Chapter 5

Analysis on Impacts to the Power Sector

March 2022

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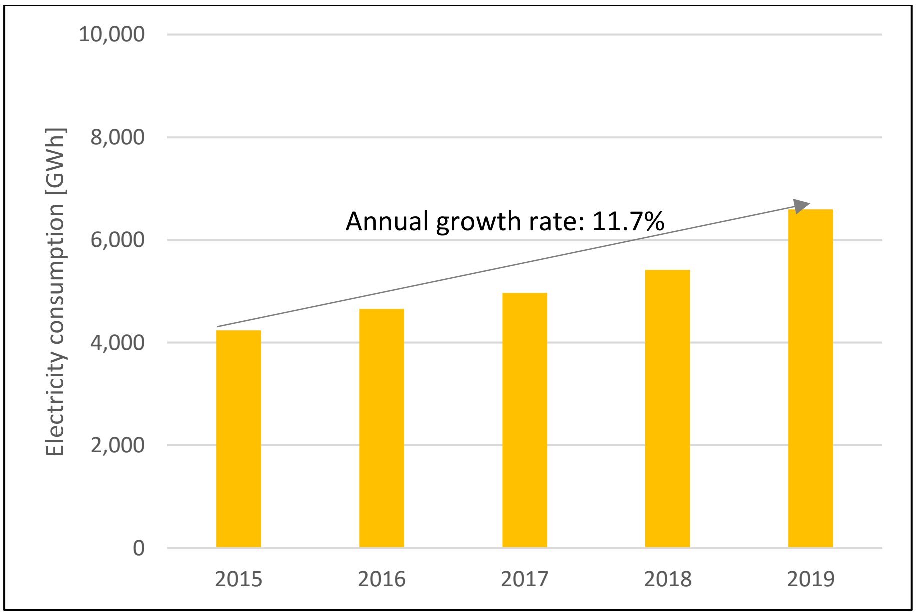
Chapter 5
Analysis on Impacts to the Power Sector

1. Current Situation of Power System in the Lao PDR

1.1. Power Demand

Actual power demand data was obtained from the Ministry of Energy and Mines (MEM). The changes in electricity consumption in the Lao People's Democratic Republic (Lao PDR) are shown in Figure 5.1. The electricity consumption in 2015 was 4,239 gigawatt hours (GWh). It steadily increased from 2015 and reached 6,596 GWh in 2019. The annual growth rate of electricity demand from 2015 to 2019 was about 11.7%.

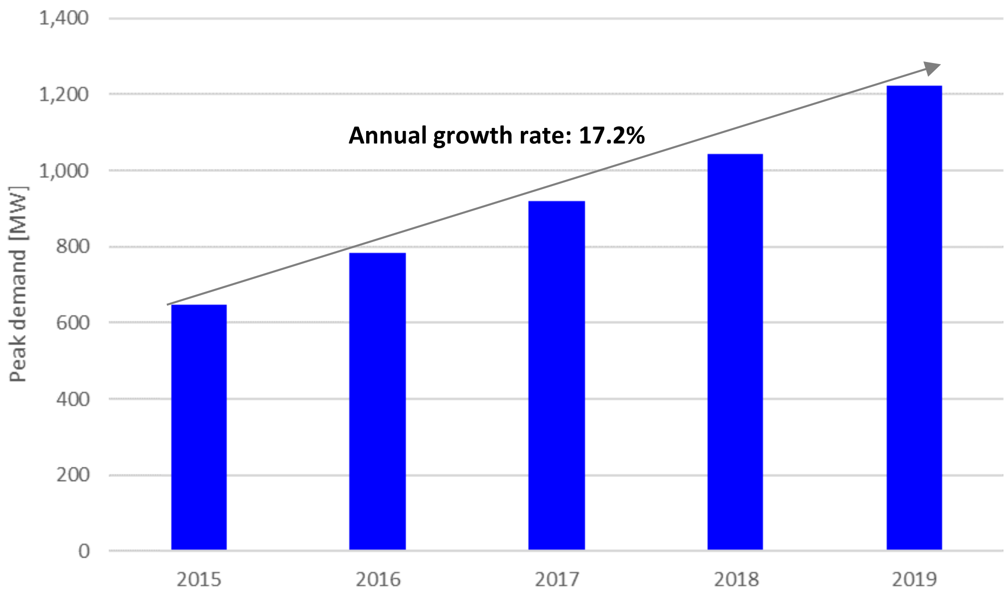
Figure 5.1: Changes in Electricity Consumption in Lao PDR



GWh = gigawatt hour.
Source: Ministry of Energy and Mines (MEM) data, modified by the author.

The changes in peak demand in the Lao PDR is shown in Figure 5.2. The peak demand in 2015 was 648 megawatts (MW). It steadily increased from 2015 and reached 1,223 MW in 2019. The demand growth rate from 2015 to 2019 was approximately 17.2%.

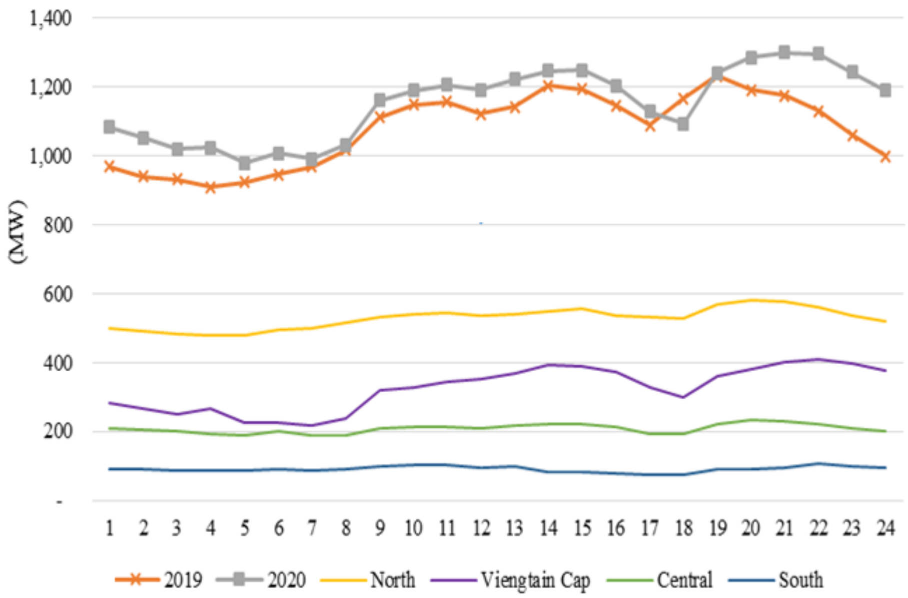
Figure 5.2: Changes in Peak Demand in Lao PDR



MW = megawatt.
Source: MEM data, modified by the author.

Figure 5.3 shows the daily power demand profile of daily peaks in 2019 and 2020. The power demand profile in the Lao PDR starts to increase gradually in the morning with the start of industries and offices and reaches the daytime peak around 14:00 to 15:00 due to air conditioning. Then it dips to around 18:00 with the end of work in some industries and offices and increases again. The day peak demand generally occurs around 19:00 to 21:00 due to lights and household demand. After that, it gradually decreases and reaches a minimum demand around 4:00 to 5:00. Since the minimum demand is about 75% of daily peak demand, the power demand is relatively flat throughout the day.

Figure 5.3: Power Demand Profile of Daily Peaks in 2019 and 2020

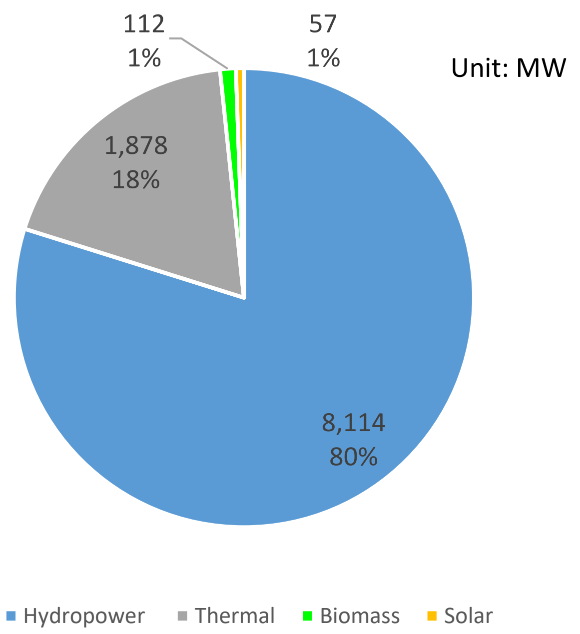


MW = megawatt.
Source: MEM data.

1.2. Power Generation

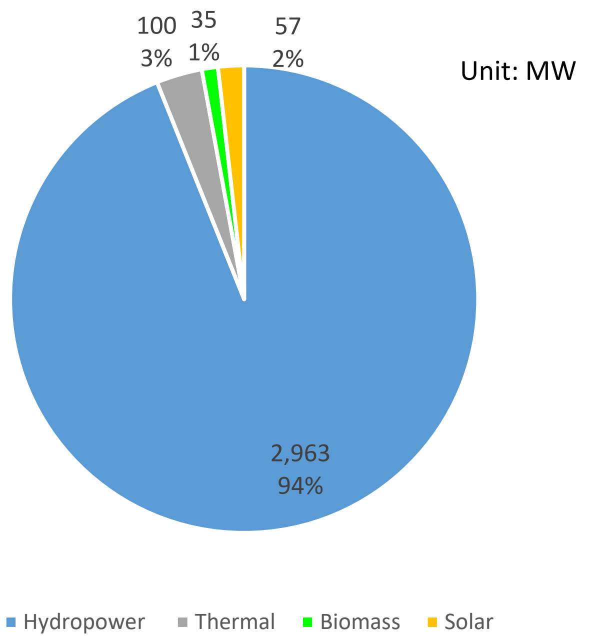
The Lao PDR has a large potential of hydropower generation. As of 2020, the total installed capacity in the Lao PDR was 10,161 MW, of which 3,155 MW was for domestic use. The total installed capacity portfolio in the Lao PDR and the total installed capacity portfolio for domestic use are shown in Figure 5.4 and Figure 5.5, respectively. Generation in the Lao PDR relies on hydropower as the main generation. For the whole country, the installed capacity of hydropower accounted for 80%. Next to hydropower was thermal power, which accounted for 18%. On the other hand, for domestic use, the installed capacity of hydropower accounted for 94%. The installed capacity for domestic use depends mostly on hydropower. The installed capacity of other power generation types such as biomass and solar is still very low.

Figure 5.4: Installed Capacity Portfolio in Lao PDR (as of 2020)



MW = megawatt.
Source: MEM data, modified by the author.

Figure 5.5: Installed Capacity Portfolio for Domestic Use in Lao PDR (as of 2020)



MW = megawatt.
Source: MEM data, modified by the author.

1.3. Overview of the Power System

Although the current power system in the Lao PDR consists of transmission and distribution lines at 500 kilovolts (kV), 220 kV, 115 kV, 33 kV, 22 kV, and low voltage, the domestic power supply system as of 2017 consisted of under 230 kV transmission lines. The 500 kV transmission line is used only for exporting power to neighbouring countries as a dedicated line.

Since the Nam Ngum 1 power station was constructed in the 1970s and a 115 kV transmission line between Thailand and the Lao PDR was constructed, power generated in the Lao PDR has been exported to Thailand in the wet season, with the rich generating power via hydropower plants, while 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 and the Pakbo substation in Central-2 Area directly received power from Thailand because 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 has been connected to the power grid in Thailand, and power output from power plants and the protection of power flow in the interconnecting line between Thailand and the Lao PDR is controlled by instructions from the national control centre in Thailand.

Recently, an extension of the 115 kV transmission line from the independent northern area to the Central-1 area has taken place, and transmission and substation facilities for connecting Central-2 and Southern areas started operation in 2016. This means that a single national grid with 115 kV and 230 kV transmission lines was 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, and a 230 kV transmission line between Vientiane, Luang Prabang, and the Namo substation has started operation. Furthermore, the national control centre in Vientiane plays a role in the operation of 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 substation and Udon 3 substation in Thailand is currently operating at 230 kV and exporting power from only Nam Ngum 2 power station to the Electricity Generating Authority of Thailand (EGAT), in Thailand. Although this transmission line is owned by the Nam Ngum 2 power station company, the power generated at the Nam Ngiep 1 power plant was also connected to this transmission line in 2019. In order to interconnect with neighbouring countries, currently, there are 500 kV and 230 kV transmission lines for direct export of power from independent power producers and a 115 kV transmission line between the grids of Electricité du Laos (EDL) and EGAT. In addition, power trading between the Lao PDR and neighbouring countries is conducted by not only supplying from the domestic power grid but also 35 kV and 22 kV distribution lines, which are adopted in areas that are out of service of the domestic power grid and more than 115 kV transmission line, such as areas located near the national border.

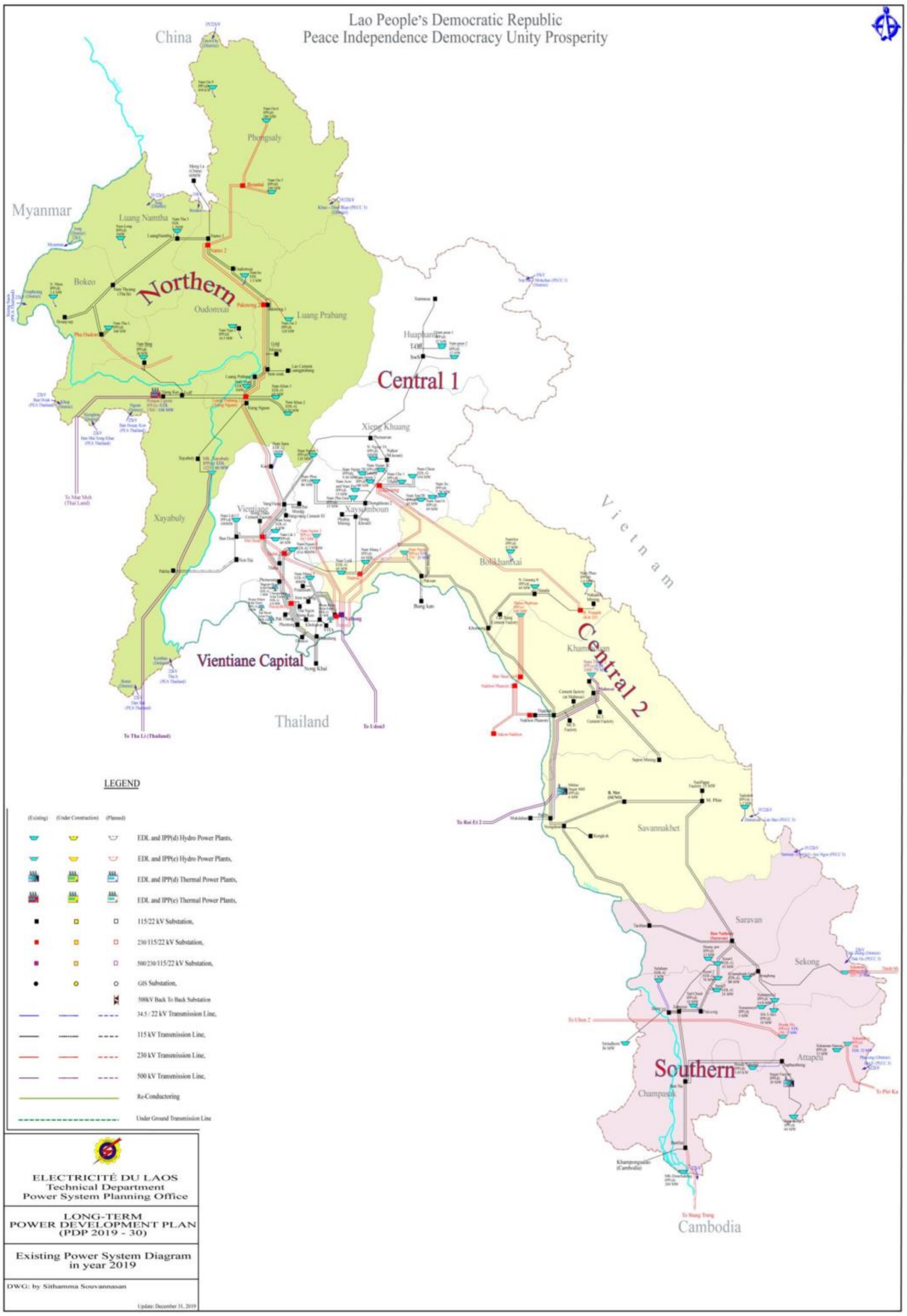
A map of the power system and interconnection lines in Lao PDR as of December 2019 is shown in Figure 5.6: Power Grid Map in Lao PDR. In addition, Table 5.1 shows the EDL transmission line and substation facilities (as of 2020).

Table 5.1: EDL's Transmission Line and Substation Facilities (as of 2020)

Regional	230 kV and 115 kV Ssubstation		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

EDL = Electricité du Laos, km = kilometre, kV = kilovolt, TR = transformer, MVA = mega var, cct = circuit.
Source: MEM.

Figure 5.6: Power Grid Map in Lao PDR

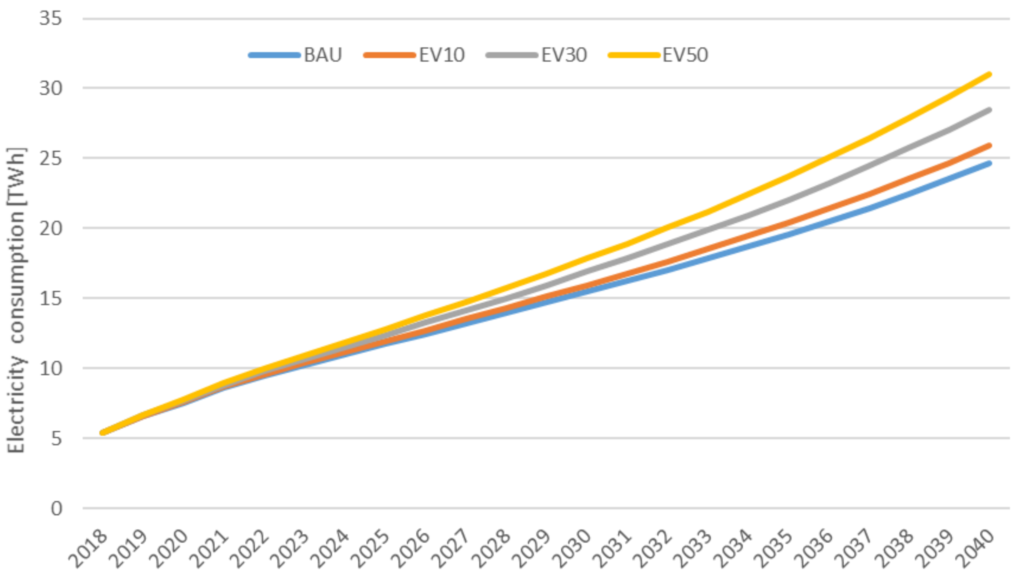


Source: MEM.

2. Electricity Consumption and Peak Demand Forecast

In Chapter 1, the study assumed a scenario in which 10%, 30%, and 50% of vehicles in the Lao PDR would be replaced by EVs as of 2040 and analysed the amount of gasoline used and the increase in power demand by EV charging. Figure 5.7: Electricity Consumption Forecast up to 2040 shows the electricity consumption forecast up to 2040 by EV penetration calculated in Chapter 1.

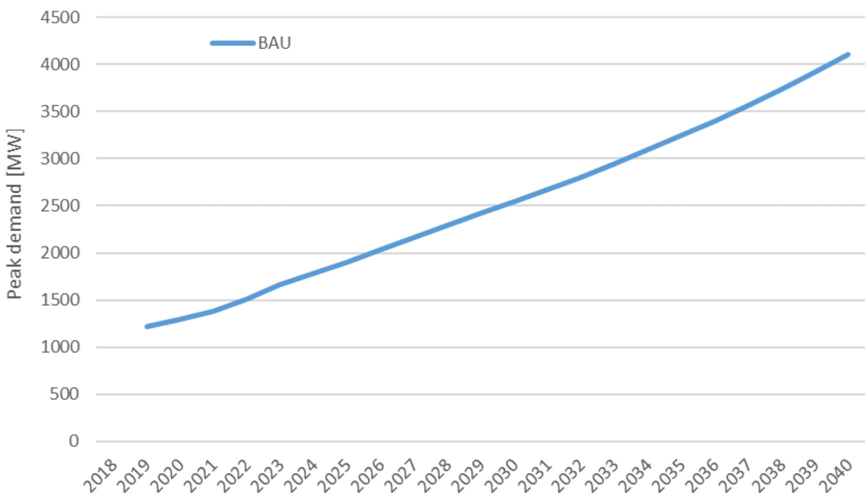
Figure 5.7: Electricity Consumption Forecast up to 2040



BAU = business-as-usual, TWh =terawatt hour.
Source: Authors' calculation.

The peak demand forecast up to 2030 was provided by the MEM. However, since we did not obtain the peak demand forecast after 2030, the peak demand from 2030 to 2040 was assumed to increase at the same growth rate as electricity consumption. Figure 5.8 shows the peak demand forecast up to 2040. The peak demand will steadily increase and reach to about 2,500 MW in 2030 and about 4,100 MW in 2040. Regarding the cases of EV10, EV30, and EV50 where EVs are introduced, since the fluctuation of daily charging demand is large, the peak demand forecast similar to BAU cannot be applied. Therefore, the study will describe the peak demand forecast for EV10, EV30, and EV50 in section 4.

Figure 5.8: Peak Demand Forecast up to 2040



BAU = business-as-usual, MW = megawatt.
Source: Author's calculation.

3. Draft National Power Development Plan

The 'Law on Electricity' is the basic law on electricity business in the Lao PDR. It defines the power development plan, permissions for electricity business and development, environmental and social considerations, electric technical standards compliance, power imports and exports, rural electricity, general principles of electricity tariff setting, and so on. The latest version was amended in 2017 and consists of 13 chapters with 119 articles.

The Power Development Plan (PDP) is stipulated in Chapter 2 of the Law on Electricity. Conventionally, EDL has formulated the PDP. However, with the 2017 revision of the Law on Electricity, the MEM is now responsible for formulating the National Power Development Plan (NPDP).

According to the Law on Electricity, the NPDP is a five-year plan which is established in conformity with the plans and strategies on the national socio-economic development from time to time.

The NPDP consists of the following main contents:

I) power demand forecast for domestic use and for export.

II) power generation resources, volume of production, expansion of transmission and distribution lines to meet the demand as stipulated as well as the identification of priority projects, which integrate with the other sectors' development plans such as the natural resources and environment, agriculture and forestry, industry and commerce, public works and transportation information, culture, and tourism sectors.

III) funding and budgetary plans.

The MEM shall research, prepare the NPDP in coordination with line ministries, ministry equivalent organisations, and relevant local administrative authorities in order to submit the draft plan to the Government for consideration and further submission to seek approval from the National Assembly.

The preparation of the NPDP shall be based on the following conditions and factors:

I) conformity with policies, strategies, and national socio-economic development plans
II) the use and management of water resources, land, and forests in an integrated manner and in compliance with the laws
III) electricity demand for consumption of households, businesses, industries, and export plan
IV) alternative power resources of least–cost type
V) quality of supply and efficiency in the use of electrical power
VI) transmission lines
VII) other conditions and factors (as deemed necessary).

According to the MEM, the draft of the NPDP has been prepared to seek approval from the National Assembly.

Table 5.2: Power Development Plan up to 2030

	BAU		EV	
	Capacity (MW)	Type	Capacity (MW)	Type
2021	680.8	Hydro	680.8	Hydro
2022	265 200	Hydro Solar	265 200	Hydro Solar
2023	305 30	Hydro Solar	305 30	Hydro Solar
2024	52.8 100	Hydro Solar	52.8 100	Hydro Solar
2025	30 300	Hydro Thermal	30 300	Hydro Thermal
2026	290	Hydro	322	Hydro
2027	120	Hydro	120 200	Hydro Solar
2028	200 25	Hydro Solar	200 25	Hydro Solar
2029	180	Hydro	180	Hydro
2030	100	Solar	300	Thermal
Total	2,878.6		3,310.6	

BAU = business-as-usual, EV = electric vehicle, MW = megawatt.

Source: Draft NPDP data provided by the MEM, modified by the author.

Table 5.3: Difference Between BAU and EV Case in the Draft NPDP

	Capacity (MW)
Hydro	32
Thermal	300
Solar	100
Total	432

BAU = business-as-usual, EV = electric vehicle, MW = megawatt, NPDP = National Power Development Plan.
Source: Draft NPDP data provided by MEM, modified by the author.

4. EV Charging Power Demand

Table 5.4 shows the annual charging power demand by EV penetration calculated in Chapter 1. In this study, the required generation capacity to meet EV charging power demand is calculated from the monthly charging power demand. Furthermore, in order to consider the impact on the peak demand, the daily charging power demand is also required. The EV charging power demand varies slightly on weekdays and holidays, but it is thought that there is not much difference depending on the season. In addition, since the purpose of this study is to roughly analyse the impact of EV charging power on power sector in Lao PDR, the monthly charging power demand and daily charging power demand are calculated by dividing the annual power amount evenly. Monthly charging power demand and daily charging power demand are shown in Table 5.5 and Table 5.6, respectively.

Table 5.4: Annual Charging Power Demand

[GWh/year]

	2020	2025	2030	2035	2040
EV10	40	220	480	830	1,280
EV30	140	650	1,420	2,480	3,850
EV50	230	1,080	2,360	4,130	6,410

GWh = gigawatt hour.
Source: Authors.

Table 5.5: Monthly Charging Power Demand

[GWh/month]

	2020	2025	2030	2035	2040
EV10	3.3	18.3	40.0	69.2	106.7
EV30	11.7	54.2	118.3	206.7	320.8
EV50	19.2	90.0	196.7	344.2	534.2

GWh = gigawatt hour.
Source: Authors.

Table 5.6: Daily Charging Power Demand

[GWh/day]

	2020	2025	2030	2035	2040
EV10	0.1	0.6	1.3	2.3	3.5
EV30	0.4	1.8	3.9	6.8	10.5
EV50	0.6	3.0	6.5	11.3	17.6

GWh = gigawatt hour.
Source: Authors.

4.1. Daily Charging Demand Profile

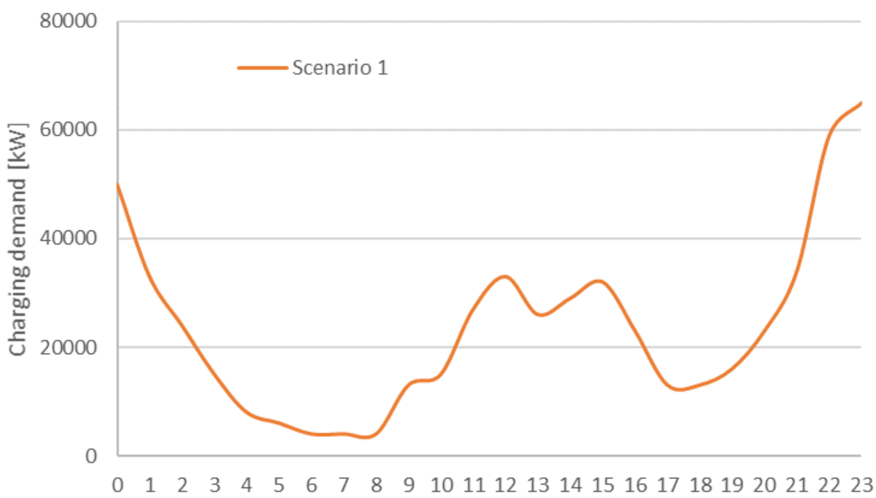
The EV charging power demand changes greatly from hour to hour depending on people's lifestyles. For example, in private cars, people use EVs during the day and charge them after returning home. Thus, the peak charging demand will occur after the evening. Furthermore, if there is a discount on electricity prices at midnight, the peak charging demand will occur at midnight. Also, if you commute to work by car and you can charge at work, it is possible that the charging power will increase in the morning after you go to work. Also, if people commute to work by car and can charge their cars at the office, it is possible that the charging power demand will increase in the morning after commuting (CRIEPI, 2014). Therefore, in order to evaluate the impact of EV charging power demand on the peak demand, it is necessary to consider using the daily charging demand profile.

There are many studies investigating the daily charging demand profile of EVs. Chen et al., (2020) for instance, referred to the results of a study conducted in Hefei city in China to assume the daily charging demand profile. The China study used the driving data of individual EVs and charging data of individual charging piles to estimate the daily charging demand profile in multiple scenarios including temporal distribution of the daily charging demand.

Scenarios are designed with an EV penetration rate of 10% in the future. Furthermore, Scenario 2 assumed that the ratio of EVs/private charging piles increases to 5:4 as an increasing number of EV owners prefer installing private charging piles. Scenario 3 is designed with the consideration of smart charging, which means all private charging piles are directly operated by smart software provided by operation companies (Chen et al., 2020). Scenario 2 and Scenario 3 added assumptions in addition to the EV penetration rate. Therefore, in order to assume the charging demand profile, the study referred to that of Scenario 1.

However, the referenced paper contained only figures of the daily charging demand profile and did not include accurate numerical data of the daily charging demand profile. Therefore, we created an approximate daily charging demand profile for Scenario 1 from this figure and table and used it as the assumption of the daily charging demand profile in this study.

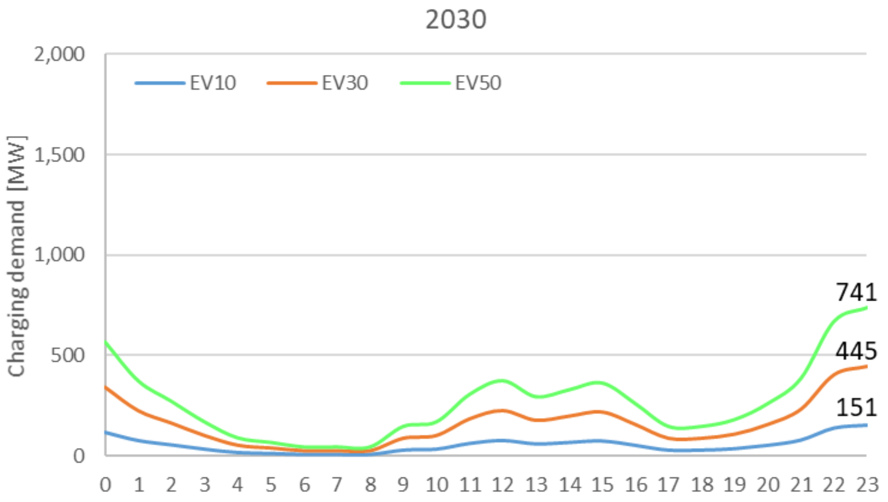
Figure 5.9: Assumed Charging Power Demand Profile



kW = kilowatt.
Source: Chen et al. (2020), modified by the authors.

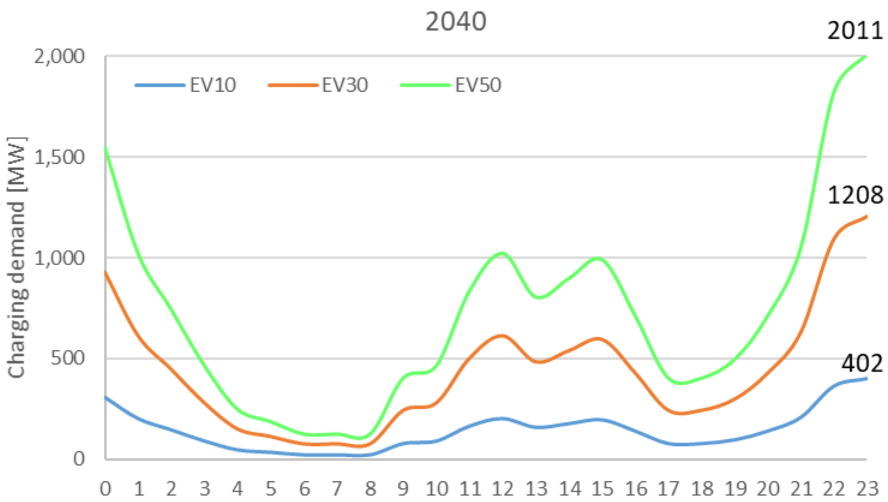
Next, based on the assumed profile, the study estimated the daily charging demand profile in the Lao PDR. The daily charging demand profiles for 2030 and 2040 are estimated as shown in Figure 5.10 and Figure 5.11.

Figure 5.10: Charging Power Demand Profile in 2030



MW = megawatt.
Source: Authors.

Figure 5.11: Charging Power Demand Profile in 2040



MW = megawatt.
Source: Authors.

As a result of estimating the daily charging demand profiles from the assumed daily charging demand profile, the peak charging demands in 2030 were estimated to be about 450 MW for EV30 and about 740 MW for EV50. The peak charging demands in 2040 were estimated at about 1,210 MW for EV30 and about 2,010 MW for EV50. Considering that the peak demand of the Lao PDR in 2019 was 1,223 MW, it can be seen that the EV charging demand may have a large impact on the power system.

4.2. Peak Demand Forecast Considering Charging Demand

Based on the profile estimated in the previous section, the study will estimate the peak charging demand in the future. It is necessary to estimate the peak demand of the power system in consideration of charging demand, but the timing of peak demand excluding the charging demand and that of the peak charging demand do not always match. As shown in Table 5.7 as the daily power demand profile on the day when the annual peak demand occurred, the peak demand occurs from 19:00 to 21:00. On the other hand, in the profile assumed by this survey, the peak demand occurs at 23:00 in the daily charging demand profile assumed by the study. Therefore, the study set the following assumptions for estimating the peak demand in the Lao PDR considering charging power demand.

- ❖ Peak demand excluding EV charging demand appeared from 19:00 to 21:00.
- ❖ Peak charging demand occurs at 23:00.
- ❖ Based on the above assumptions, peak demand including EV charging demand is expected to occur around 22:00.
- ❖ According to daily demand profiles in Table 5.7, the power demand at 22:00 is about 80% to 90% of daily peak demand. Thus, the study assumed that the power demand excluding charging power demand at 22:00 is 90% of peak demand.
- ❖ The peak demand was estimated from the peak demand forecast of BAU and the peak demand of charging demand.

Based on the above assumptions, the study estimated the power demand forecast including charging power demand at 22:00 (Table 5.7). Here, it is noted that the power demand of BAU is peak demand, not power demand at 22:00. In case of EV10, since the charging power demand is not large, the power demand at 22:00 is smaller than the peak demand of BAU. Thus, the impact on peak demand is small. On the other hand, the peak demand of BAU was estimated to be about 2,500 MW in 2030, but that of EV30 was about 2,750 MW and that of EV50 was about 3,050 MW. In addition, the peak demand of BAU was estimated to be about 4,100 MW in 2040, but that of EV30 was about 4,900 MW and that of EV50 was about 5,700 MW. From this result, it was found that the peak demand will reach about 1.4 times the peak demand of BAU in case of EV50 by EV penetration. The study will also analyse the impact on generation capacity in a later section in terms of peak demand including assumed charging demand.

Table 5.7: Power Demand Forecast Including Charging Power Demand at 22:00 (MW)

	2030	2040
EV10	2,438	4,102
EV30	2,733	4,909
EV50	3,028	5,712
BAU (Peak)	2,541	4,112

BAU = business-as-usual, MW -= megawatt.
Source: Authors.

5. Impact Analysis on Power Sector by EV Penetration

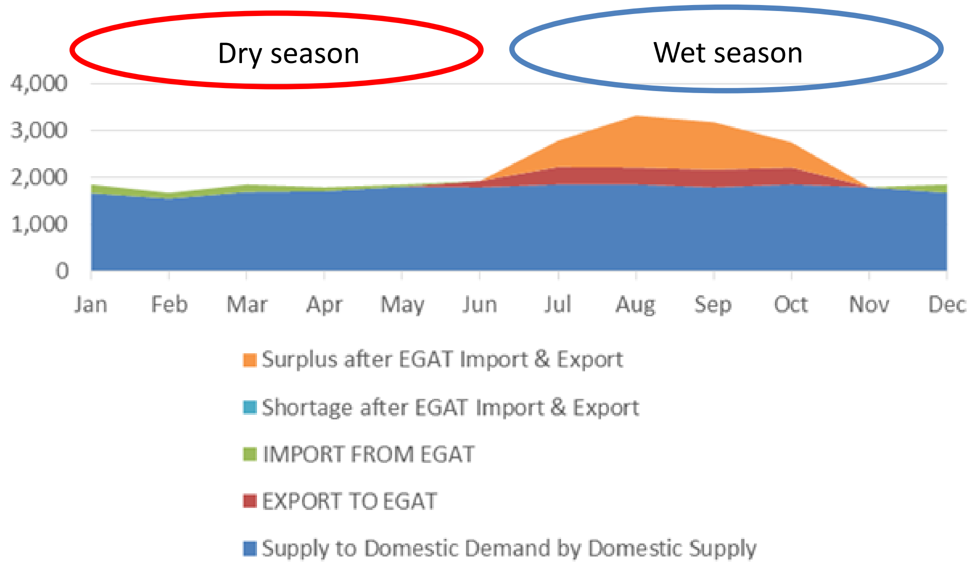
In this section, the study will analyse the required power generation, transmission, and distribution networks to meet the increased power demand due to EV penetration. Then the study will estimate the required cost. In addition, the study will estimate the number of new employment positions expected due to the construction of new power stations.

5.1. Concept of Analysis

The climate of the Lao PDR is typical of tropical monsoons, with two seasons, the rainy season from June to October and the dry season from November to May. The output of hydropower plants in the Lao PDR fluctuates from season to season, and the amount of power generation in the rainy season is large and the output in the dry season is small. On the other hand, seasonal fluctuations in domestic power demand are small.

Figure 5.12 shows the conceptual diagram of current monthly demand/supply balance in the Lao PDR. Since hydropower plants have a small power generation in the dry season, it is necessary to install a power plant with a considerably large capacity in order to secure the supply capacity in the dry season by constructing a new hydropower plant. In addition, since it is not necessary to generate electricity during the rainy season, the capacity factor of newly constructed hydropower plants will be small. The current development centre on hydropower cannot effectively solve the shortage of power supply in the dry season. For this reason, the Lao PDR is currently securing power supply in the dry season by utilising other types of power sources such as thermal power plants and importing from Thailand.

Figure 5.12: Conceptual Diagram of Current/Monthly Demand/Supply Balance in Lao PDR



EGAT = Electricity Generating Authority of Thailand.
Source: Authors' calculation.

In the rainy season, the power supply will be sufficient in the future only with the power output of existing and under construction hydropower plants. On the other hand, if coal-fired power is newly installed to secure power supply in the dry season and stops in the rainy season, the capacity factor of coal-fired power will be lower than the normal value, and economic efficiency will also decline. Furthermore, the development of solar power is planned in the Lao PDR in the future. If the Lao PDR uses a reservoir type that can store water during the day and night, it can be combined with solar power to turn the generated energy of solar power generation at night. Also, it can be expected as a supply capacity in the dry season.

As can be seen from the context of power generation in the Lao PDR, even if many EVs are introduced and power demand increases due to charging demand, the existing and planned power plants will have sufficient power generation during the rainy season. On the other hand, even now, part of the power demand in the dry season depends on imports from Thailand, and if the power demand increases due to charging demand, it is thought that the power generation shortage in the dry season will become even more severe.

This study will focus on the dry season and analyse the required power for the charging demand of EVs. Specifically, in estimating the required power generation capacity, the study adopts the dry season value for the capacity factor of the hydropower plants. The items to be considered in the survey for the impact of EV penetration on the power sector are:

- ❖ Required generation capacity and installation cost
- ❖ Required transmission network and installation cost
- ❖ Required distribution network and installation cost
- ❖ Expected new employment by constructing new power stations

5.2. Required Generation Capacity and Cost Estimation

Study Assumptions for Analysing Required Generation Capacity

The study set the following assumptions for analysing the required generation capacity.

A. Capacity Factor

- ❖ In order to calculate the capacity factor of hydropower, the study referred to the power generation plan up to 2030 under construction (Table 5.8) (JICA, 2019).

Table 5.8: Power Development Plan of Hydropower up to 2030 (under construction)

	Type	Capacity (MW)	Wet Season (GWh)	Dry Season (GWh)	COD
Xekaman – Xanxai (to Viet NamNNam)	Reservoir	32	49.9	81.8	2019
Nam Tha 1	Reservoir	168	340	419	2019
Xepien – Xenamnoy	Reservoir	40	103	126	2019
Xepien – Xenamnoy	Reservoir	370	804	990	2019
Nam Peun1	Run of river	15	54	18	2019
Nam Sim	Run of river	9	18	14	2019
Nam Hao	Run of river	15	51	35	2019
Nam Mon1	Run of river	10	42	31	2019
Xeset – Kengxan	Run of river	13	25	18	2019
Nam Chiene	Reservoir	104	201	247	2019
Nam Ngiep 2A	Run of river	13	41	30	2019
Nam Ngiep 2B	Run of river	9	18	14	2019
Nam The	Run of river	15	37	13	2019
Nam Pha Gnai	Reservoir	15	54	33	2019
Nam Lik 1	Run of river	64	168	81	2019
MK. Xayaboury	Run of river	60	128	113	2019
Nam Ngiep 1 (to Thailand)	Reservoir	294	731	749	2019
Nam Ngiep Regulation	Run of river	18	50	56	2019

	Type	Capacity (MW)	Wet Season (GWh)	Dry Season (GWh)	COD
Nam Hinboun	Reservoir	30	97	59	2019
MK. Xayaboury (to Thailand)	Run of river	1,225	3,015	2,663	2019
Nam Houng Down	Run of river	13	29	21	2019
Nam Aow (Nam Pot)	Reservoir	15	52	32	2019
Nam Sor (Borikhamxai)	Run of river	4.8	13.2	9.8	2020
Nam Ngao	Reservoir	15	39	19	2020
Nam Tha 2	Run of river	15	43	32	2020
Houay Chiae	Run of river	8	22	16	2020
Nam Xam 3 (to Viet Nam)	Reservoir	156	372	254	2020
Nam Hinboun (Down)	Run of river	15	59	20	2020
Nam Samoi	Run of river	5	6	5	2020
Nam Ngum 1 (Extension Phase 2)	Reservoir	40	43	16	2020
Nam Kong 3	Reservoir	45	124	46	2021
Nam Kong 1	Reservoir	160	291	358	2021
Houaypalai	Reservoir	26	64	32	2021
Houay Yoi – Houaykod	Run of river	15	58	20	2021
Nam Long New	Run of river	13	47	35	2021
Xelanong 1	Reservoir	70	148	121	2021
Nam Ngum 4	Reservoir	240	646	226	2021
Nam Ou 4	Reservoir	132	288	236	2020
Nam Ngum 3	Reservoir	480	1,451	894	2020
Nam Dick 1	Run of river	15	58	20	2020
Nam Ou 3	Run of river	210	630	190	2020
Nam Ou 1	Run of river	180	450	260	2020
Nam Ou 7	Reservoir	210	386	425	2020
MK. Donsahong	Run of river	195	680	866	2021
MK. Donsahong (to Cambodia)	Run of river	480	1,451	894	2021
Nam Mo 2	Reservoir	120	296	202	2022
Nam Theun 1	Reservoir	130	322	227	2022
Nam Theun 1 (to Thailand)	Reservoir	520	1,157	819	2022
Nam Ngum Keng	Run of river	1	3	2	2022

	Type	Capacity (MW)	Wet Season (GWh)	Dry Season (GWh)	COD
Houay Palai (Downstream)	Run of river	4	9	7	2022
Houykapheu 1	Run of river	5	12	9	2022
Nam Karp	Run of river	12	31.4	23.2	2022
Houaylamphan Gai (Downstream)	Run of river	15	60	20	2023
Total		**6,083.8**	**15,367.5**	**12,147.8**	

COD = commercial operation date, GWh = gigawatt hour, MW = megawatt.
Source: JICA (2019), modified by the author.

❖ The study assumed that November to May was the dry season and June to October was the wet season.

❖ Based on these data, the capacity factor of hydropower was about 69% in the wet season and about 39% in the dry season (Table 5.9).

Table 5.9: Capacity Factor of Hydropower

Total Capacity (MW)	**Wet Season** (GWh)	**Capacity Factor Factor in Wet Season**	**Dry Season** (GWh)	**Capacity Factor in Dry Season**
6083.8	15367.5	68.8%	12,147.8	39.2%

GWh = gigawatt hour, MW = megawatt.
Source: Authors.

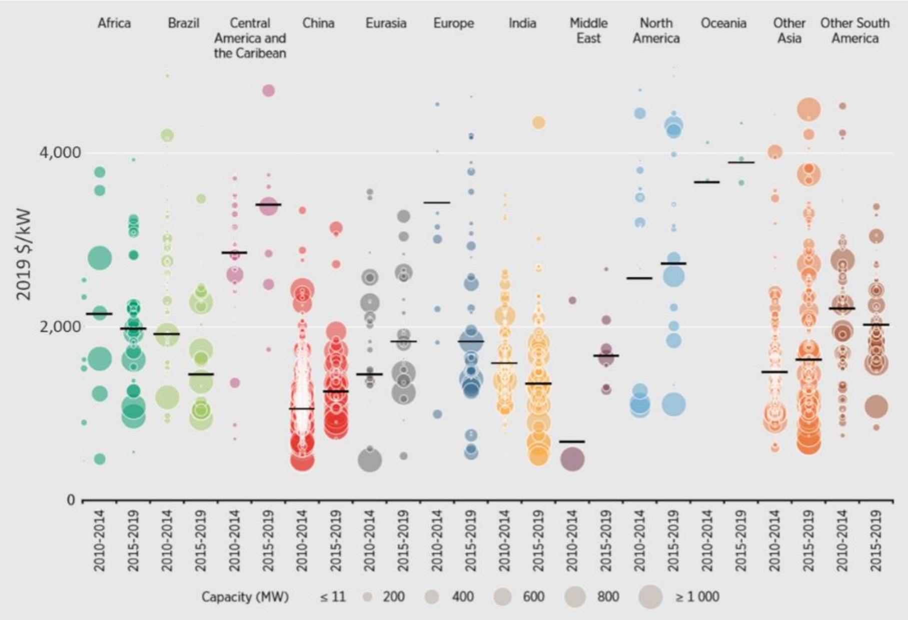
❖ The capacity factor of coal-fired thermal power was 75%.
❖ The capacity factor of solar power was 17%. (JICA, 2019)

B. Unit Cost of Each Type Power Generation

❖ According to the International Renewable Energy Agency (IRENA, 2019), the total installed cost of hydropower and solar vary from region to region of the world (Figure 5.13).

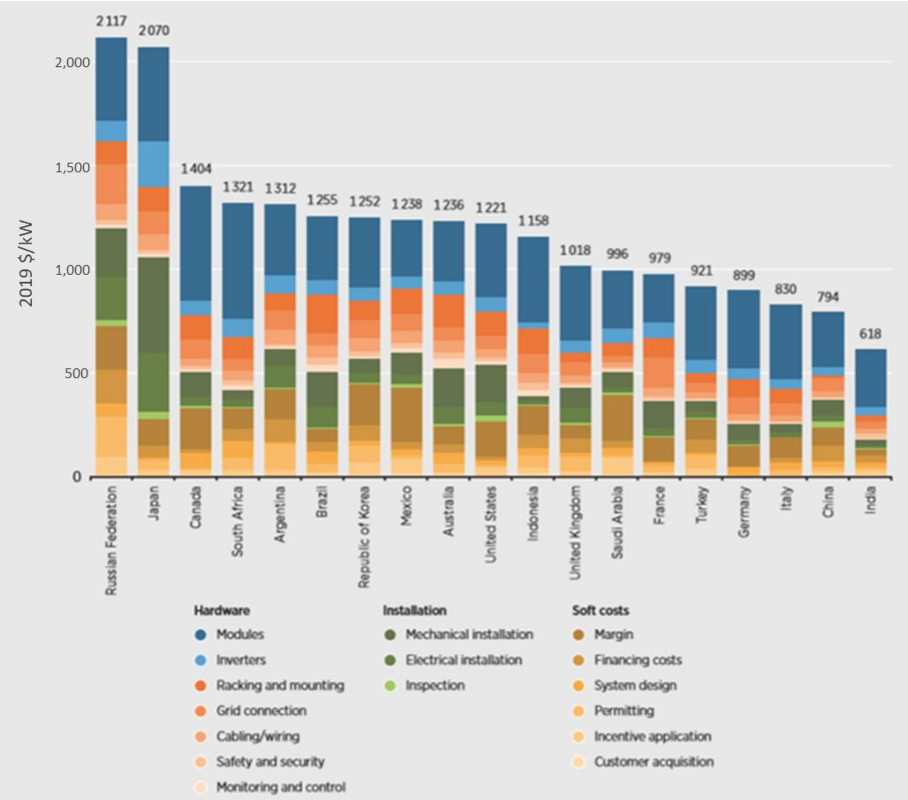
❖ The study referred to the installation cost of China for the calculation of the construction cost of hydropower plants and solar power plants (Figure 5.14).

Figure 5.13: Total Installed Cost Ranges and Capacity Weighted Averages for Large Hydropower Projects by Country/Region



kW = kilowatt, MW = megawatt.
Source: IRENA (2019).

Figure 5.14: Utility-scale Solar PV Total Installed Costs by Country (as of 2019)



kW = kilowatt, PV = photovoltaic.
Source: IRENA (2019).

- According to the International Energy Agency (IEA), the installation cost of coal fired thermal power was $1.6 million/MW.
- The unit cost of each type of power generation is shown in Table 5.10.

Table 5.10: Unit Cost of Each Type of Power Generation

Type	Unit cost ($ million/MW)
Hydropower	1.264
Coal-fired	1.600
Solar	0.794

MW = megawatt.
Sources: IRENA(2019), IEA (2015), modified by the authors.

C. Expected Power Generation of EV Case in NPDP

In order to calculate the required power generation, the study preferentially applied the additional difference of between EV case and BAU in the draft NPDP as the required power generation. Table 5.11 shows the monthly power generation of the additional power plant in the EV case of the draft NPDP. Approximately 183.3 GWh of power generation is expected per month from the additional power stations in the draft NPDP EV case.

Table 5.11: Monthly Power Generation of Additional Power Stations in the Draft NPDP EV Case

Type	Capacity (MW)	Expected generation (GWh/month)
Hydropower	32	9.0
Coal-fired	300	162.1
Solar	100	12.2
Total	432	183.3

EV = electric vehicle, GWh= gigawatt hour, MW = megawatt, NPDP = National Power Development Plan.
Source: Authors.

D. Study Cases

Power stations of the draft NPDP EV case will be applied preferentially, and additional power generation will be required for the shortage of those power generation. The study assumed that the types of additional power generation were hydropower and thermal power, and analysed the required power generation in the following two cases.

- ❖ Case 1: EV case in NPDP + hydro power only
- ❖ Case 2: EV case in NPDP + coal-fired thermal power 300MW + hydro power

Required Power Generation

Based on the above assumptions, the study analysed the required power generation. The required power generation is calculated by applying the power generation of the draft NPDP EV case to the monthly charging power demand in Table 5.5. Table 5.12 shows the required power generation.

Table 5.12: Required Power Generation

Unit: GWh/month

	2030	2035	2040
EV10	0.0	0.0	0.0
EV30	0.0	23.4	137.6
EV50	13.4	160.9	350.9

GWh =gigawatt hour.
Source: Authors.

It can be seen that the power generation of the draft NPDP EV case is sufficient for EV10. On the other hands, the power generation of the draft NPDP EV case will be insufficient for EV30in 2035 and for EV50in 2030. From this shortage of power generation, the study analysed the required generation capacity of power stations. Based on the capacity factor of Assumption A, the required generation capacity of Case 1 and Case 2 in 2040 is as shown in Table 5.13 and Table 5.14.

Table 5.13: Required Capacity for Case 1

	Case 1
	Required capacity (hydropower) (MW)
EV10	0.0
EV30	471.3
EV50	1,215.9

MW = megawatt.
Source: Authors.

Table 5.14: Required Capacity for Case 2

	Case 2		
	Required capacity (thermal power) (MW)	Required capacity (hydropower) (MW)	Total (MW)
EV10	0.0	0.0	0.0
EV30	0.0	300	300
EV50	642.6	300	942.2

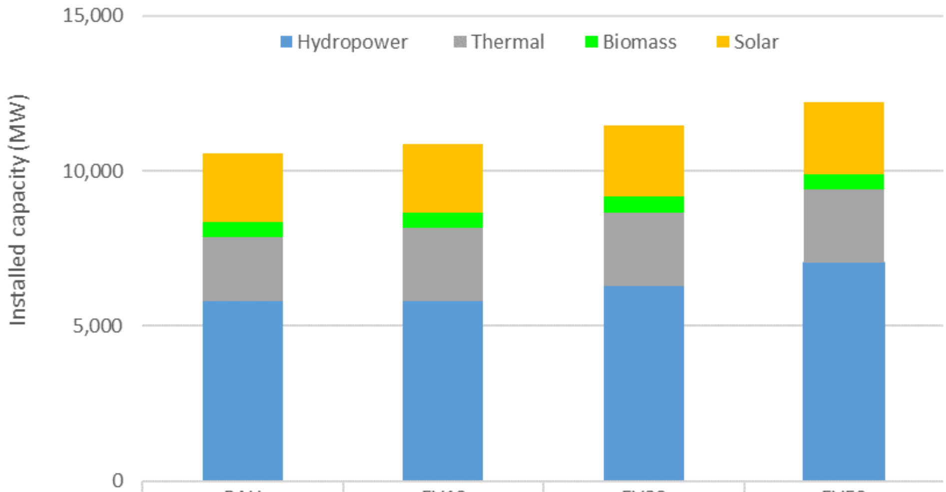
MW = megawatt.
Source: Authors.

As mentioned above, for EV10, the capacity of the draft NPDP EV case is sufficient for both Case 1 and Case 2. In the case of EV30, Case 1 required a capacity of 471 MW of hydropower, and Case 2 required only 300 MW of thermal power. In the case of EV50, Case 1 required a capacity of 1,216 MW of hydropower, and Case 2 requires an additional 643 MW of hydropower in addition to 300 MW of thermal power. As can be seen from these results, the capacity factor of the thermal power is larger than that of the hydropower, so Case 2 requires less capacity than Case 1.

Change in Installed Capacity in 2040

From the required capacity obtained in the previous section, the change in installed capacity in 2040 is shown in Figure 5.15 to Figure 5.18.

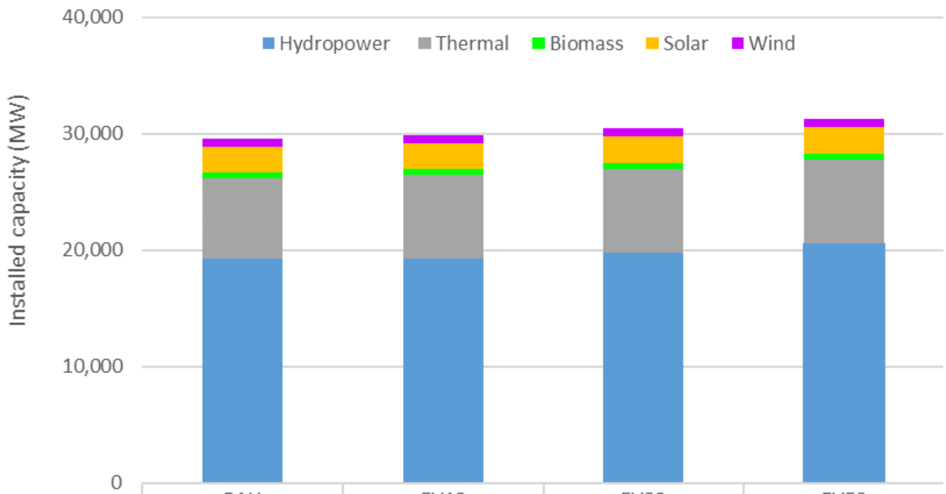
Figure 5.15: Installed Capacity of Case 1 of Domestic Use in 2040



	BAU	EV10	EV30	EV50
Solar	2,200	2,200	2,300	2,300
Biomass	500	500	500	500
Thermal	2,070	2,370	2,370	2,370
Hydropower	5,790	5,790	6,293	7,038

BAU = business-as-usual, MW = megawatt.
Source: Authors.

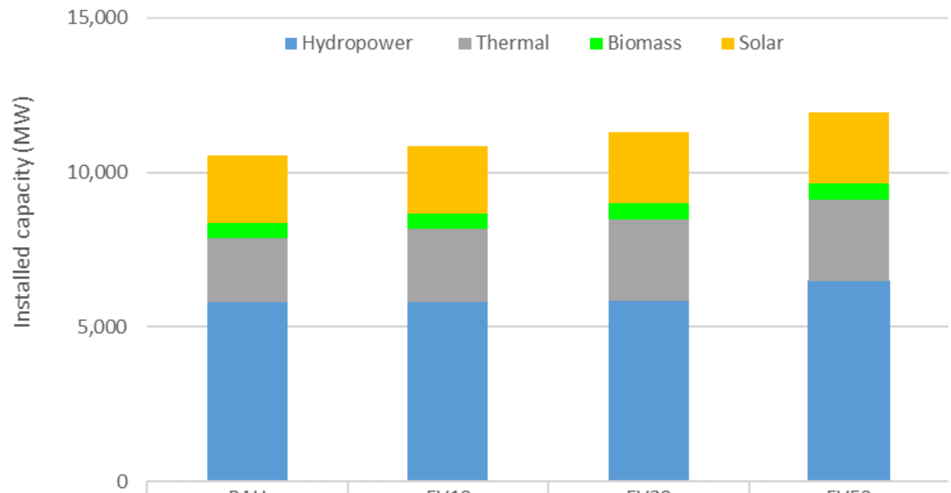
Figure 5.16: Installed Capacity of Case 1 of Whole Country in 2040



	BAU	EV10	EV30	EV50
Wind	700	700	700	700
Solar	2,200	2,200	2,300	2,300
Biomass	500	500	500	500
Thermal	6,900	7,200	7,200	7,200
Hydropower	19,300	19,300	19,803	20,548

BAU = business-as-usual, MW = megawatt.
Source: Authors.

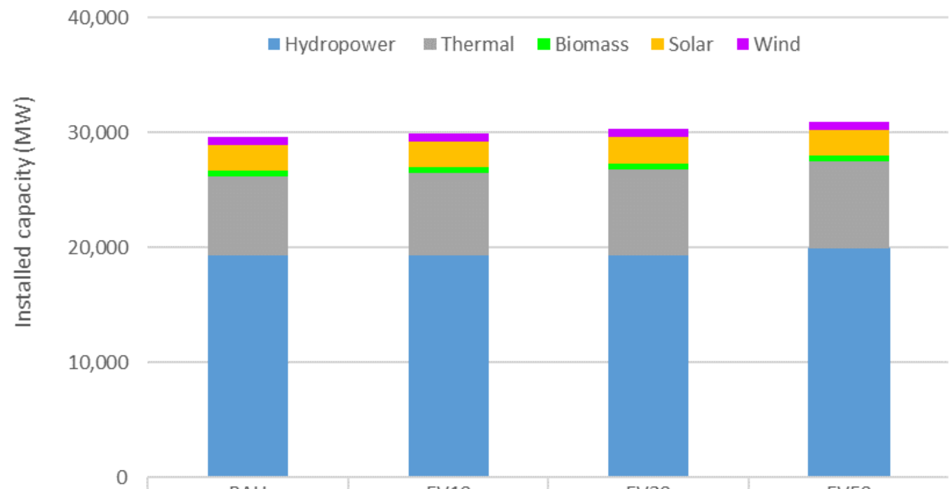
Figure 5.17: Installed Capacity of Case 2 of Domestic Use in 2040



	BAU	EV10	EV30	EV50
Solar	2,200	2,200	2,300	2,300
Biomass	500	500	500	500
Thermal	2,070	2,370	2,670	2,670
Hydropower	5,790	5,790	5,822	6,465

BAU = business-as-usual, MW = megawatt.
Source: Authors.

Figure 5.18: Installed Capacity of Case 2 of Whole Country in 2040



	BAU	EV10	EV30	EV50
Wind	700	700	700	700
Solar	2,200	2,200	2,300	2,300
Biomass	500	500	500	500
Thermal	6,900	7,200	7,500	7,500
Hydropower	19,300	19,300	19,332	19,975

BAU = business-as-usual, MW = megawatt.
Source: Authors.

Cost Estimation for Required Generation Capacity

Based on the results of the required generation capacity and the unit cost of Assumption B, the study estimated the required cost. Table 5.15 shows the installation cost of required capacity of the NPDP EV case. The draft NPDP EV case will require aboutS$600 million to install the power stations.

Table 5.15: Installation Cost of Required Capacity of the NPDP EV Case

Type	Capacity (MW)	Installation Cost ($ million)
Hydropower	32	40.4
Coal-fired	300	480.0
Solar	100	79.4
Total	432	599.8

EV = electric vehicle, MW = megawatt, NPDP = National Power Development Plan.
Source: Authors.

Based on this result, the required cost of Case 1 and Case 2 including the capacity of the draft NPDP EV case are shown in Table 5.16 and Table 5.17.

In the case of EV10, the total installation cost is $480 million in both cases because the thermal power of 300 MW of the draft NPDP EV case is sufficient for both Cases 1 and 2. In the case of EV30, Case 1 required about $1,196 million and Case 2 required about $1,080 million. In case of EV50, Case 1 required about $2,137 million and Case 2 required about $1,892 million. The difference in total installation cost between Case 1 and Case 2 were about $120 million in EV30 and about $240 million in EV50.

Table 5.16: Total Installation Cost of Required Capacity for Case 1

	Capacity (MW)	Installation Cost ($ million)	Total Installation Cost ($ million)
EV10	· 300 MW of coal-fired thermal of NPDP EV case	480.0	480.0
EV30	· 432 MW of NPDP EV case · 471 MW of hydro power	599.8 595.7	1195.5
EV50	· 432 MW of NPDP EV case · 1,216 MW of hydropower	599.8 1,536.9	2,136.8

EV = electric vehicle, MW = megawatt, NPDP = National Power Development Plan.
Source: Authors.

Table 5.17: Total Installation Cost of Required Capacity for Case 2

	Capacity (MW)	Installation Cost ($ million)	Total Installation Cost ($ million)
EV10	· 300 MW of coal-fired thermal of NPDP EV case	480.0	480.0
EV30	· 432 MW of NPDP EV case · 300 MW of coal-fired thermal	599.8 480.0	1079.8
EV50	· 432 MW of NPDP EV case · 1,216 MW of hydropower	599.8 1,536.9	1,892.1

EV = electric vehicle, MW = megawatt, NPDP = National Power Development Plan.
Source: Authors.

5.3. Technical Evaluation of Required Generation Capacity

In the previous section, based on the capacity factor, the study analysed the required generation capacity to meet the increase in power demand from EV penetration. However, as mentioned in section 4, the charging demand of EVs fluctuates greatly depending on human activity, and there is a possibility that a very large power demand will occur at a certain time. Therefore, it is necessary to evaluate whether the power generation capacity is sufficient or not when the peak demand including the charging demand occurs. Furthermore, as can be seen from Table 5.16 Table 5.17, it can be seen that the power demand is increasing at a very large change rate just before the charging demand reaches the peak. Such abrupt changes in a short time may adversely affect the power system frequency. Therefore, the study will analyse the impact on the power system from the viewpoint of the change rate of charging demand.

Evaluation of Installed Capacity for Peak Demand

The study estimated the peak demand including charging demand in section 4. In addition, the study analysed the required generation capacity and how the installed capacity in 2040 would change. Based on these results, Table 5.18 summarises the peak demand forecast and installed capacity in 2040. Here, since peak demand including charging demand was assumed to occur around 22:00, the installed capacity did not include the capacity of solar power. Furthermore, EV10 was excluded because the peak demand of BAU was larger than the power demand of EV10 at 22:00.

Table 5.18: Peak Demand Forecast and Installed Capacity in 2040

	Peak Demand Forecast (MW)	Installed Capacity Without Solar (MW)	
		Case 1	Case 2
EV30	4,909	9,163	8,992
EV50	5,712	9,908	9,635

MW = megawatt.
Source: Authors.

As can be seen from Table 5.18, installed capacity is enough for EV30 and EV50 in both Case 1 and Case 2. However, the study considered the possibility of insufficient power generation in the dry season. Since about 60% of the installed capacity shown in Table 5.18 is of hydropower, the amount of power energy that can be expected to generate is small in the dry season. However, the charging demand increases for several hours in a day. Then the Lao PDR has a lot of reservoir type of hydropower stations. Thus, by preserving the reservoir type of hydropower during the daytime when the charging demand is small and power generation of solar can be expected and operating it during the peak time when the charging demand is large, it is possible to secure the power generation sufficiently for peak demand even in the dry season.

Evaluation of the Change Rate of Charging Demand

Another concern is whether the generators can keep the frequency due to the rapid change rate of charging demand. Generally, as the power demand increases, it is necessary to increase the output of the generator to keep the frequency constant. However, if the power demand increases too fast, the frequency may decrease. The frequency depends on the scale of the power system and the amount of change in supply and power demand. Therefore, in order to analyse the impact of the change rate of charging demand, we will consider it from the power system scale and the change rate. The study analysed the change in demand using the records of the Tokyo Electric Power Company (TEPCO) in 2020 for comparison.

In order to analyse the impact of the change rate on the power system, it is desirable to compare it with the power demand during the time when the change rate occurs. However, since the study did not receive the detailed hourly data on power demand, the study used the peak demand as a scale of power system. In addition, since the frequency is the same throughout the power system connected by alternating current (AC), it is necessary to include the power demand in Thailand when evaluating the change rate of charging demand in the Lao PDR.

According to the Power Development Plan (PDP) 2018, peak demand forecast in Thailand is shown in Table 5.19. Power demand forecast in Thailand were about 41,000 MW in 2027 and about 54,000 MW in 2037.

Table 5.19: Peak Demand Forecast in Thailand (PDP 2018)

	Peak Demand Forecast (MW)
2018	29,969
2022	35,213
2027	41,079
2032	47,303
2037	53,997

MW = megawatt, PDP = Power Development Plan.
Source: Authors.

From the power demand forecast of PDP2018 and the power demand forecast of the Lao PDR in Table 5.20, the total power demand forecast of Thailand and the Lao PDR is calculated. Here, since PDP2018 does not have power demand forecast for 2030 and 2040, the study adopted the power demand forecast in 2027 instead of the peak demand in 2030 and that of 2037 instead of the peak demand in 2040. By adopting a smaller demand assumption, the impact of the change rate can be evaluated more severely. The assumed total power demand in Thailand and the Lao PDR is shown in Table 5.20.

Table 5.20: Assumed Total Power Demand in Thailand and Lao PDR

	Total Power Demand (MW)	
	2030	**2040**
EV30	43,812	58,906
EV50	44,107	59,709

MW = megawatt.
Source: Authors.

For this scale of power demand, the study analysed how much the change rate in charging demand was. Table 5.21 shows the maximum change rate of charging demand in 2030 and 2040.

Table 5.21: Maximum Change Rate of Charging Demand in 2030 and 2040

	Change Rate of Charging Demand (MW/minute)	
	2030	**2040**
EV30	2.9	7.7
EV50	4.7	12.9

MW = megawatt.
Source: Authors.

From Table 5.20 and Table 5.21, the ratio of the change rate of charging power to the total demand in Thailand and the Lao PDR is as shown in Table 5.22.

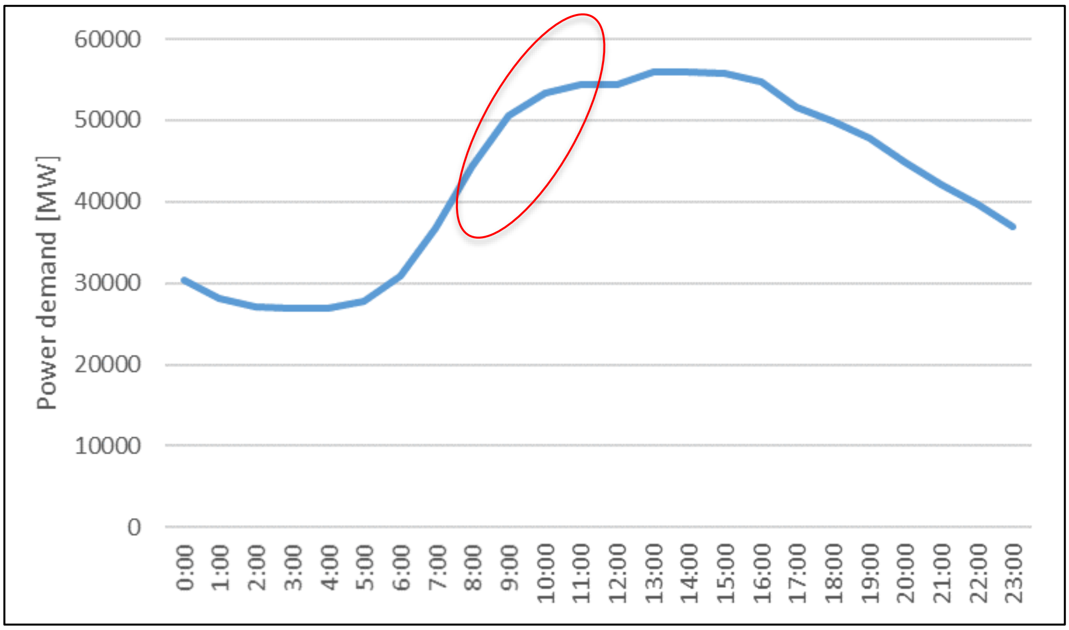
Table 5.22: Ratio of the Change Rate of Charging Power to the Total Demand in Thailand and Lao PDR

	Charging Demand Change Rate (%)	
	2030	2040
EV30	0.007%	0.013%
EV50	0.011%	0.022%

Source: Authors.

Next, in order to evaluate the ratios in Table 5.23, the study made a comparison using TEPCO's record. Figure 5.19 shows the daily power demand profile of the day when the change in power demand per hour was the largest in the year. In Japan, the power demand changes greatly between daytime and night-time, and the power demand increases sharply from around 6:00. Power demand in the TEPCO area on that day increased by about 7,600 MW in 1 hour from 7:00 to 8:00. The change rate in power demand over the past hour was 126.7 MW/minute.

Figure 5.19: Daily Power Demand Profile in TEPCO Area on 17 August 2020



MW = megawatt, TEPCO = Tokyo Electric Power Company.
Source: Authors.

The survey analysed how much this change rate was relative to demand. The power demand in the TEPCO area at 8:00 was 44,300 MW. In addition, since it is necessary to grasp the power demand of the entire power system connected by AC, the power demand of the Tohoku area was also included. The power demand in the Tohoku area at 8:00 on the same day was 9,990 MW. From these data, the relationship between the change rate and power demand in the TEPCO area from 7:00 to 8:00 on August 17 as shown in Table 5.23.

Table 5.23: Ratio of the Change Rate in TEPCO Area to the Total Demand in TEPCO and Tohoku EPCO

Total Power Demand of TEPCO andnand Tohoku EPCO at 8:00 (MW)	**Charging Demand Change Rate** (MW/minute)	**Ratio to Power Demand**
54,290 **(44,300 + 9,990)**	126.7	0.23%

EPCO = Electric Power Company, MW = megawatt, TEPCO = Tokyo Electric Power Company.
Source: Authors.

From the results, it was found that the change rate per minute was about 0.23% of the total demand in the actual record of the TEPCO area. On the other hand, in the case of the Lao PDR, even in the case of EV50 in 2040, it was about 0.022%, which was about one tenth of the actual record of TEPCO in comparison. As can be seen from this result, since the Lao PDR is connected to Thailand's power system, which is about 10 times larger in scale, it is considered that the impact of the demand change by EV charging demand in the Lao PDR on the power system frequency is not so large. In addition, in the power system connected by AC, the generators of the entire power system can contribute to keep the frequency, so even if a sudden change in power demand occurs in the Lao PDR, the output control by Thailand's generators can also be expected.

From the above results, it was found that the required generation capacity is sufficient from the technical point of view as discussed in the next section.

5.4. Transmission Network Cost Estimation

The study analysed the capacity and cost of required power generation due to EV penetration in the previous section. In order to construct a new power plant and generate electricity, a new transmission line is also required to connect to the existing power system. In this section, the study will estimate the cost of the required transmission equipment.

The study set the following assumptions for analysing required transmission equipment.

A. Power Generation of the Draft NPDP EV Case

❖ The locations of the hydropower station and coal-fired power station that are included in the draft NPDP EV case are provided by the MEM. The 32 MW hydropower station will be located in Bolikhamxay province, and the 300 MW coal-fired power station will be located in Houaphan province.

❖ According to the Japan International Cooperation Agency (JICA), the distance of the transmission line from the 32 MW hydropower station to PhonPhon Ngam is about 10 km (JICA, 2019).

❖ The voltage of that transmission line is assumed to be 115 kV.

❖ Total 600 MW of coal-fired thermal power will be constructed in Houaphan province. The 300 MW of this thermal power is for BAU and the remaining 300 MW is for the draft NPDP EV case.

❖ Since the BAU scenario of the draft NPDP includes the development plan of coal-fired thermal power in Houaphan province, BAU also has a plan to construct a transmission line from to this thermal power station to the nearest substation. Therefore, the study did not consider the cost of the transmission line from Houaphan coal-fired thermal power station.

❖ Total 100 MW of solar power of the draft NPDP EV case will be constructed in Vientiane, the capital of the Lao PDR. Since the location of solar is not fixed, the study assumed the 100 MW would be divided into 10 MW x 10 stations.

❖ The voltage of the transmission line from the solar power station to nearest substation is assumed to be 115 kV.

B. Additional Power Generation

❖ Since the capacity of hydropower plants varies from place to place, the study assumed that unit capacity is 50 MW per site. Based on this assumption, the number of required hydropower stations is shown in Table 5.24.

Table 5.24: Number of Required Hydropower Stations

	Case 1	Case 2
EV10	0	0
EV30	10	0
EV50	25	13

Source: Authors.

- ❖ According to JICA, the average distance of existing transmission lines from hydropower stations to the nearest substation is about 33 km (JICA, 2019). Thus, the distance from hydropower stations to the nearest substation is assumed to be 40 km.
- ❖ The distance from the additional 300 MW of coal-fired thermal power is assumed to be the same as the transmission line distance from the Houaphan thermal power currently planned.

C. Unit Cost of Transmission Equipment

- ❖ The transmission lines are assumed to be 500 kV and 115 kV double circuits per route.
- ❖ The costs of substations are assumed to be taken to prepare switch-yard facilities for double circuit transmission lines. The costs do not include transformers, etc.
- ❖ The unit costs of transmission lines and substations are set as shown in Table 5.25.

Table 5.25: Unit Cost for Transmission Lines and Substation Switch-yard Facilities

Type	Unit Cost ($ million//MW)
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
115 kV Transmission Line	0.14
115 kV Substation bus coupler	0.7

kV = kilovolt, MW = megawatt.
Source: Authors.

Based on the above assumptions, the required transmission equipment for the draft NPDP EV case is shown in Table 5.26. The cost of required transmission equipment from the Nam Hong hydropower station to the nearest substation was about $2.9 million. As mentioned in the assumption, the study does not include transmission equipment cost from Houaphanh thermal power station. Then the cost of required transmission equipment from solar was $2.9 million per one station, for a total of $28.7 million at 10 power stations.

Table 5.26: Required Transmission Equipment for the Draft NPDP EV Case

		Length km	S/S $ million	T/L $ million	Total $ million
1	**115 kV Nam Hong - Phon Ngam**				
	Nam Hong		0.7		0.73409
		10		1.4	1.4
	Phone Ngam		0.7		0.73409
	Total	10	1.46818	1.4	2.86818
2	**500 kV Houaphanh - 500 kV Napia (S/S) UC**				
	Total				
3	**115kV Vientiane solar (10MW) - S/S**				
	Vientien solar		0.7		0.73409
		10		1.4	1.4
	S/S		0.7		0.73409
	Total	10.0	1.5	1.4	2.9
	10 solar total	100.0	14.7	14.0	28.7
	Total				31.5

EV = electric vehicle, kV = kilovolt, km = kilometre, MW = megawatt, NPDP = National Power Development, Plan, S/S = substation , T/L = transmission line, UC = under construction.
Source: Authors.

Similarly, the required transmission equipment for additional power stations is shown in Table 5.27. The cost of required transmission equipment from the hydropower station to the nearest substation was about $7.1 million per station. Then the cost of required transmission equipment from the thermal power station was $117.8 million.

Table 5.27: Required Transmission Equipment for Additional Power Stations

		Length km	S/S $ million	T/L $ million	Total $ million
1	**115 kV Hydropower - S/S**				
	Hydro		0.7		0.73409
		40		5.6	5.6
	Substation		0.7		0.73409
	Total	40	1.46818	5.6	7.06818
2	**500kV Thermal (300MW) - S/S**				
	Thermal		6.2		6.18431
		170		105.4	105.4
	S/S		6.2		6.18431
	Total	170.0	12.4	105.4	117.8

MW = megawatt, S/S = substation, T/L = transmission line.
Source: Authors.

Based on these costs, the total costs of Case 1 and Case 2 are shown in Table 5.28. As mentioned above, in the case of EV10, the additional transmission equipment is not necessary in both Case 1 and Case 2. In the case of EV30, Case 1 required about $102 million, and Case 2 required about $149 million. In the case of EV50, Case 1 required about $208 million, and Case 2 required about $210 million. The difference in total installation cost between Case 1 and Case 2 were about $47 million in EV30 and about $1 million in EV50. In the case of EV50, the total costs for Case 1 and Case 2 were almost the same.

Table 5.28: Total Cost of Required Transmission Equipment

	Case 1 ($ million)	**Case 2** ($ million)
EV10	0.0	0.0
EV30	102.2	149.3
EV50	208.3	209.7

Source: Authors.

5.5. Distribution Network Cost Estimation

The study set the following assumptions for analysing required distribution equipment.

A. Distribution Cost

Since we could not obtain unit prices for distribution lines, we referred to the project costs of distribution line projects by the World Bank, which provided support for the Rural Electrification Project (REP).

Total length of distribution lines, number of transformers and project costs in REP I and REP II are shown in Table 5.29.

Table 5.29: Project Outline of Rural Electrification Project, Supported by World Bank

	Unit	REP 1	REP 2
Total cost for grid extension	$	26,400,000	44,031,000
Electrified household	No.	49,397	37,614
22 kV distribution line	km	1,471	1,880
12.7 kV distribution line	km	49	49
Total length of distribution line	km	1,521	1,929
Unit cost of distribution line	$	17,362	22,826
Average	$	20,093.7	

km = kilometre, REP = Rural Electrification Project.
Source: JICA (2019).

As shown in Table 5.29, we set the unit price per kilometre so that the total costs are divided by the total length of distribution line, except for low voltage lines, and applied the average price of the two projects as the unit price. Installation data for distribution lines in the Statistic Report 2019 provided by the MEM, is as shown in Table 5.30.

Table 5.30: Installation Data for Distribution Network (as of 2019)

	Unit	FY 2019
Electrified household	No.	1,244,853
Electrification rate	%	93.93%
22kV distribution line	km	32,241
12.7kV distribution line	km	305
Total length of distribution line	km	32,546

FY = fiscal year, km = kilometre.
Source: MEM.

From Table 5.30 and the peak demand in 2019, the existing distribution network cost is shown in Table 5.31.

Table 5.31: Existing Distribution Network Cost (as of 2019)

Peak Demand in 2019 (MW)	**1,223**
Construction Cost ($ million)	654

Source: Authors.

In section 4, the study estimated the peak demand in the future by charging EVs. Based on the peak demand estimation, the cost of required distribution network is shown in Table 5.32. Here, it should be noted that the cost of required distribution network is the same for Case 1 and Case 2 because it is not directly affected by the construction of a new power stations.

Table 5.32: Cost of Required Distribution Network up to 2040

	Increase in Peak Demand (MW)	**Installation Cost** ($ million)
EV10	402	215
EV30	1,208	646
EV50	2,011	1,076

Source: Authors.

The costs of the required distribution network up to 2040 were estimated to be $215 million for EV10, $646 million for EV30, and $1,076 million for EV50. Therefore, huge costs for constructing the distribution network will be required.

5.6. Fuel Cost Estimation in Case 2

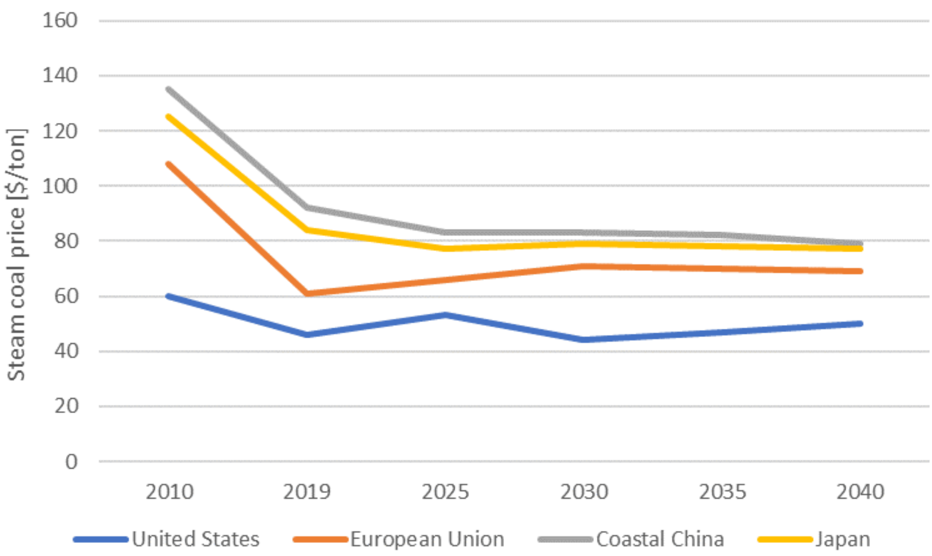
The study has analysed the costs of required generation capacity, and transmission and distribution networks in response to the increase in power demand due to EV penetration. Comparing Case 1 in which only hydropower is added to the draft NPDP EV case and Case 2 in which 300 MW of thermal power and hydropower are added, the total cost of Case 1 is several million dollars higher than that of Case 2. However, the study results only evaluate the initial costs. Since Case 2 assumed the addition of 300 MW of thermal power, the fuel cost of Case 2 must also be considered in order to compare the costs.

The study set the following assumptions for analysing the fuel cost estimation in Case 2.

❖ Unit fuel cost of coal referred to the Indonesian free-on-board coal price of $77.9/ton which was the average price in 2019.

❖ Future unit fuel cost was estimated based on the future fuel prices described in the IEA data as shown in Figure 5.20. This study referred to the trend of China's future price scenario for the future price calculation.

Figure 5.20: Trend in Coal Prices



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

Based on the above assumptions, the study set the unit coal price ($/ton) as shown in Table 5.33.

Table 5.33: Assumption of Future Unit Coal Price

	2019	2025	2030	2035	2040
Unit price ($/ton)	77.89	70.27	70.27	69.43	66.89

Source: Authors.

❖ Coal consumption is calculated based on the ratio of power generation input and output in the ERIA Energy outlook (ERIA, 2019).

❖ The fuel cost is calculated for the 15 years from 2026 to 2040.

Table 5.34 shows the calculated fuel cost of Case 2 based on the above assumptions.

Table 5.34: Fuel Cost Estimation for Case 2

	Power Generation by Thermal (GWh)	Coal Consumption (Mtoe)	Coal Consumption (Mtce)	Fuel Cost ($ million)
EV10	0	0.00	0.00	0
EV30	3,191	1.02	1.45	97.3
EV50	9,167	2.92	4.17	283.0

GWH = gigawatt hour, Mtoe = million tons of oil equivalent, Mtce = million tons of carbon equivalent.
Source: Authors.

As a result, Case 2 additionally requires about $97 million for EV30 and about $283 million for EV50. The difference in initial cost between Case 1 and Case 2 is about $240 million in EV50 and Case 1 is larger than Case 2. However, considering the fuel cost, the total costs of Case 1 and Case 2 up to 2040 will be about the same level.

5.7. Investment Cost Evaluation

The study found that EV penetration would require significant cost for the construction of new power stations and the enhancement of power systems such as transmission and distribution networks. The study evaluated how much this cost will affect the power sector, based on the investment cost data of the Lao PDR.

The Lao PDR's government agency, the Ministry of Investment Planning (MPI) is responsible for the government and regional administration of planning and investment, research strategies, master plans, planning for the National Socio-Economic Development Plan (NSEDP), mechanisms and policies related to economic management, statistics, the promotion, and management of domestic and foreign private investment, attract and seek official development, and international cooperation.

In order to analyse the impact on the power sector, the study referred to the MPI's investment data. As data related to electric power, the MPI's investment data included 'Electricity Generation Investment', but it did not include investment data related to power systems such as transmission and distribution lines. Therefore, the study used data related to 'Electricity Generation Investment' to analyse the impact of the power generation costs required for new construction. In addition, since the transmission and distribution networks are owned and operated by the state-owned power utility company, EDL, the study used data related to government investment in all sectors and analysed the impacts of the costs required to reinforce the transmission and distribution networks.

Table 5.35 shows the investment record of electricity generation investment in the Lao PDR from 2015 to 2019. Regarding local investment, government investment was larger than private investment from 2015 to 2018, but in 2019, the private sector made a large investment. In addition, the amount of local and domestic investment has a large overseas share except for 2019. Comparing local and foreign investment share, it can be seen that the foreign share is large except for 2019, and that the Lao PDR depends on foreign investment.

The average amount of investment in electricity generation investment from 2015 to 2019 was $1,989 million. The study applies this value to the evaluation.

Table 5.35: Electricity Generation Investment in Lao PDR from 2015 to 2019 ($ million)

	Local Share		Foreign Share	Total
	Private	Government		
2015	30	108	430	568
2016	227	228	1,492	1,946
2017	15	217	712	944
2018	8	89	358	455
2019	4,331	483	1,217	6,031
Average	**922**	**225**	**842**	**1,989**

Source: Authors.

The costs of required generation capacity for EV penetration are shown in Table 5.16 and Table 5.17. Since these results are the total of the initial cost up to 2040, it is necessary to use the annual cost in order to compare it with the investment performance in the above table. Assuming that the costs in Table 5.16 and Table 5.17 are the costs for the 15 years from 2026 to 2040, the average annual costs are shown in Table 5.36.

Table 5.36: Annual Cost of Required Generation Capacity

	Case 1 ($ million)	**Case 2** ($ million)
EV10	46	46
EV30	130	125
EV50	228	212

Source: Authors.

Comparing the annual cost with the average of electricity generation investment for the 5 years from 2015 to 2019, the ratio is as shown in Table 5.37.

Table 5.37: Ratio of the Cost of RGC Required Generation Capacity to Electricity Generation Investment

	Case 1	Case 2
EV10	1.6%	1.6%
EV30	4.0%	3.6%
EV50	7.2%	6.3%

Source: Authors.

As can be seen from Table 5.37, the installation cost of the required generation capacity for EV penetration is less than 10% in both Case 1 and Case 2, even for EV50 compared to the current electricity generation investment in the Lao PDR.

Next, Table 5.38 shows the government investment record in all sectors in the Lao PDR from 2015 to 2019. The average amount of investment in government investment from 2015 to 2019 was $384 million. The study applies this value to the evaluation.

Table 5.38: Government Investment in Lao PDR from 2015 to 2019

	Government investment ($ million)
2015	120
2016	946
2017	278
2018	89
2019	485
Average	**384**

Source: Authors.

From Table 5.28 and Table 5.32, the total cost of transmission and distribution network required for EV penetration is shown in Table 5.39. As with the evaluation of power generation costs, assuming that the costs in Table 5.39 are the costs for the 15 years from 2026 to 2040, the average annual costs are shown in Table 5.40.

Table 5.39: Total Cost of Required Transmission and Distribution Network

	Case 1 ($ million)	**Case 2** ($ million)
EV10	215	215
EV30	748	795
EV50	1,284	1,285

Source: Authors.

Table 5.40: Annual Cost of Required Transmission and Distribution Network

	Case 1 ($ million)	**Case 2** ($ million)
EV10	14	14
EV30	50	53
EV50	86	86

Source: Authors.

Comparing the annual cost with the average of electricity generation investment for the 5 years from 2015 to 2019, the ratio is as shown in Table 5.41.

Table 5.41: Ratio of the Cost of Required Transmission and Distribution Network to Government Investment

	Case 1	**Case 2**
EV10	3.7%	3.7%
EV30	13.0%	13.8%
EV50	22.3%	22.3%

Source: Authors.

The reinforcement cost of the required transmission and distribution networks for EV penetration were about 13% for EV30 and about 22% for EV50 compared to the current government investment in the Lao PDR. In terms of ratio, the burden of government investment may increase in the case of EV50. However, the GDP of the Lao PDR will grow from now on, the amount of investment will also increase. Therefore, even if the power demand increases due to EV penetration, the Lao PDR will be able to invest sufficiently.

5.8. Expected Employment from New Power Station Construction

With EV penetration, the construction of new power stations is expected to not only create new investment but also to create new employment. It can be considered as a social benefit.

The study roughly estimated how much new employment could be expected by constructing the required power stations found in the previous section. The study set the following assumptions for estimating new employment.

- The staff number data of hydro, thermal, and solar power stations were provided by EDL.
- The average number of people per MW in hydropower stations with an output of 100 MW or less is 2.5 people/MW.
- For thermal power, this study refers to the number at the Hongsa thermal power station (458 people in the Lao PDR, excluding sub-contractors). The study assumed that the number of staff at the thermal power plant is 450 people.
- There are 36 people in the 32 MW mega solar power stations. The study assumed that 30 people are at one solar power station.

Based on the above assumptions, the expected new employment for the draft NPDP EV case is shown in Table 5.42. About 930 new employees will be expected from the construction of power stations.

Table 5.42: Expected New Employment for the Draft NPDP EV Case

	Capacity (MW)	New Employees
Hydropower	32	80
Thermal power	300	450
Solar	100 (10 MW x 10 stations)	300
Total	432	930

EV = electric vehicle, MW = megawatt, NPDP = National Power Development Plan.
Source: Authors.

Next, the expected new employment for Case 1 and Case 2 including the draft NPDP EV case are shown in Table 5.43 and Table 5.44, respectively.

Table 5.43: Expected New Employment for Case 1

	Power Station	New Employees
EV10	Thermal 300 MW (NPDP)	450
EV30	EV case of NPDP + 10 hydropower stations	1,780
EV50	EV case of NPDP + 25 hydropower stations	3,655

EV = electric vehicle, MW = megawatt, NPDP = National Power Development Plan.
Source: Authors.

Table 5.44: Expected New Employment for Case 2

	Power Station	New Employees
EV10	Thermal 300 MW (NPDP)	450
EV30	EV case of NPDP + 1 thermal power station	980
EV50	EV case of NPDP + 1 thermal power station + 13 hydropower stations	2,605

EV = electric vehicle, MW = megawatt, NPDP = National Power Development Plan.
Source: Authors.

In Case 1, the expected employment was about 1,800 people for EV30 and about 3,650 people for EV50. In Case 2, the expected employment was about 980 people for EV30 and about 2,600 people for EV50. Since the additional thermal power station is constructed in Case 2, the expected new employment is less than in Case 1, where only hydropower is constructed. Therefore, it can be seen that many new employees can be expected in the power sector by EV penetration.

6. Conclusion

The study has analysed the impact on the power sector due to EV penetration. As a large number of EVs will be introduced, power demand will also increase from EV charging demand. Currently the Lao PDR depends on power imports from Thailand to meet the power demand in the dry season. If the power demand increases, the situation of power supply capacity in the dry season will become even more severe.

The study focused on the dry season and analysed the following items:

- ❖ Required generation capacity and installation cost
- ❖ Required transmission network and installation cost
- ❖ Required distribution network and installation cost
- ❖ Expected new employment by constructing new power stations

In order to calculate the required power generation, the study preferentially applied the additional difference between the EV case and BAU in the draft NPDP as the required power generation. The additional difference between EV case and BAU in the draft NPDP was 432 MW.

Then the study conducted two scenarios:

- ❖ Case 1: EV case in NPDP + hydropower only
- ❖ Case 2: EV case in NPDP + coal-fired thermal power 300 MW + hydropower

In the case of EV30, Case 1 required a capacity of 471 MW of hydropower, and Case 2 required only 300 MW of thermal power. In the case of EV50, Case 1 required a capacity of 1,216 MW of hydropower, and Case 2 requires an additional 643 MW of hydropower in addition to 300 MW of thermal power.

Based on the results of the required generation capacity, the study also estimated the installation cost. The draft NPDP EV case will require about $600 million to install the power stations. Then, in the case of EV30, Case 1 required about $1,196 million and Case 2 required about $1,080 million. In the case of EV50, Case 1 required about $2,137 million and Case 2 required about $1,892 million. The difference in the total installation cost between Case 1 and Case 2 was about $120 million in EV30 and about $240 million in EV50.

The required generation capacity was calculated in terms of power energy. However, the charging demand of EVs fluctuates greatly depending on human lifestyles, and there is a possibility that a very large demand for power will occur at a certain time. Thus, the study also evaluated the required generation capacity from the viewpoint of peak charging demand and the change rate of charging demand.

Based on the results of required generation capacity, the study analysed the required transmission equipment. In the case of EV30, Case 1 required about $102 million, and Case 2 required about $149 million. In the case of EV50, Case 1 required about $208 million, and Case 2 required about $210 million. The difference in the total installation cost between Case 1 and Case 2 was about $47 million in EV30 and about $1 million in EV50. In the case of EV50, the total costs for Case 1 and Case 2 were almost the same.

The study also estimated the costs of the required distribution network up to 2040 to be $646 million for EV30 and $$1,076 million for EV50.

It is that EV penetration would require significant cost for the construction of new power stations and the enhancement of power systems such as transmission and distribution networks. The study evaluated how much this cost will affect the power sector, based on the investment cost data of the Lao PDR. In order to analyse the impact on the power sector, the study referred to the MPI’s investment data from 2015 to 2019. The installation cost of the required generation capacity for the EV penetration is less than 10% in both Case 1 and Case 2 even in EV50 compared to the current ‘EV Generation Investment’ in the Lao PDR. On the other hand, the reinforcement cost of required transmission and distribution network for EV penetration was about 13% for EV30 and about 22% for EV50 compared to the current government investment in the Lao PDR. In terms of ratio, the burden of government investment may increase in case of EV50. However, according to ERIA’s Energy Outlook, the Lao PDR’s GDP in 2040 will grow about three times from 2020 (ERIA, 2019). Therefore, even in the case of EV50, it will be possible to invest domestically.

Lastly, the study estimated how much new employment could be expected by constructing the required power stations. In Case 1, the expected employment was about 1,800 people for EV30 and about 3,650 people for EV50. In Case 2, the expected employment was about 980 people for EV30 and about 2,600 people for EV50. Therefore, it can be seen that many new employment opportunities can be expected in the power sector through EV penetration.

Finally, the study analysed the impact of power sector by EV penetration in the Lao PDR. As a result, it was found that it is necessary to construct new power stations and strengthen transmission and distribution networks, and new investment can be expected. The required new investment is large compared to the current investment record but considering the future growth of the Lao PDR's GDP, it would be possible to sufficiently continue to invest in the country.

However, the study only roughly analysed the impact of EV penetration and referred to the example of China in the daily charging demand profile. Generally, people’s lifestyles differ from country to country, so the charging demand of EVs will naturally differ. If EVs become widespread in the Lao PDR, they have to collect related data at the initial stage and will need to consider in more detail the required power generation capacity, power system enhancement, etc. as carried out in the study. We hope that the results of the study will contribute to a detailed study in the Lao PDR in the future.