energy are related to support the APG realisation. They also requested for the studies to be synergised so that recommendations are well coordinated and holistically considered.

As noted above, many efforts and studies on multilateral power trade have been implemented in ASEAN. The information and road map necessary to realise multilateral power trade have also been presented. First, it is important to move power trade from the current bilateral basis to the subregional basis based on the LTMS-PIP. As Figure 8-1 shows, multilateral power trade will initially take place in three subregions. At this stage, the regional institution mentioned above should be established in each subregion. From the current efforts mentioned in this chapter, the subregion closest to the realisation of multilateral power trade amongst these three regions is the northern part, that is, ACMECS. ACMECS countries have been discussing multilateral power trade within the framework of the GMS for many years and have accumulated knowledge. In addition, the Lao PDR and Thailand are included in the LTMS-PIP framework. Based on this experience, ACMECS as a pioneer will develop multilateral power trade on a subregional basis. The knowledge gained in ACMECS will be expanded to other subregions, which is the best way to realise the APG. After multilateral power trade is achieved in the three subregions, it will be developed throughout ASEAN, as the APG.

Chapter 9

Conclusions

The study analysed the benefits of the Transmission Highway in the ACMECS region and identified the cross-border interconnections that will benefit all countries within the ACMECS. In the concept of the Transmission Highway, the Lao PDR could play a role in exporting additional power energy to Cambodia, Myanmar, Thailand, and Viet Nam. The benefits include the use of hydro resources in the Lao PDR to reduce thermal power generation in Cambodia, Myanmar, Thailand, and Viet Nam and improve GDP through electricity access in Cambodia and Myanmar.

Figure 5-1 shows the candidate cross-border interconnections for the Transmission Highway. Selected for the Transmission Highway are six routes of cross-border interconnections and three routes of domestic transmission lines in Thailand. Also set are the voltage level and capacities of the candidate transmission lines based on the SIL and the amount of expected power trade. The total construction cost of the Transmission Highway is about US$1,500 million.

The electric power trade to be transmitted from the Lao PDR through the candidate interconnections is expected from the increase in energy export volume of the domestic power grid and new export-dedicated IPPs in the Lao PDR. In addition, the rise in power energy import from Thailand into the domestic power grid of the Lao PDR during the dry season is also expected. According to IRENA (2019), in China, the unit cost for installing the hydropower plant is US$1,264/kW and US$1,223/kW for the onshore wind power. Based on these prices, the total installation cost of new IPPs is about US$4,016 million.

Figure 6-2 shows the expected power trade through the Transmission Highway. Basically, the Lao PDR could export additional electric power energy to a neighbouring country.

Based on the expected power trade, this study carried out a benefit analysis. The power trade through cross-border interconnections can result in many benefits. One is reduced fuel cost in thermal power plants, an economic benefit. Fuel cost reductions for 25 years amount to US$1,569 million in Thailand; US$2,614 million in Viet Nam; US$1,667 million in Myanmar; and US$448 million in Cambodia. The total fuel reduction is expected to cost US$6,298 million.

The second benefit is reduced new investment in thermal power plants. A new investment of US$2,093 million with 1,504 MW of total thermal generation capacity can be decreased by power trade through the Transmission Highway.

The third benefit is the decreased CO_2 emissions through the reduction of thermal power generation. This result is calculated as the social benefit. CO_2 emission reduction for 25 years total 3 Mt-C in Thailand, 31 Mt-C in Viet Nam, 21 Mt-C in Myanmar, and 5 Mt-C in Cambodia. The total CO_2 emission reduction is expected to be 60 Mt-C. In addition, decreased thermal power generation yields the benefit of carbon pricing. No carbon pricing incentive currently exists in ACMECS countries. If carbon pricing incentive will be introduced, its benefits for 25 years are US$46.2 million in Thailand, US$1,984.1 million in Viet Nam, US$1,294.1 million in Myanmar, and US$365.7 million in Cambodia. The total benefits of carbon pricing are expected to be US$3,690.2 million. Thus, carbon pricing is feasible.

The fourth benefit, improved GDP through the electricity access, is both a social and economic benefit. The electricity access ratios in Myanmar and Cambodia are still low. Thus, this study assumed that imported electricity is used for thermal power generation reduction and electricity access in Myanmar and Cambodia. Using electricity imports from Thailand for electricity access will improve Myanmar's GDP by 0.7% in 2030 and 0.5% in 2035, and Cambodia by 0.6% in 2030 and 0.3% in 2035 (ERIA, 2019).

The fifth benefit is income from the wheeling charge. This study roughly conducted a benefit analysis of wheeling charge, assuming a unit price of 1.0 cent/kWh for all candidate cross-border interconnections. The income from the wheeling charge for 25 years in each candidate cross-border interconnection ranged from US$446 million to US$1,500 million. The total income from the wheeling charge is expected to be US$5,545 million.

Based on these benefits, this study analysed the FIRR, EIRR, and NPV of the Transmission Highway. The FIRR was 15.9%. For a discount rate of 8%, the estimated NPV for the Transmission Highway is US$859 million, and the payback period is 8.9 years. For a discount rate of 10%, the NPV is US$557 million, and the payback period is 10.1 years. The FIRR is higher than Myanmar's long-term interest rate (9.5%). Furthermore, the EIRR was 13.9%. For a discount rate of 8%, the estimated NPV for the Transmission Highway is US$2,170 million, with a payback period of 11.1 years. For a discount rate of 10%, the NPV is US$1,249 million and the payback period is 11.9 years. The EIRR is also higher than 9% of the standard adopted by ADB. From these results, the Transmission Highway is financially and economically feasible.

Based on the results of the quantitative analysis on the potential economic benefits and costs of cross-border interconnections in ACMECS, the Transmission Highway's routes will be constructed and their benefits reaped. While the results of the analysis in this study may lead to further discussions and decisions, it has to be acknowledged that this study insufficiently addresses several issues. For instance, the route selection for transmission lines and cost calculations must be examined. In addition, detailed physical analyses such as power flow calculation, power system stability, short circuit current should be considered. Addressing these issues, which were analysed insufficiently, will improve the reliability of this research.

Finally, the Transmission Highway will greatly benefit ACMECS countries. To maximise the benefits of the Transmission Highway, multilateral power trade should be realised in the ASEAN region. The APG aims to expand power trade gradually and realise a total integrated Southeast Asia power grid system. As noted in Chapter 8, ACMECS countries have been discussing multilateral power trade within the framework of the GMS for many years, and they have accumulated knowledge. Therefore, ACMECS will hopefully be a pioneer in developing multilateral power trade subregionally, then throughout ASEAN. That is the direction of this study.

References

ADB (2017), Guidelines for the Economic Analysis of Projects. Manila: Asian Development Bank.

Brigham, E.F. and M.C. Ehrhardt (2010), *Financial Management: Theory & Practice*. Singapore: Cengage Learning. Inc.

Dunlop, R.D., R. Gutman, and P.P. Marchenko (1979), Analytical Development of Loadability Characteristics for EHV and UHV Transmission Lines, *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-98, No. 2, March/April 1979.

EDC (2019), *Cambodia: National Solar Park Project*. Phnom Penh: Electricité .

EGAT (2018), *Annual Report 2018*. Bangkok: Electricity Generating Authority of Thailand.

EGAT (2020), *EGAT Overview*. Bangkok: Electricity Generating Authority of Thailand

EIA (2020) *How Much Carbon Dioxide Is Produced per Kilowatt-Hour of US Electricity Generation?*, US Energy Information Administration, 15 December, https://www.eia.gov/tools/faqs/faq.php?id=74&t=11 (accessed 11 January 2021).

Energy & Environment (2015), Wheeling Charges Made Easy, 9 October, https://ee.ricardo.com/news/wheeling-charges-made-easy (accessed 14 January 2021).

ERIA (2017a), Study on the Formation of the ASEAN Power Grid Transmission System Operator Institution. Jakarta: Economic Research Institute for ASEAN and East Asia.

ERIA (2017b), Study on the Formation of the ASEAN Power Grid Generation and Transmission System Planning Institution. Jakarta: Economic Research Institute for ASEAN and East Asia.

ERIA (2017c), Study of Renewable Energy Potential and Its Effective Usage in East Asia Summit Countries. Jakarta: Economic Research Institute for ASEAN and East Asia.

ERIA (2019), *Energy Outlook and Energy Saving Potential in East Asia 2019.* Jakarta: Economic Research Institute for ASEAN and East Asia.

ERIA (2020), *Temburong Ecotown Development Phase 4*. Jakarta: ERIA. Economic Research Institute for ASEAN and East Asia.

IEA, Report Extract Macro Drivers. Paris: International Energy Agency. https://www.iea.org/reports/world-energy-model/macro-drivers (accessed 3 February 2021).

IEA (2015), *Southeast Asia Energy Outlook 2015*. Paris: International Energy Agency.

IEA (2019), *Establishing Multilateral Power Trade in ASEAN*. Paris: International Energy Agency .

IRENA (2019), *Renewable Power Generation Costs in 2019*. Abu Dhabi: International Renewable Energy Agency.

JEPIC, *Electricity Business in Each Country (9 Countries and Regions in Asia) – Viet Nam*. Tokyo: Japan Electric Power Information Center, Inc. (in Japanese). https://www.jepic.or.jp/data/asia06vtnm.html (accessed 8 February 2021).

JEPIC (2019), Electric Power Business in Overseas Countries, Volume 1. Tokyo: Electric Power Information Center, Inc. (in Japanese)

JICA (2017), Data Collection Survey on Southern African Power Pool Final Report. Tokyo: Japan International Cooperation Agency.

JICA (2020a), *Overview of Power Sector in Cambodia*. Tokyo, Japan: Japan International Cooperation Agency (in Japanese), https://www.jica.go.jp/cambodia/office/information/investment/ku57pq00001vjq3m-att/electric_power_202010.pdf (accessed 12 January 2021).

JICA (2020b), The Study on Power Network System Master Plan in Lao People's Democratic Republic, Tokyo: Japan International Cooperation Agency.

MoEN (2016), *Thailand Energy Outlook 2016*. Bangkok: Ministry of Energy.

MoEN (2018), *Power Development Plan 2018*. , Bangkok: Ministry of Energy.

Slater H., D. De Boer, G. Qian, W. Shu (2020), *2020 China Carbon Pricing Survey*. Beijing: China Carbon Forum.

The Rockefeller Foundation, 'Access to Electricity is Critical to Africa's Growth', https://www.rockefellerfoundation.org/blog/access-to-electricity-is-critical-to-africas-growth/ (accessed 15 October 2020).

Timilsina, G.R. (2020), Demystifying the Costs of Electricity Generation Technologies. Washington, DC: World Bank.

UNFCCC, *The Paris Agreement*. United Nations Framework Convention on Climate Change, https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement (accessed 12 January 2021)

World Bank (2019), Greater Mekong Subregion Power Market Development—All Business Cases including the Integrated GMS Case. Washington, DC: World Bank.

Yurnaidia, Z., M. Merdekawatia, B. Suryadia, H.F. Sagbakkenb, I. Overlandb, and R. Vakulchukb (2021), *ASEAN Climate Action: A Review of Nationally Determined Contributions Updated in 2020*. Jakarta: ASEAN Centre for Energy.

World Bank (2021), *State and Trends of Carbon Pricing 2020*. Washington, DC: World Bank.