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Assessment of Electric Vehicle Penetration in the Lao People's Democratic Republic

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ENERGY AND MINES

ERIA

Assessment of Electric Vehicle Penetration in the Lao People's Democratic Republic

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Preface

The Lao People's Democratic Republic (Lao PDR) has achieved remarkable economic growth. Its average gross domestic product growth rate of 7.7% in 2000–2019 was the highest amongst the Association of Southeast Asian Nations (ASEAN) member states during the same period. However, according to the World Bank's Lao PDR Economic Monitor August 2021 (Phouthavisouk, 2021), due to the pandemic, the country's economic growth shrank to only 0.5% during 2020 and was estimated to rebound back to a 3.6% rate by 2021. Again, its strong growth would be driven by government policies promoting private sector investment in all sectors. Energy demand is also expected to bounce back to support economic growth in the foreseeable future. Fortunately, the Lao PDR largely relies on hydropower for its energy.

At the same time, the Lao PDR depends on the import of petroleum products from neighbouring countries. The main use of petroleum products is transport fuel such as gasoline, diesel oil, and jet fuel but the majority is gasoline and diesel oil. According to the energy outlook produced by the Ministry of Energy and Mines in February 2020, the Lao PDR will still depend on petroleum products and the import ratio would reach 26% in 2040.

One option for the Lao PDR to reduce the import of petroleum products such as gasoline and diesel oil is the use of electric vehicles. If electric vehicles use electricity from hydropower in the Lao PDR, the country will be able to reduce the amount of gasoline and diesel oil imported, reduce CO_2 emissions, and save the outflow of the Lao PDR's national wealth.

On behalf of the Ministry of Energy and Mines, I am grateful for the technical and financial support of the Economic Research Institute for ASEAN and East Asia (ERIA) for this study on the Assessment of Electric Vehicle Penetration in the Lao PDR. We will continue to consult with ERIA to build the energy data to support energy policies and planning in the Lao PDR.

H.E. Dr Sinava Souphanouvong

Deputy Minister of the Ministry of Energy and Mines, the Lao PDR

February 2022

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Special acknowledgement is also given to Mr Khammun Sorpaseth, Deputy Director General, Institute of Renewable Energy Promotion, Ministry of Energy and Mines, the Lao PDR, for his very helpful comments and suggestions as head of the Lao PDR team.

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List of Abbreviations

AC	alternating current
BAU	business as usual
CO_2	carbon dioxide
CRIEPI	Central Research Institute of Electric Power Industry
DC	direct current
EBT	Energy Balance Table
EDL	Electricité du Laos
EGAT	Electricity Generating Authority of Thailand
ERIA	Economic Research Institute for ASEAN and East Asia
EV	electric vehicle
ICE	internal combustion engine
IEA	International Energy Agency
JETRO	Japan External Trade Organization
JICA	Japan International Cooperation Agency
kcal	kilocalorie
km	kilometre
ktoe	kiloton of oil equivalent
kWh	kilowatt hour
LEAP	Long-Range Energy Alternatives Planning System
Mcal	megacalorie
MEM	Ministry of Energy and Mines
MPDI	Multidisciplinary Digital Publishing Institute
MPI	Ministry of Investment Planning
Mt-C	million tons of carbon
NPDP	National Power Development Plan
NSEDP	National Socio-Economic Development Plan
PDP	Power Development Plan
TEPCO	Tokyo Electric Power Company
TFEC	Total Final Energy Consumption
TPES	Total Primary Energy Supply

Executive Summary

Transition towards a carbon neutral society is currently a top energy topic in the Association of Southeast Asian Nations (ASEAN). Regarding CO_2 emissions, the power sector is the biggest emitting sector in ASEAN, followed by the transport sector, especially the road transport sub-sector. In the Lao People's Democratic Republic (Lao PDR), the road sub-sector was the biggest regarding CO_2 emissions, but after 2013 when the Hongsa coal-fired power plant started operation to export electricity to Thailand, the power sector has been the biggest CO_2 emitting sector.

For the power sector, the Lao PDR has significant potential of hydropower, so that the country still has the possibility to shift from coal-fired power generation to hydropower generation in the future. Thus, a remaining sector regarding significant CO_2 emissions will be the road transport sub-sector, in other words, vehicles.

There are several ways in ASEAN to decarbonise the road transport sub-sector: (i) increase biofuel consumption, (ii) shift from internal combustion engines (ICE) to battery electric vehicles (EV), and (iii) shift to hydrogen vehicles such as fuel cell vehicles. Paying attention to the energy supply situation in the Lao PDR, EVs will be an option to achieve zero emissions in the road transport sub-sector. Consequently, this report analyses the positive and negative impacts to be brought by shifting to EVs from ICE vehicles in the Lao PDR.

First, a positive impact is the energy saving effect to be brought by EVs. If we assume that EVs will reach at least half of the vehicle stock in 2040, oil demand (gasoline and transport diesel oil) will decrease to 1,460 kilotons of oil equivalent (ktoe) in 2040, and on the other hand, the increase in electricity demand will be 551 ktoe in 2040. Therefore, the total final energy consumption (TFEC) will decrease to 909 ktoe in 2040 compared to the business-as-usual (BAU) scenario. The second positive impact will be to improve the energy supply security situation when the Lao PDR will penetrate EVs. Because the additional power needed from the penetration of EVs will come from hydro or coal-fired power generation, both hydro and coal will be classified as domestic energy. In addition, gasoline and diesel oil for transport will be imported from Thailand. Thus, import dependency defined as import / (domestic production + import) will decline. The third positive impact of EVs is to increase the GDP (gross domestic product) due to a decrease in the imports of gasoline and diesel oil.

CO_2 emissions will reduce due to the decrease in gasoline and diesel consumption, but we need to consider whether the Lao PDR will generate the additional electricity demand from hydropower or coal-fired power plants. According to our analysis result, the maximum rate of coal-fired power generation should be lower than 50%. If we apply 50% of EV penetration ratio, the total CO_2 emissions will be 9.2 million tons of carbon (Mt-C) under 50% of coal-fired power generation to BAU 9.4 Mt-C in 2040.

Next, we analyse how EV penetration will impact the oil industry and power sector. Firstly, we analyse negative impacts to the oil industry due to a decrease in gasoline and diesel oil demand: (i) revenue of the oil companies will decrease compared to the BAU scenario; and (ii) in the case of the EV 50% scenario, gasoline and diesel oil demand will saturate at around the 2018 level up to 2040, thus an expansion of the transport fuel market in the Lao PDR will not be expected. In other words, existing oil companies will be able to survive because the current market volume will be continued to 2040. But they will face severe competition due to the limited oil market volume in the future.

EV penetration in the Lao PDR will bring several positive impacts to the electricity sector due to an increase in electricity demand: (i) investment in additional power plants by Electricité du Laos and independent power producers will be around $2,000 million in the case of EV 50%, (ii) investment in transmission and distribution lines will be around $1,300 million in the case of EV 50,%, (iii) as a result, a total of $3,300 million will be necessary to support the increase in electricity demand in the case of EV 50%, and (iv) EV penetration will also expect 2,600–3,600 additional employees to engage in the electricity sector that includes power plants, and the transmission and distribution networks.

The penetration of EVs will need EV charging stations and a small number of charging stations does not contribute to the penetration of EVs, the so-called chicken-and-egg dilemma. Finally, following are policy recommendations to penetrate EVs in the Lao PDR: (i) necessary government support for penetration of EVs with the assistance of the international community that has much EV experience; (ii) penetration of EV charging stations with numerical targets, (iii) define positive expectations such as energy saving, CO_2 reduction, improvement of energy supply security, and increase of GDP; (iv) huge investment in the power sector ($3,300 million); and (v) application of foreign investment because of the huge investment needed for EV penetration, but applies only to power plants like independent power producers. For the transmission and distribution networks, Electricité du Laos and the Ministry of Energy and Mines should also make investments in order to maintain national security on power supply.

Chapter 1

Impacts Brought by Electric Vehicles

1. Introduction

The transport sector in the Association of Southeast Asian Nations (ASEAN) countries accounts for 40%–60% of the total energy demand. The sector is dominated by oil (gasoline and diesel) imports, which have been increasing rapidly in parallel to the slowing down of domestic production, which affects the security of supply (Koyama and Kutani, 2012). The increased combustion of oil products has worsened the air quality, which potentially has significant socio-economic impacts.

In many cases, there has been inadequate development in infrastructure for public transport, walking, and cycling due to overbuilt roadways that accelerate greater use of private vehicles. As the public transport system is inadequate and unreliable there is often the urge to own a private vehicle or a motorised two-wheeled vehicle. This also, in turn, makes walking and cycling redundant, mainly due to unfavourable and not public-friendly walking and cycling pathways. The United States Energy Information Administration (2017) pointed out that in 2017, non-Organisation for Economic Co-operation and Development (OECD) Asian countries, including China and India, accounted for more than 70% of the increase in transport fuel consumption due to an increase in personal mobility.

Two principal ways can improve the delivery of efficient and sustainable transport infrastructure, which are the use of information and communications technology and the electrification of mobility.

This study of electric vehicle penetration in the Lao People's Democratic Republic (Lao PDR) focuses on the use of more efficient vehicle technology, propulsion, and energy. It analyses the electrification of mobility, the second principal way. Nowadays, we are witnessing electromobility as a fast-growing technological and social trend, which has become one of the main opportunities and challenges for smart cities. The opportunities lie in the fact that the penetration of electric vehicles (EVs) would help shift oil consumption to electricity, reducing on-street greenhouse gas (GHG) emissions and air pollution and reaching a higher energy efficiency in mobility. On the other hand, however, smart cities need to build smart infrastructure for EVEV electric charging (Xu et al., 2016; Wagner, Götzinger, and Neumman, 2014).

Often considered within the category of EVs are hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), full battery electric vehicles (BEVs), and fuel-cell hydrogen-electric vehicles (FCEVs). Electricity produced in these four EV types is different. In HEVs, electricity is produced by the braking mechanism; in PHEVs and BEVs, electricity is produced in the grid system and fed into the vehicle's battery unit during charging.

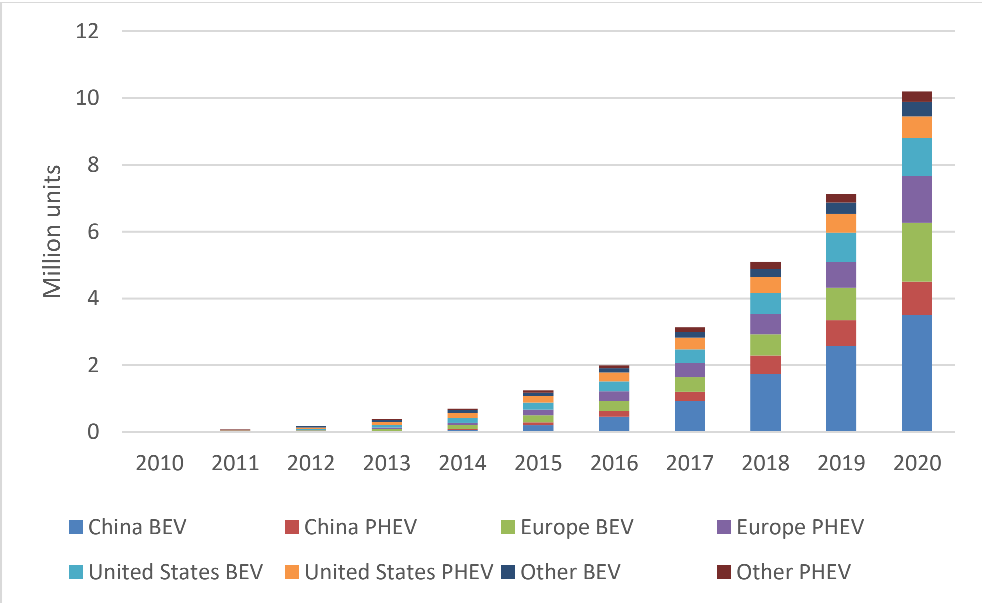
In FCEVs, electricity is produced by electrochemical oxidation of hydrogen in the vehicle's fuel cell unit that is equipped with hydrogen storage.

In this chapter we analyse the possibility of having battery electric cars in the Lao PDR in the horizon of 2040. In sections 4 and 5, we analysed the impacts of each new car technology on energy use at the national level.

2. Trends, Policies, and Possibilities

Electromobility is developing rapidly. As shown in Figure 1.1, by 2020, the global passenger electric car fleet is estimated at nearly 10.2 million, which is 3.0 million more than in the previous year and almost double the earlier sales of new electric vehicles.

Figure 1.1: Global Electric Passenger Car Stock



BEV = battery electric vehicle, PHEV = plug-in hybrid electric vehicle.
Source: IEA (2021).

China is the world's largest market for electric cars, with nearly 1.1 million sold in 2018. With 2.3 million units, it accounts for almost half of the global electric car stock, followed by Europe (1.2 million) and the United States (US) (1.1 million) (IEA, 2019). China started in 2009 with the '10 cities, 10,000 vehicles' business model to promote plug-in electric vehicle (PEV) development. However, it established targets only in June 2012: 500,000 vehicles by 2015 and 5 million by 2020. China aimed to reach new EV sales shares of 7%–10% by 2020, 15%–20% by 2025, and 40%–50% by 2030 (Marklines, 2021).

In Japan, a leading EV market, government support for BEV development started in the early 1970s191970s. Strong government commitment to promoting EVs is reflected in a heavy emphasis on research and development of vehicle and component technologies, infrastructure, and market support for EV users. The Ministry of Economy, Trade and Industry funded the Clean Energy Vehicle Introduction Project, which provided subsidies and tax discounts for purchasing EVs (Loveday, 2013).

In 2017, Japan's EV production ranked fourth in the world at around 8%, after China (50%), Europe (21%), and the US (17%) (Lutsey et al., 2018). The government works with industry stakeholders to reduce by 80% GHG emissions from domestically produced vehicles (by 90% for passenger vehicles), including exported vehicles, by 2050, with a combination of HEVs, BEVs, PHEVs, and FCEVs. Under the new policy scenario, Japan targets increasing the EV sale share of all modes (excluding two- and three-wheelers) by 21% and scaling up to 37% market share under the EV30@30 scenario in 2030. To provide more charging stations throughout Japan, in 2018 the government set the goal of having fast chargers every 9.3 miles (15 kilometres [km]) or within every 19-mile (30 km) radius (Kane, 2018). Japan's success in the EV market is due to government commitment, strong support from the automotive industry, and user-friendly infrastructure.

In 2013, the Government of India established the National Electric Mobility Mission Plan 2020 and, in 2015 enacted Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India). The government announced its intention to move towards all-EV sales in 2025–2040, and through the EV30@30 programme, to ensure that EVs will account for at least 30% of all vehicle sales by 2030 (Lutsey et al., 2018; IEA, 2019). All vehicles, including two-wheelers, are targeted for electrification. EVs have penetrated the van and urban bus markets, accounting for 14% of all passenger cars and light commercial vehicles and 11% of all bus sales (IEA, 2019). As a member of the Electric Vehicle Initiative, India is dedicated to accelerating the deployment of EVs.

Only two ASEAN countries produce and commercialise PEVs – Thailand and Malaysia. Thailand's first PEV development road map – the Electric Vehicle Promotion Plan – was approved by the government in March 2015. In 2017, the Board of Investment approved incentives for manufacturers of BEVs, HEVs, and PHEVs, mostly in the form of corporate tax exemptions for 5 to 8 years. The project to develop next-generation automotive vehicles, focusing on PEVs, was included in the Eastern Economic Corridor, approved in February 2018, to spur investment. In March 2019, the Board of Investment agreed to renew the investment package for HEVs to attract more investment in PEV production. Investors had to apply to produce HEVs in 2019 and assemble BEVs within 3 years. HEV and PHEV sales rose by 24.7% in 2017 to 11,945 units whilst BEV sales reached 165 units (Nicholls et al., 2018). Vehicles sold in that year totalled 870,748 units. By 2036, Thailand targets having 1.2 million electric cars on its streets and setting up 690 charging stations.

On 8 August 2019, the Government of Indonesia issued Presidential Decree No. 55/2019, which laid the general framework to accelerate the penetration of (plug-in) battery-based electric vehicles in the country. Before that decree, the Ministry of Industry told a newspaper that the government would target sales of 400,000 EVs by 2025 to reduce GHG emissions by 29% in 2030 (Tempo.co, 2021). One source mentioned that 400,000 PEVs would be produced domestically by then. Other sources estimate that around 2 million electric-powered two-wheelers would be sold by 2025. Jakarta has around 1,000 charging stations, built by PLN (State Electricity Company) (Aji, 2017). On 23 October 2019, the government issued Regulation (PP) No. 73/2019 concerning luxury sale tax of private cars that gives advantage to low CO_2-emitting cars, including the different classes and types of EVs.

3. Methodology and Scenarios

In this study, we modelled the Lao PDR's national energy systems on the Long-Range Energy Alternatives Planning System (LEAP) software during the Working Group of ERIA's Energy Outlook and Energy Saving Potential Project organised in Jakarta on 3–7 February 2020. Historical data of the Lao PDR's energy consumption from the different sectors and the energy supply system were used to develop the model that contains the relationship between energy demand and supply and the different socio-economic and demographic assumptions, which allow long-term forecasting.

Based on this model, we developed a business-as-usual (BAU) scenario of the road transport sector in the Lao PDR to the horizon of 2040 as a benchmark scenario to assess the impacts of penetration of new technologies in the road transport vehicle fleet.

We define BAU as the scenario where the country's road transport vehicle fleet would develop to the horizon of 2040 without any penetration of electric vehicles. This scenario means that up to 2040, there will be only two kinds of road transport fuel: gasoline and diesel fuels.

We elaborated three EV scenarios representing certain penetration levels of full BEVs in the country's road passenger car fleet in 2018–2040.

The level of penetration is represented by the exogenously defined percentages of shares of BEVs in the total number of road transport vehicles in the Lao PDR in 2040. We assumed that there was no electric vehicle in the base year in all scenarios, i.e., 2018.

The three EV scenarios in the Lao PDR are:

- EV10 – a scenario where BEVs would make 10% share of the total road vehicle fleet in 2040
- EV30 – a scenario where BEVs would make 30% share of the total road vehicle fleet in 2040
- EV50 – a scenario where BEVs would make 50% share of the total road vehicle fleet in 2040

In other words, we assume that the total number of electric vehicles in the Lao PDR will grow linearly from zero electric vehicles in 2018 to reach 10%, 30%, and 50% of the total road vehicle fleet in 2040, respectively in the EV10, EV30, and EV50 scenarios. The assumptions, method, and equations used to calculate the exact number of electric vehicles differentiated by categories and types are given in section 4.2.

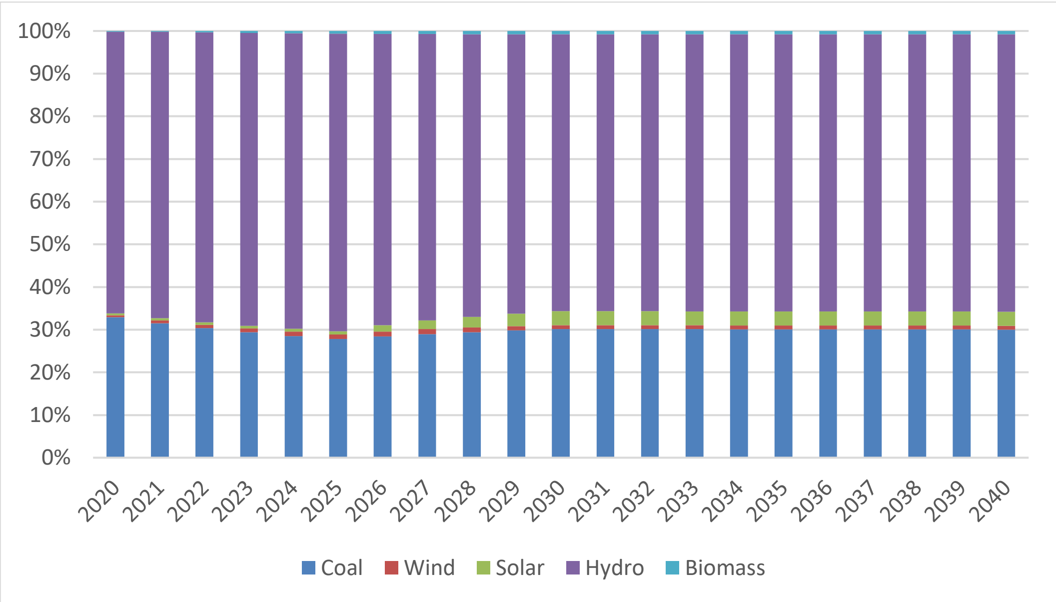
4. Assumptions of the Study

4.1. Population, GDP, and Power Generation Energy Mix

The population is expected to grow at 1.5% per year during the whole observation period. We used the projection of the International Monetary Fund (IMF, 2019) as our main source for gross domestic product (GDP) growth, i.e., the annual growth rates are 7.1% up to 2020, 6.4% in 2020-2030, and 5.7% in 2030-2040.

As shown in the Figure 1.2, we assumed that natural hydropower plants comprise 66% of the total electricity generation in 2020; whilst coal-fired plants comprise 33%; and the remaining 1% is shared between wind, solar photovoltaic (PV), and biomass plants. During the whole simulation period the share of hydro was assumed to experience a slight decrease to 65% by 2040, whilst that of coal-fired plants would also drop to 30%. The share of solar PV would increase to around 3.2% by 2040 whilst that of wind and biomass would remain below 1% each.

Figure 1.2: Fuel Share in Electricity Generation in Lao PDR



Source: Lao PDR LEAP model assumption used in the Working Group of ERIA's Energy Outlook and Energy Saving Potential Project, Jakarta, 3–7 February 2020.

4.2. Road Transport Vehicles

The total number of road transport vehicles in the future is a key assumption that would determine energy consumption and the transport sector's profile. Forecasting the future number of road transport vehicles can be estimated using the Lao PDR's future vehicle ownership rate, given the number of vehicles per 1,000 inhabitants. A usual method in estimating the vehicle ownership rate is using the vehicle ownership model developed, for example, by Dargay, Gately, and Sommer (2007). This model employs an S-shaped function, i.e. the Gompertz function, to estimate the relationship between vehicle or car in the case of Dargay, Gately, and Sommer (200720072007), ownership, and per-capita GDP.

Equation (1) $$V_{year} = \gamma . e^{\alpha . e^{\beta . GDPCAP_{year}}}$$

where

V_{year} = long-run equilibrium of car ownership rate (cars per 1,000 inhabitants at purchasing power parity)

γ = saturation level (cars per 1,000 inhabitants)

$GDPCAP_{year}$ = GDP per capita (expressed in constant local current unit of 2018)

α, β = parameters defining the shape, or curvature, of the function

Using road vehicle stock, GDP, and population data from 2000 to 2016, we calculated the vehicle ownership rate and estimated the parameters of equation (1) for all the four vehicle categories, i.e., motorbikes, cars, trucks, and buses. Table 1.1 show that 76.9% of vehicle stock in the Lao PDR by 2016 were motorbikes, 20% were cars, 2.8% were trucks, and 0.3% were buses. The 2016 road vehicle stock comprised 80% gasoline-fuelled vehicles and 20% diesel-fuelled vehicles. The total road vehicle stock in the Lao PDR grew rapidly during the period 2000–2016 at an annual average rate of 15%, whilst the two vehicle types with the fastest annual growth during the same period were diesel vans (21.4% average annual growth rate) and diesel pickups (18.4%). The estimated values of the equation (1) parameters are given in the Table 1.2.

Table 1.1: Road Vehicle Stock Data of Lao PDR

Fuel Type	Gasoline	Gasoline	Gasoline	Diesel	Diesel	Diesel	Diesel	Diesel
Vehicle Category	Motorbike		Car				Truck	Bus
Vehicle Type	Two-wheeler	Three-wheeler	Sedan	Pickup	Van	Jeep	Truck	Bus
2000	153,781	4,347	8,045	15,074	2,199	3,970	8,424	1,831
2001	168,379	4,405	8,995	17,581	2,603	4,355	10,559	1,899
2002	195,353	4,405	9,428	19,042	2,691	4,584	11,346	2,042
2003	196,963	6,407	9,696	25,490	2,729	5,832	11,841	2,164
2004	285,740	7,871	10,063	38,214	3,777	6,949	13,085	2,179
2005	337,719	8,043	11,204	45,029	4,862	7,909	13,441	2,199
2006	453,158	8,441	12,939	60,352	7,236	8,668	15,296	2,200
2007	509,421	8,518	14,792	68,360	10,355	9,399	17,994	2,242
2008	623,310	8,460	15,203	77,616	12,675	9,752	19,070	2,520
2009	711,800	8,624	17,671	93,080	18,634	10,801	23,031	2,707
2010	804,087	8,542	21,638	109,362	24,727	12,155	25,452	2,825
2011	899,685	8,554	28,096	128,892	32,667	14,169	28,873	3,203
2012	1,005,047	8,588	35,514	147,497	37,831	17,231	33,460	3,532
2013	1,112,072	8,601	43,860	162,633	50,124	19,876	38,454	3,861
2014	1,218,379	8,737	51,284	185,086	42,770	22,515	44,293	4,120
2015	1,318,107	8,761	58,871	204,360	47,553	26,665	48,739	4,448
2016	1,413,990	8,879	65,699	225,060	49,061	30,223	52,443	4,665

Source: Ministry of Public Works and Transport, Lao PDR (2019).

Table 1.2: Estimated Parameters of Equation (1)

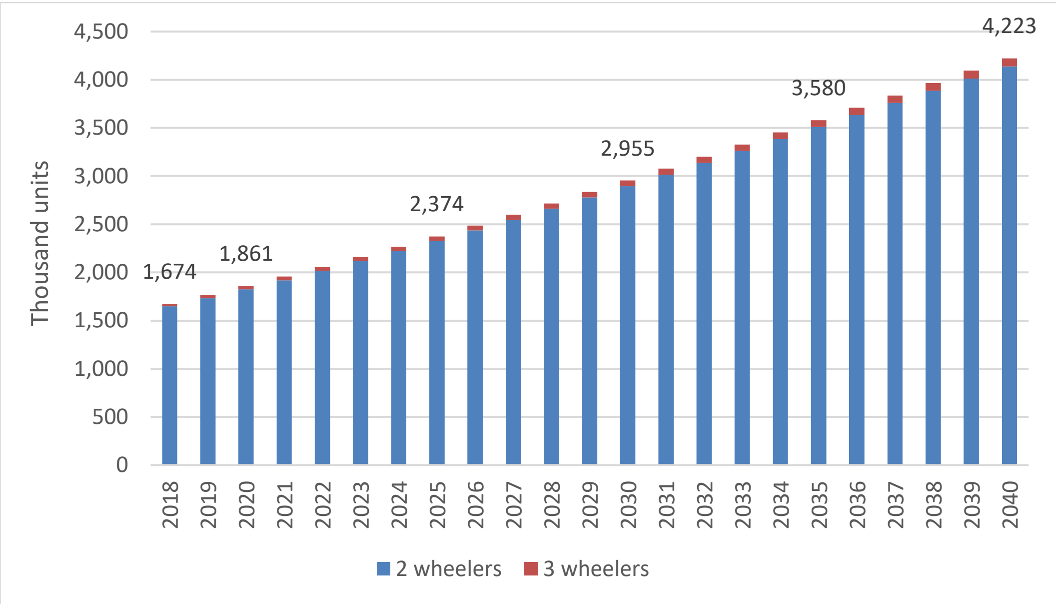
Parameters	Estimated Value			
	Vehicle Category			
	Motorbike	Car	Truck	Bus
γ	750	220	18	1.6
α	–6	–5.7	–3.5	–2.1
β	-9.10^{-4}	$-8.9.10^{-4}$	-9.10^{-4}	-6.10^{-4}

Source: Authors' calculation.

Combined with the Lao PDR's estimated future population, we obtained the estimated number of motorbikes, cars, and trucks and buses in Figure 1.3, Figure 1.4, and Figure 1.5, respectively. We classified road vehicles into four categories: motorbike, car, truck, and bus. The motorbike category is further divided into two motorbike types: two- and three-wheelers, whilst the car category is divided into four car types: sedan, pickup, van, and jeep. We use the 2016 data to calculate the share of each vehicle type in each category. These shares are assumed to remain the same during the 2018–2040 period, so that the units of vehicle in a particular type are calculated by simply multiplying the total units of vehicle in the corresponding category with the vehicle type's share.

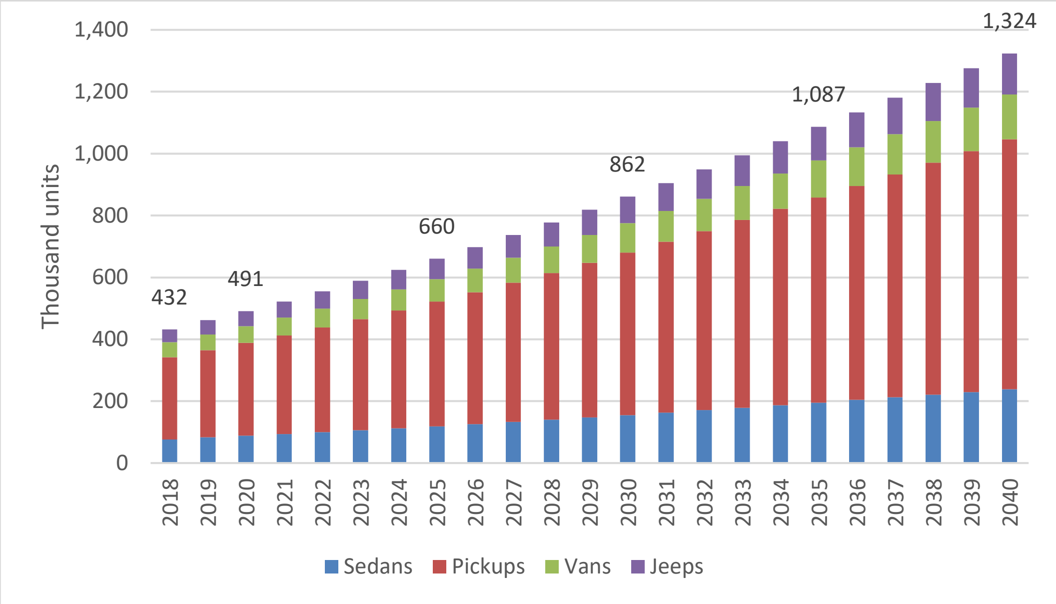
We expected that the number of motorbikes would grow at an annual rate of 5% per annum until 2025 and then at 3.4% per annum until 2040. The number of cars is expected to grow at an annual rate of 6% until 2025 and then 4% until 2040. Trucks and buses together were expected to grow at 4.4% per year until 2025 and then at 3.6% per year until 2040.

Figure 1.3: Estimated Number of Motorbikes



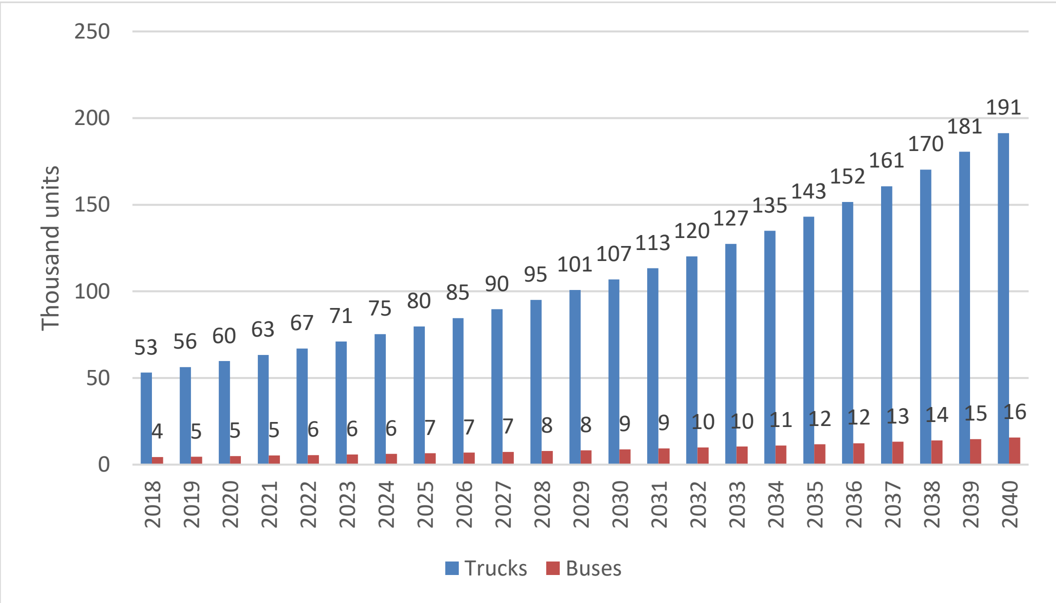
Source: Authors' calculation.

Figure 1.4: Estimated Number of Cars



Source: Authors' calculation.

Figure 1.5: Estimated Number of Trucks and Buses



Source: Authors' calculation.

Table 1.3 shows our assumptions in the electric vehicle scenarios that consist mainly of fuel economy of internal combustion engine (ICE) vehicles, battery efficiency of electric vehicles and average yearly kilometres travelled.

Table 1.3: Kilometres Travelled, Fuel Economy, and Battery Efficiency Assumptions

Variable	unit	**Motorbikes**		**Cars**				**Trucks**	**Buses**	**Sources**
		gasoline	Gasoline	gasoline	diesel	diesel	diesel			
		Two-wheelers	Three-wheelers	Sedans	Pickup	Van	Jeep	diesel	Diesel	
ICE vehicle fuel economy	km/litre	35	35	12	15	8.5	8.5	7	4.5	Ministry of Public Works and Transport, Lao PDR (2019) and authors' estimates
Electric vehicle battery efficiency	km/kWh	12	12	5	5	5	5	0.9	0.6	Buses and Trucks: IEA (2019) Other modes: Ministry of Public Works and Transport, Lao PDR (2019) and authors' estimates
Kilometres travelled	km/year	4,380	3,650	6,570	14,000	15,000	5,110	37,500	44,800	Ministry of Public Works and Transport, Lao PDR (2019)

ICE= internal combustion engine, km = kilometre, kWh = kilowatt hour.

Source: authors' elaboration from various sources.

Table 1.4 gives the basic equations to calculate road vehicle stock in each vehicle category and type. Electric vehicle (EV) penetration in each vehicle type was assumed to increase from 0% in 2018 to reach x% in 2040 where x is 10%, 30%, and 50% that correspond respectively to EV10, EV30, and EV50 scenarios. The number of non-EV vehicle units in each vehicle category and type is the number of the corresponding vehicle category or type deduced by the assumed number of electric vehicles of that category or type.

Table 1.4: Basic Equations for Electric Vehicle Scenarios

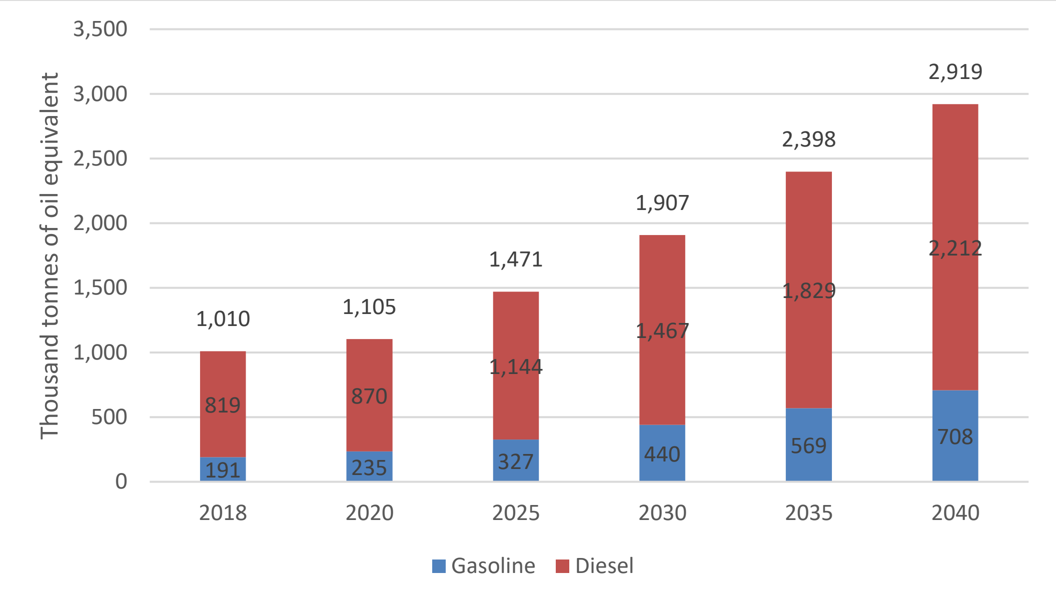
Variable	Description	Unit	2018	2019–2039	2040
$TOTCAT_{year,cat}$	Total number of vehicle units per vehicle category	million units of vehicle	$TOTCAT_{year,motorbike}$: *1.67* $TOTCAT_{year,car}$: *0.43* $TOTCAT_{year,truck}$: *0.06* $TOTCAT_{year,bus}$: *0.01*	See equation (1) and Table 1.1 for the corresponding vehicle category (*cat*) parameter values	
$TOTYPE_{year,2\text{-}wheelers}$	Total number of vehicle units per vehicle type	million units of vehicle	1.65	$\left(TOTCAT_{year,motorbike} - BEV_{year,2-wheelers}\right).0.98$	
$TOTYPE_{year,3\text{-}wheelers}$			0.03	$\left(TOTCAT_{year,motorbike} - BEV_{year.3-wheelers}\right).0.02$	
$TOTYPE_{year,sedan}$			0.08	$\left(TOTCAT_{year,car} - BEV_{year,sedan}\right).0.18$	
$TOTYPE_{year,pickup}$			0.27	$\left(TOTCAT_{year,car} - BEV_{year.pickup}\right).0.61$	
$TOTYPE_{year,van}$			0.05	$\left(TOTCAT_{year,car} - BEV_{year,van}\right).0.11$	
$TOTYPE_{year,jeep}$			0.04	$\left(TOTCAT_{year,car} - BEV_{year,jeep}\right).0.10$	
$TOTYPE_{year,truck}$			0.06	$\left(TOTCAT_{year,truck} - BEV_{year,truck}\right)$	
$TOTYPE_{year,bus}$			0.01	$\left(TOTCAT_{year,bus} - BEV_{year,bus}\right)$	
$BEVSH_{type,year}$	Share of BEV based on scenarios	%	0	$\frac{x.(year - 2017)}{(2050 - 2017)}$	x; which is the BEV share target in each scenario
$BEV_{type,year}$	Number of BEVs	million cars	0	$TOTCAT_{year}.BEVSH_{year}$	

ICE = internal combustion engine, BEV = battery electric vehicle.
Source: Authors' elaboration.

4.3. Business-as-Usual Scenario

Figure 1.6 shows that the total energy consumption of road transport vehicles in the Lao PDR would increase from around 1,010 thousand tonnes oil equivalent (ktoe) in 2018 to around 2918 ktoe in 2040, i.e., a 4.9% yearly increase in that period. With 6.1% average annual growth rate, gasoline is expected to grow faster than diesel (4.6%). Gasoline and diesel shares are 19% and 81% in 2018 and it would be 24% and 76% in 2040. These figures of the BAU scenario matched almost perfectly to the BAU scenario noted in the Ministry of Energy and Mines Lao PDR and ERIA (2018 and 2020a).

Figure 1.6: Gasoline and Diesel Consumption of Road Transport Vehicles – BAU Scenario



BAU = business-as-usual.
Source: LEAP model running results (2021).

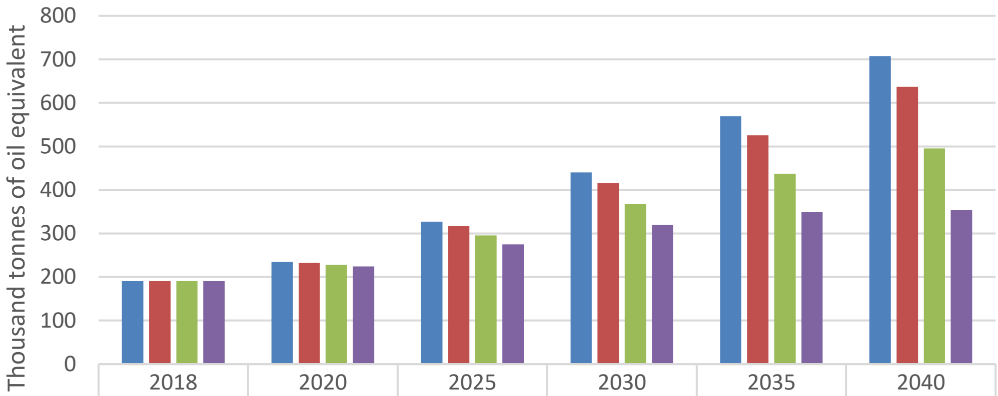
5. Results

Conventional fuel consumption, i.e. gasoline and diesel fuel, would decrease proportionally with the increasing penetration rate of electric vehicles.

Gasoline consumption in the BAU scenario would reach around 708 ktoe by 2040, whilst that in the EV50 scenario would reach only half of it, i.e., around 354 ktoe as shown in Figure 1.7. The average yearly growth rate in the period 2018-2040 would decrease from 6.2% in the BAU scenario to 5.6%, 4.4%, and 2.9%, respectively in the EV10, EV30, and EV50 scenarios.

In terms of saving, Figure 1.8 shows that the EV10 scenario would potentially save nearly 85,000 kilolitres of gasoline by 2040, whilst that of EV50 would save nearly 425,000 kilolitres.

Figure 1.7: Gasoline Consumption by Scenarios

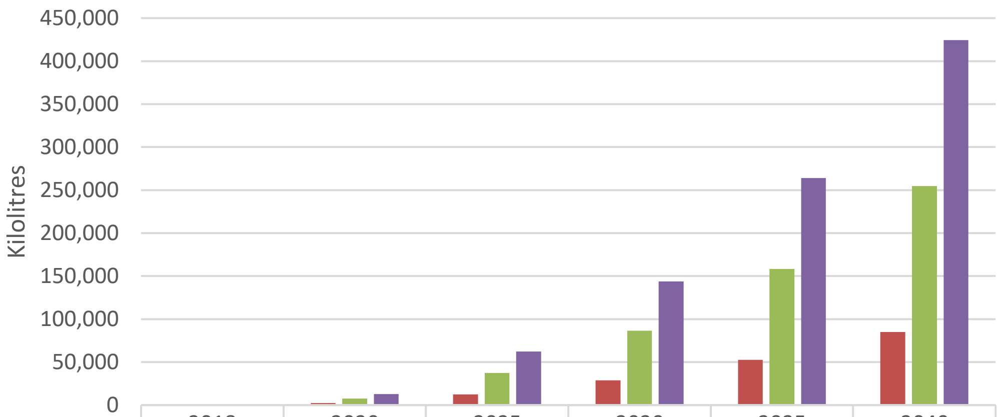


	2018	2020	2025	2030	2035	2040
BAU	191	235	327	440	569	708
EV10	191	233	317	416	525	637
EV30	191	228	296	368	437	495
EV50	191	224	275	320	349	354

BAU   EV10   EV30   EV50

BAU = business-as-usual.
Source: LEAP model running results (2021).

Figure 1.8: Gasoline Saving by Electric Vehicle Scenarios



	2018	2020	2025	2030	2035	2040
EV10	0	2,555	12,477	28,793	52,788	84,892
EV30	0	7,678	37,455	86,380	158,340	254,689
EV50	0	12,801	62,422	143,967	263,891	424,486

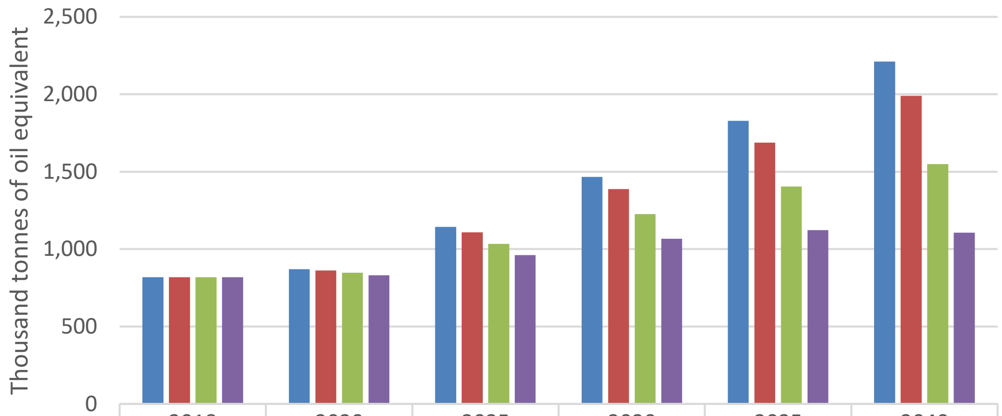
EV10   EV30   EV50

Source: LEAP model running results (2021).

The electrification of diesel-fuelled road transport vehicles by 50% (EV50 scenario) would reduce the diesel fuel consumption in the BAU scenario from around 2,200 ktoe to around 1,100 in 2040 (Figure 1.9). The average yearly growth rate in the period 2018–2040 would decrease from 4.6% in the BAU scenario to 4.1%, 2.9%, and 1.4% respectively in the EV10, EV30 and EV50 scenarios.

The saving potential of the electric vehicle penetration scenarios would range from 239,000 kilolitres in the EV10 scenario to nearly 1.2 million kilolitres in the EV50 scenario as shown in Figure 1.10.

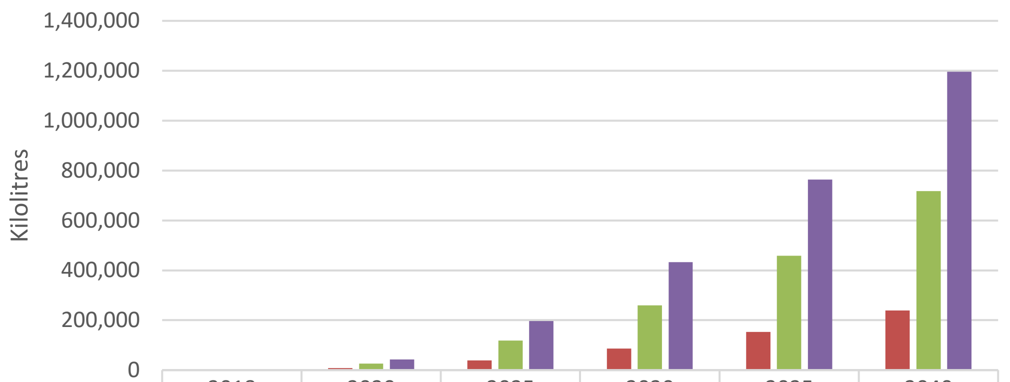
Figure 1.9: Diesel Fuel Consumption by Scenarios



	2018	2020	2025	2030	2035	2040
BAU	819	870	1,144	1,467	1,829	2,212
EV10	819	862	1,107	1,387	1,688	1,991
EV30	819	846	1,035	1,227	1,405	1,548
EV50	819	831	962	1,067	1,122	1,106

BAU = business-as-usual, EV = electric vehicle.
Source: LEAP model running results (2021).

Figure 1.10: Diesel Fuel Saving by Electric Vehicle Scenarios

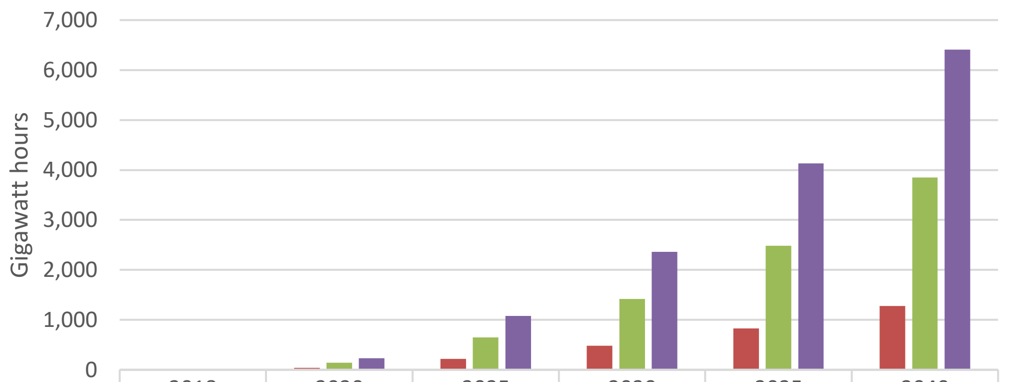


	2018	2020	2025	2030	2035	2040
EV10	0	8,553	39,346	86,520	152,821	239,136
EV30	0	25,658	118,038	259,582	458,464	717,420
EV50	0	42,774	196,730	432,645	764,097	1,195,703

EV = electric vehicle.
Source: LEAP model running results (2021).

The electric power needed for the road transport electric vehicles in the three scenarios is given in Figure 1.11. A 10% penetration scenario (EV10) would need nearly 1,300 gigawatt hours in 2040, whilst that of EV30 and EV50 would be around 3,850 and 6,400 gigawatt hours, respectively.

Figure 1.11: Electricity Consumption of Road Transport Electric Vehicles



	2018	2020	2025	2030	2035	2040
EV10	0	40	220	480	830	1,280
EV30	0	140	650	1,420	2,480	3,850
EV50	0	230	1,080	2,360	4,130	6,410

Source: LEAP model running results (2021).

Chapter 2

Electric Vehicle Infrastructure

Several Association of Southeast Asian Nations (ASEAN) countries have strategies for low-emissions mobility, with decreasing oil import dependency as a main objective. The strategies emphasise, amongst others, removing obstacles to the electrification of transport to promote market development of plug-in electric vehicles (PEV), especially cars, powered two-wheelers, and light-duty vehicles or vans.

Removing obstacles means that ASEAN countries must secure critical technological system requirements: road electric vehicle (EV) manufacturing and supporting or supplier industries, and the corresponding EV charging infrastructure.

Since January 2018, the ASEAN Free Trade Agreement has dropped import duties for vehicles originating in other ASEAN countries to 0%. Investment in the domestic EV manufacturing industry might benefit the countries if the final purchasing price of the vehicles can compete with those of imported vehicles.

Whilst EV manufacturing and its support industries might rely mostly on integration with global value chains, developing charging points needs significant domestic public and private investment. This chapter focuses on building the decision-making framework for charging infrastructure investment to encourage EV deployment.

We start with a brief introduction on the state of charging technology development, including the different charging technologies and modes, and the need for standardisation to ensure interoperability. We then discuss the costs of the different charging technologies, followed by a synthesis of the 'chicken-and-egg' relationship between charging infrastructure and the EV penetration rate. The most-used indicator is the number of PEVs per charging point. Some argue that developing more charging infrastructure will stimulate PEV penetration, but it is often the electric car manufacturers that encourage deploying the infrastructure (Li et al., 2016).

We then present a simple model called the public charging supply-cost model and implement the model as an exercise to calculate the number of chargers in the Lao PDR with some other related indicators that give a high-level indication of the impacts of these chargers rolling out such as the power load on the charger, comfort to users, and the needed installation costs.

We give illustrations of some more sophisticated models to optimally roll-out charging infrastructure that consider mobility or spatial and electricity aspects. We also present some strategies that have been done in the forerunning countries to facilitate charging infrastructure investments. At the end we also discuss the charging scheme strategy to ensure that electric vehicle charging activities would not have a harmful effect to the power load on the grid as well as to the emissions from power plants.

1. Introduction to Electric Vehicle Charging Infrastructure

Internal combustion engine (ICE) vehicle users benefit from refuelling station networks being located nearly everywhere. But PEV charging infrastructure is in its early development stage, especially in ASEAN countries.

In principle, a PEV can simply be plugged into a home wall-mounted box, which is the simplest EV service equipment, but home charging is not as simple as it seems, and the long charging time is its main inconvenience. Moreover, increasing grid pressure is a risk as home charging takes place mainly in the late afternoon after working hours, when household electricity demand is peaking. These are the main reasons for developing different types of chargers and installing them in public spaces such as parking lots, workplaces, petrol stations, and motorway rest areas.

1.1. Charger Types

Chargers on the market can, in principle, be divided into slow and fast. Slow chargers use an alternating current (AC) under 400 volts, whilst fast chargers use a direct current (DC) of 400 volts and above. Most charging stations are slow and more than 88% have 22 kilowatt (kW) power or lower. This category includes 2.3 kW household plugs that take about 9 hours to completely recharge a common PEV. Most PEVs can be home-charged via an AC outlet of 3.3–11 kW.

Slow chargers are level 1 (120 volts) and level 2 (200–240 volts) and suitable for short trips, whilst DC fast chargers, most often found in public locations such as motorway rest areas, are best for longer journeys (Hall and Lutsey, 2017). Both recharging times are significantly longer than ICE vehicle refuelling time.

Table 2.1 classifies chargers into four modes, each corresponding to a specific charging speed, required voltage, electric current, and level of communication between vehicle and power outlet.

Slow chargers are also often grouped into slow and semi-fast. It takes 6–8 hours to fully charge a pure battery electric vehicle (BEV) using slow chargers with a single-phase 3.3 kW of power and 120–240 volts. This practice corresponds to home charging using a shared circuit without any safety protocol.

Table 2.1: Different Modes of Plug-in Electric Vehicle Charging

<table>
<tr><th>Mode</th><th>Name</th><th>Power (kilowatt)</th><th>Current</th><th>Phase</th><th>Charging Time</th><th>Place</th><th>Voltage (volt)</th><th>Power Range (ampere)</th><th>Communication Level</th><th>Further Description</th></tr>
<tr><td>1</td><td>Slow</td><td>3.3</td><td>AC</td><td>Single</td><td>6–8 hours</td><td>Household, workplace wall box</td><td>120–240</td><td>Up to 16</td><td>NA</td><td>Shared circuit without safety protocols</td></tr>
<tr><td>2</td><td>Slow, semi-fast</td><td>7.4</td><td>AC</td><td>Single</td><td>3–4 hours</td><td rowspan="2">Household, workplace wall box and public charging poles</td><td>120–240</td><td>Over 16 and up to 32</td><td>Semi-active connection to vehicle to communicate for safety purpose</td><td>Shared or dedicated circuit with safety protocols, including grounding detection, overcurrent protection, temperature limits, and a pilot data line</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Slow, semi-fast or fast</td><td>10</td><td>AC</td><td>Three</td><td>2–3 hours</td><td rowspan="2">240</td><td rowspan="3">Any</td><td rowspan="2">Active connection between charger and vehicle</td><td rowspan="2">Wired-in charging station on a dedicated circuit, mode-2 safety protocols, active communication line with the vehicle, i.e., smart charging suitability</td></tr>
<tr><td>22</td><td>AC</td><td>Three</td><td>1–2 hours</td><td>Mostly public charging poles</td></tr>
<tr><td>4</td><td>Fast</td><td>50</td><td>DC</td><td>–</td><td>20–30 minutes</td><td>Motorway service area or dedicated charging stations in urban areas (current standard)</td><td>400</td><td>Active connection between charger and vehicle</td><td>Mode-3 features with more advanced safety and communication protocols</td></tr>
</table>

Mode	Name	Power (kilowatt)	Current	Phase	Charging Time	Place	Voltage (volt)	Power Range (ampere)	Communication Level	Further Description
		120	DC		10 minutes	Motorway service area or dedicated charging stations in urban areas (future standard)				

AC = alternating current, DC = direct current, NA = not applicable.

Sources: E-Mobility NSR (2013), Hall and Lutsey (2017), Spöttle et al. (2018).

With slow to semi-fast chargers, charging time should be reduced from 4 hours to 1 hour. Facilities with power greater than 3.3 kW but less than 22 kW can be found in households, workplaces, and public spaces. Chargers with power lower than 22 kW allow a maximum speed up to 2 hours of charging and can be applied to shared or dedicated circuits with safety protocols. Facilities with power higher than 22 kW reduce charging time down to 1 hour. Semi-fast chargers are installed mostly in public charging facilities often equipped with an active communication line between the charging point and the vehicle.

Finally, the DC fast chargers allow BEVs to be fully charged in less than 111 hours. They are often installed in motorway service areas or in urban dedicated charging stations where long charging time is less tolerated.

The situation is, however, complicated. Compatibility between PEVs and charging point technology standards is an issue as there are at least five technology standards or connector types:

- Type-1 AC. Amongst the most popular PEV connectors in this category are some produced by the Japanese manufacturer Yazaki, following the North American SAE J1772 standard. They are mostly slow chargers and can be found in North America and Japan.
- Type-2 AC. Most are fabricated by the German company Mennekes, following the AC charging technology standard gaining market share in Europe and China. This type is compatible with most PEVs and AC chargers and can facilitate only single-phase and three-phase AC charging.
- Type-3 AC. Built by the PEV Plug Alliance, mostly in Italy and in France, and used only up to 2012, when the Type-2 AC became dominant in Europe.
- Type-4 DC. Also known as the Japanese standard, CHAdeMO. It was the first widespread technical standard for DC fast charging developed by a Japanese consortium. This type is found not only in Japan but also in European countries, mostly in France.
- CCS or combined charging system. The combined AC and DC fast-charging plugs are CCS Combo 1, preferred by United States (US) car manufacturers, and CCS Combo 2, preferred by German manufacturers.
- Tesla supercharger infrastructure. This DC fast charger is used mostly in North America.

1.2. Standardisation and Interoperability

Charging stations are considered interoperable if they can serve a large variety of PEV models and offer payment methods accessible to all PEV drivers (Spöttle et al., 2018). Standardisation guarantees interoperability, provides clarity to manufacturers, allows for economies of scale, and ensures compliance with safety standards. PEV charging interoperability means that PEV users can charge their cars at any charging point using their usual choice of authorisation and payment method.

Charging infrastructure – at least the physical equipment, payment systems, and charging protocol – must be standardised. In Europe, for example, Type-2 AC and Type-3 AC coexisted, as did CHAdeMO and CCS Combo 2. In 2014, European Commission Directive 2014/94/EU required that all providers of public chargers include a Type-2 AC connector where level-2 or fast AC charging is available, and a CCS connector where level-3 charging is provided. In Southeast Asia, the rolling out of charging infrastructure is still in its development phase, but some trends are visible: Type-2 connectors are available for AC charging, and CCS Combo connectors are also available for DC charging in Thailand, Malaysia, and Singapore. CHAdeMO is available in Thailand and Malaysia.

Many charging station network operators in the early years of PEV penetration developed their own payment systems. PEV users normally subscribe to a charging station operator and cannot always charge or pay at a station belonging to another operator. A simple solution is for the user to subscribe to more than one operator. A more sophisticated solution is to allow roaming between operators as mobile phone network operators have been doing for years.

Finally, charging activity needs protocols that standardise the communication interface between the car, the charging stations, and the system that oversees monitoring and managing of the charging station, including the roaming platforms. That system is usually referred to as the charge point operator or charging service operator. For example, Europe has the open clearing house protocol supported by national charging infrastructure providers in Belgium, Germany, the Netherlands, Luxembourg, Austria, Ireland, and Portugal; open charge point protocol, initiated by ElaadNL, which is also involved in open clearing house protocol; and open charge point interface, supported by European operators.

1.3. Cost of Charging Infrastructure

Simple home charging can compete with more efficient gasoline cars and is even significantly cheaper when a time-of-use (TOU) electricity tariff with lower prices in off-peak periods is in place. More powerful home charging is sensitive to capital cost but competitive with moderately efficient ICE vehicles and would be substantially cheaper under a TOU regime (Lee and Clark, 2018).

The issue, however, is how to develop non-home-based charging points or stations as home charging has limitations. Developing such stations needs significant investment, supporting regulations, an adequate business model, and, in many places, central government intervention or initiatives.

China's central government, for instance, has funded a programme in 88 pilot cities, led by Shanghai, Beijing, and Shenzhen, to provide one charging point for every eight PEVs. The charging points are grouped into stations, which must be no more than 1 kilometre from any point within the city centre (Hall and Lutsey, 2017).

The 13th Five-Year Plan (2016–2020) states that China shall build a nationwide charging-station network that will fulfil the power demand of 5 million EVs by 2020 (Xin, 2017). The

State Grid Corp of China, the state-owned electric utility monopoly, had built more than 40,000 charging stations by 2016 and was planning to build a network of 120,000 public-individual charging points for electric cars by 2020, throughout major regions in China (Chen et al., 2018). China's National Energy Administration says that the country had a total of 450,000 stationary charging points in 2017, including around 210,000 publicly accessible units (Ying and Xuan, 2018).

Another example, Singapore's Land Transport Authority announced in 2016 it would install 2,000 charging points, and in 2017 reached an agreement with a private company, BlueSG Pte Ltd., to launch a nationwide car-sharing programme with a fleet of 1,000 plug-in hybrid electric vehicles (PHEVs). The company planned to install and operate the charging points. Singapore Power Group, the state-owned electricity and gas distribution company, planned to roll-out 1,000 charging points by 2020, of which 250 would be 50 kW fast DC chargers able to fully charge a car in 30 minutes. Normal slow chargers cost around $3,700, whilst fast chargers cost $48,000. By September 2018, hybrid electric vehicles (HEVs) made up 4.3% of the total of around 615,000 registered vehicles, PHEVs 0.06%, and BEVs 0.08% (Tan, 2018). Many industrial players think the lack of charging facilities has been a main cause of slow PEV penetration.

In Japan, the government created the massive Next Generation Vehicle Charging Infrastructure Deployment Promotion Project to fund charging stations around cities and highway rest stations in 2013 and 2014 (CHAdeMO Association, 2016). The nationwide Nippon Charge Service, a joint project of the state-owned Development Bank of Japan with Nissan, Toyota, Honda, Mitsubishi, and Tokyo Electric Power Company, operates almost 7,500 stations.

In the US, by 2017, around 47,000 charging outlets had been built all over the country. The General Services Administration had installed EV charging stations for federal employees and other authorised users, and more than 10 states were offering rebates and tax credits to commercial customers and homeowners for installing charging stations (Lu, 2018).

In several PEV front-runner countries in Europe, the public sector and private investors financed early charging infrastructure when the use of chargers was not yet high enough to be profitable. Public subsidies will be phased out in 2020–2025. Technological acceptance and spread and economies of scale should stimulate similar developments in other European countries (Transport & Environment, 2018).

What follows is a summary of public charging facility costs in PEV front-runner countries. We focus on the top priority for ASEAN countries, which is to develop slow or semi-fast level-2 charging facilities, and on fast-charging infrastructure, installation of which will be much more limited, depending on mobility purposes and needs.

Slow to Semi-fast AC Charging Facility Costs

Table 2.2 shows that the hardware costs of slow to semi-fast charging facilities are comparable, even between the US and Europe and India.

Table 2.2: Examples of Slow and Semi-fast Charging Facility Purchase and Installation Costs

Countries (Currency)	Application	Costs	Included Items	Report
United States ($, 2017)	L2 – home	450–1,000 (50–100)	Charging station hardware (additional electrical material costs in parentheses)	Fitzgerald and Nelder (2017)
	L2 – parking garage	1,500–2,500 (210–510)		
	L2 – curb side	1,500–3,000 (150–300)		
France, Germany, Italy, Netherlands, Spain, UK (€ 2017)	3.7 kW new residential building	1,170	Materials (for installation, including cables); wall-box (hardware of charging station, excluding cables); and labour (around 20% of total costs)	CREARA Analysis (2017)
	3.7 kW operating residential building	1,280		
	7.4 kW new non-residential building	1,760		
	7.4 kW operating non-residential building	2,025		
Germany (€ 2017)	>3.7 kW – one charging point	1,200	Complete hardware, including communication and smart meter	NPE (2018)
	11 kW or 22 kW – two charging points	5,000		

Countries (Currency)	Application	Costs	Included Items	Report
India ($, 2019)	Bharat charger AC 001-1 point(s)-3 phase 415 volt-3 x 3.3 kW	980	Approximate cost, including goods and services tax at 18%	Pillai et al. (2018)
	Type-2 AC Charger-1 point(s)-7.2 kW	1,050		
	CCS-2-1 point(s)-3 phase 415 volt-25 kW	9,800		
European Union 28 average (€, 2018)	AC mode 2 – home (up to 11 kW)	<800	Purchase cost for a single charging point, not installation, grid connection, or operational costs	Spöttle et al. (2018)
	AC mode 2 – commercial (up to 19.4 kW)	<2,000		
	AC mode 3 – fast (22 kW of 43 kW)	1,000–4,000		

AC = alternating current, kW = kilowatt.
Source: Authors' compilation.

In the US, a simple home 3.7 kW charger costs only around $500, whilst a 7.2 kW charger that can fully charge a PEV in around 4 hours costs around $1,000 – almost the same as in Europe and India, which shows that local content of charger production in India is low. For chargers of 22 kW or more, costs in India are much higher than in the US or Europe, which means India still does not enjoy economies of scale for charging hardware production.

The charger's power, electric power phases, and number of charging points are amongst the factors that determine the cost of PEV charger hardware and materials.

Home installations are used less intensively and have lower safety requirements and are therefore less costly than public stations, which are more sophisticated and might include liquid-crystal display screens, advanced payment and data tracking communication, and dual-port power routing capabilities (Fitzgerald and Nelder, 2017).

Installation methods significantly affect total installation costs: installation from scratch is always cheaper than from partially make-ready facilities such as those that are pre-piped or pre-cabled. Several European governments stimulate development of partially make-ready charging facilities by the private sector, e.g., building or utility owners (CREARA Analysis, 2017).

Fast DC Charging Facility Costs

DC level-3 charging stations reduce charging time, but they cost significantly more than a level-2 charger because of two factors: expensive equipment and the frequent need to install a 480 V transformer. Fast-charger hardware is significantly more expensive than level 2, and in the US a transformer might cost another $10,000–$20,000 (Fishbone, Shahan, and Badik, 2017). Installing DC fast charging stations in the US typically costs as much as $50,000. Inclusion of project development, design, permits, and system upgrades can raise the total cost of DC fast charging deployment as high as $300,000 each (Fitzgerald and Nelder, 2018).

Table 2.3: Examples of Fast-Charging Facility Purchase and Installation Costs

Countries (Currency)	Application	Costs	Included items	Report
United States ($, 2017)	DC fast charging	12,000–35,000 (300–600)	Charge station hardware (plus extra electrical materials)	Fitzgerald and Nelder (2017)
Germany (€, 2017)	50 kW	25,000	Complete hardware, including communication and smart meter	NPE (2018)
European Union 28 average (€, 2018)	DC fast – standard (20 kW–50 kW)	20,000	Purchase cost for a single charging point, not installation, grid connection, or operational costs	Spöttle et al. (2018)
	DC high power – fast (100 kW–400 kW)	40,000–60,000		

DC = direct current, kW = kilowatt.

Source: Authors' compilation.

2. Electric Vehicles and their Charging Infrastructure: A Chicken and-Egg Issue

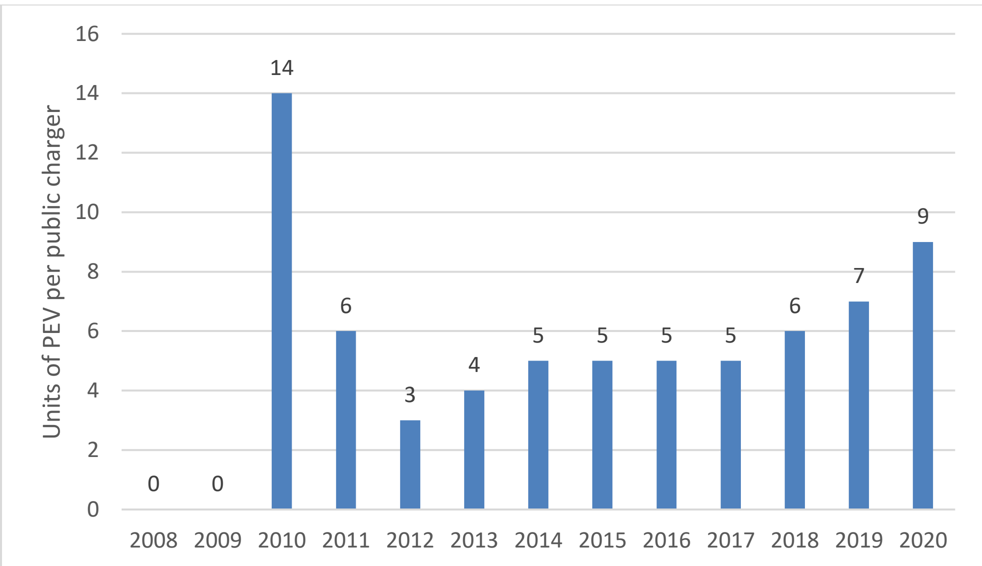
Fast-charging stations need to achieve a sufficiently high utilisation ratio to compensate for the high total cost of installation and operation where grid impact will be low. DC fast-charging hubs should serve high-usage fleets and ride-hailing vehicles, ideally along high-usage corridors and commuting routes around major cities, and rest areas for interurban trips on major highways (Lee and Clark, 2018).

Since 2011, we have witnessed the unprecedented growth of PEV sales and the number of charging infrastructure points in different parts of the world.

The European Alternative Fuels Observatory (EAFO, 2021) database shows that in the European Union (EU)-27 and in six non-EU countries (United Kingdom, Iceland, Norway, Switzerland, Turkey, and Lichtenstein), total road PEV sales have increased from only 1,792 units in 2010 to 1,117,546 units in 2020, i.e., more than 620-fold during the 10-year period. Around 93% of the total road PEV sales in 2020 consisted of passenger cars (M1 category). The EAFO database reveals that recharging infrastructure points in Europe have increased from 400 in 2010 to 224,237 in 2020 – more than 560-fold during the same period. In 2020, almost 89% of recharging points are normal chargers with power equal or less than 22 kW. The rest 11% are fast chargers with power higher than 22 kW.

The ratio of the number of PEV units per charger has fluctuated between 2008 and 2020 in the EAFO countries, i.e. EU-27 plus the United Kingdom, Iceland, Norway, Switzerland, Turkey, and Lichtenstein. As shown in Figure 2.1, there was practically no public charging in 2008 and 2009. In 2010 around 400 chargers were built and operated. A massive installation of chargers in those countries reduced the ratio from 14 in 2010 to 3 in 2012. The ratio went up again afterwards to reach around nine PEVs per public charger in 2020.

Figure 2.1: Units of PEV per Public Charger in EAFO Countries



EAFO = European Alternative Fuels Observatory, PEV = plug-in electric vehicle.
Source: EAFO (2021).

Public charging infrastructure is key to EV market growth. Rough apparent patterns are observed between EV uptake and charging infrastructure availability, with substantial variability across markets. The development of a robust charging infrastructure network is a key requirement for large-scale transition to electromobility, but there is no universal benchmark for the number of EVs per public charge point (Hall and Lutsey, 2017).

Table 2.4 shows that the average ratios of PEVs to charging station in EV front-runners vary greatly between or even within regions.

Table 2.4: Indicated Average Ratios of Electric Vehicles per Public Charge Point

Country/Region	Region	Electric Vehicle /Public Charge Point Ratio	Source
China	China average	8 (pilot cities) 15 (other cities)	NDRC (2015)*
World	Worldwide	8 (2015) 15 (2016)	IEA Electric Vehicle Initiative (2016, 2017)*
United States	United States average	7–14	Cooper and Schefter (2017)*; EPRI (2014)*
		24	Wood et al. (2017)*
	California	27	CEC and NREL (2017)*
European Union	European Union average	10	European Parliament (2014)*
	The Netherlands	3.6	Spöttle et al. (2018)
	Norway	15.2	
	Germany	6.7	
	The UK	9.7	
	France	7.6	

Note: * From Hall and Lutsey (2017).

EU data show that the PEV market share of new registrations rises as the vehicle to charging point ratio drops from 25 to 5. A low ratio would benefit PEV uptake but infrastructure coverage denser than 1 charging point per 10 PEVs would be inefficient: sales numbers become insensitive with a decreasing ratio. The high costs of additional charging infrastructure, therefore, do not justify high investments (Harrison and Thiel, 2017).

A study on the relationship between the number of PEVs and the publicly accessible charging points in Europe (EU 28 + Norway) demonstrates two interesting findings. First, with some variation in the countries' national context, the density of charging infrastructure generally correlates positively with PEV adoption. A range of other factors are proven or suspected to be correlated with PEV uptake, such as model availability, financial incentives, urban density, etc. Charging infrastructure is necessary but not enough for PEV adoption. Most front-runner countries have applied a demand-oriented approach to rolling out charging infrastructure. Second, the ideal ratio of PEVs per charging point will, in the long run, lies between 10 and 16 (Spöttle et al., 2018).

The roll-out of charging infrastructure may be oriented towards demand or coverage. The demand-oriented approach assumes that charging infrastructure should be constructed where existing and future demand can be determined and aims for optimal allocation and utilisation of all charging points and avoids redundancies. The coverage-oriented approach is premised on public infrastructure guaranteeing a minimum standard of service to the widest possible public by minimising the distance between the charging points. None of the front-runner countries take the coverage-oriented approach, except the US, with its designated alternative fuel corridors; China, which has required 88 pilot cities to install a charging network with charging points positioned no farther than 1 kilometre (km) from any point within the city centre; and Norway, where the government financed the deployment of at least two fast-charging stations every 50 km on all main roads by 2017 (Figenbaum, 2019).

A study for Thailand by Thananusak et al. (2020) proposed two types of policies to deal with the chicken-and-egg issue. The first type of policy, the 'demand pull' deals with boosting demand for electric vehicles. This type might consist of providing rebates and tax credits for consumers, increasing the demand for electric vehicles through government procurement activities, establishing regulations and standards that facilitate demand growth, and the building of consumer awareness. The second type of the policy, the 'technology pull' might consist of policies that aim at giving favourable loans with low interest rates for investors, providing public co-funding charging stations, setting up preferential electricity selling rates, providing financial support for chargers and equipment purchase, providing rebates, investment subsidies, tax incentives, tax holidays, and so on, and creating EV charging consortia to lay the foundation of interoperability.

3. Public Charging Supply-Cost Model

In this chapter we implemented a methodology of public charging supply-cost model to the Lao PDR. The method was developed by Transport & Environment (2020) and can be used to calculate the number of public electric vehicle chargers needed at an aggregated level as well as the costs needed to roll-out those chargers.

This implementation is nevertheless a mere exercise as it involved many assumptions that are made based on practices in other countries or literature. A more proper implementation of the method should include an in-depth series of consultation and survey with many stakeholders in the Lao PDR which is beyond the scope of this study.

Further lower-level results such as the spatial distribution of chargers can be determined using other methods whose illustrations are given in section 4.

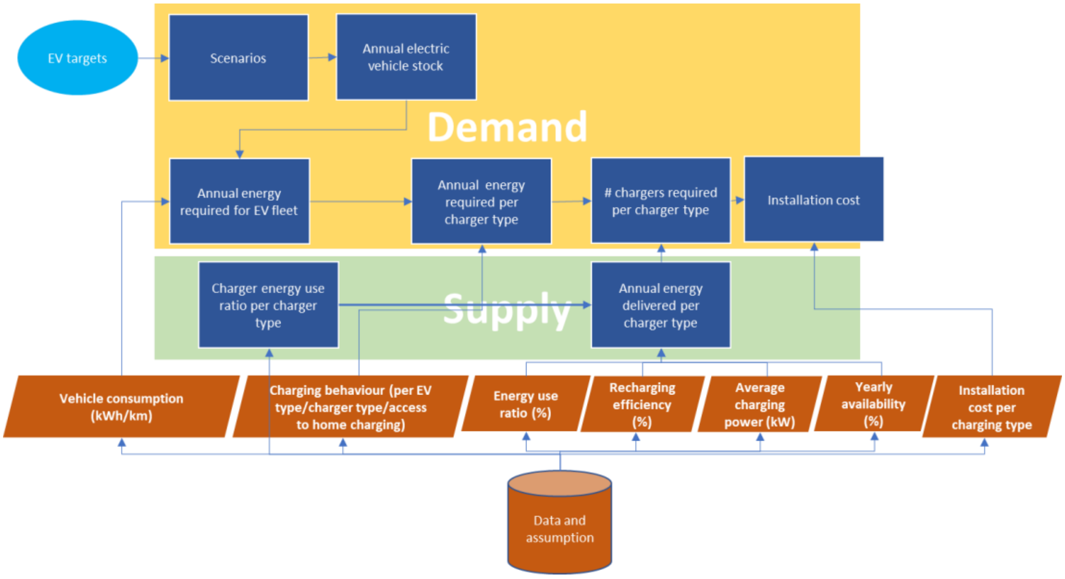
3.1. Methodology

The public charging supply-cost model considers the determination of the number of public charging from both demand and supply sides.

Basically, the number of electric vehicle chargers in the model is calculated by dividing the electric energy needed per charger type, which represents the demand side, by the electric energy to be delivered by each charger type, which represents the supply side. Therefore, from the demand side we need to have at least four main inputs, i.e., the energy required by the electric vehicle fleet, the number of electric vehicles, charging behaviour, and battery efficiencies of the electric vehicles. From the supply side, we need to have the following inputs at charger type level, i.e., charger energy use ratio, energy use ratio, recharging efficiency, charging power, and periodical charger availability.

Figure 2.2 shows the flowchart summarising the public charging supply-cost model. Paragraphs that follow explain the detailed calculations of the model. In line with chapter 1, the time scope of this exercise for the Lao PDR would be the period between 2018 and 2040 with calculation done on a yearly basis.

Figure 2.2: Flowchart of Public Charging Supply-Cost Model



EV = electric vehicle, km = kilometre, kW = kilowatt, kWh= kilowatt hour.
Source: Authors' adaptation of the model from Transport & Environment (2020).

Demand Side

Calculated at electric vehicle type level, as given in equation (1), the annual electricity required by the electric vehicle fleet is calculated by multiplying the number of electric vehicles, the average battery efficiency, and the average kilometres travelled of the corresponding year. The total electricity needed by all electric vehicle is simply the sum of electricity needed for all electric vehicle types (equation (2).

$$\boldsymbol{ENEREQEV_{ev\,type} = VEHTOT_{ev\,type}.\,BATTEFF_{ev\,type}.\,MILEAGE_{ev\,type}}$$

1 (1)

Where

$ENEREQEV_{ev\,type}$: annual energy required for each electric vehicle type (kWh)

$VEHTOT_{ev\,type}$: total stock of electric vehicle per electric vehicle type

$BATTEFF_{ev\,type}$: average battery efficiency for each electric vehicle type (kWh/km)

$MILEAGE_{ev\,type}$: average annual travelled kilometre for each electric vehicle type (km)

$$\boldsymbol{ENEREQTOT = \sum_{evtype} ENEREQ_{evtype}\,.\,10^{-6}}$$

2 (2)

Where

$ENEREQTOT$: annual total energy required for all electric vehicles (GWh)

The annual energy required for each charger type is calculated by multiplying the total electric energy required to feed electric vehicles by the usage percentage of each charger type and the access to chargers as given in equation (3).

The usage percentage of each charger type represents the charging behaviour, i.e., how power is distributed in the different charger types in a particular region and period. Since public chargers have been usually rolled out starting from the slow types, it is logic to assume high usage percentages of slow chargers at the beginning of the period. With time, semi-fast and fast chargers should be quantitatively more available and therefore the usage percentages should also be shifting gradually from the slow to semi-fast and fast charger types.

$$\boldsymbol{ENEREQCHAR_{charger\ type} = ENERQTOT . CHARBHV_{charger\ type} . CHARACC_{charger\ type}} \quad \mathbf{3} \qquad \mathbf{(3)}$$

where

$ENEREQCHAR_{charger\ type}$: annual energy required for each charger type (GWh)

$CHARBHV_{charger\ type}$: charging behaviour or usage percentage amongst the different charger types (%)

$CHARACC_{charger\ type}$: access to charger (home charger: 95%, the rest of chargers: 100%)

Supply Side

Annual electric energy delivered by each charger type is calculated using equation (4) as the result of multiplying recharging efficiency or losses from plug to battery, the availability of each charger during the day, the ratio of total electric energy delivered to the total maximum energy capacity (charger at maximum power of 24 hours in 7-day period), and the average power level than can be delivered by a charger in one hour.

$$\boldsymbol{ENERDLVCHAR_{charger\ type} = CHAREFF_{charger\ type} . AVAILYEAR_{charger\ type} . ENERATIO_{charger\ type} . CHARPWR_{charger\ type} . 24.365} \quad \mathbf{4} \qquad \mathbf{(4)}$$

where

$ENERDLVCHAR_{charger\ type}$: annual electric power delivered by each type of charger (GWh)

$CHAREFF_{charger\ type}$: recharging efficiency or losses from plug to battery (%)

$AVAILYEAR_{charger\ type}$: availability or uptime during the day (%)

$ENERATIO_{charger\ type}$: energy use ratio (%) or the ratio of total energy delivered to the total max power capacity (charger at maximum power of 24 hours in 7-day period)

$CHARPWR_{charger\ type}$: average power level can be delivered by a charger in one hour (kW)

As shown in equation (5), the number of needed chargers is calculated by dividing the annual power required for each charger type, obtained by the equation (3), by the annual power delivered by each charger type obtained inequation (4). The number of public chargers is the sum of all chargers that belong to public charger categories as given in the equation (6).

$$\boldsymbol{NBCHAR_{charger\ type} = \frac{ENEREQCHAR_{charger\ type}}{ENERDLVCHAR_{charger\ type}}} \ldots \quad \textbf{(5)}$$

where

$NBCHAR_{charger\ type}$: number of chargers needed by charger type (GWh)

$ENEREQCHAR_{charger\ type}$: annual energy required for each charger type (GWh)

$ENERDLVCHAR_{charger\ type}$: annual energy delivered by each type of charger (GWh)

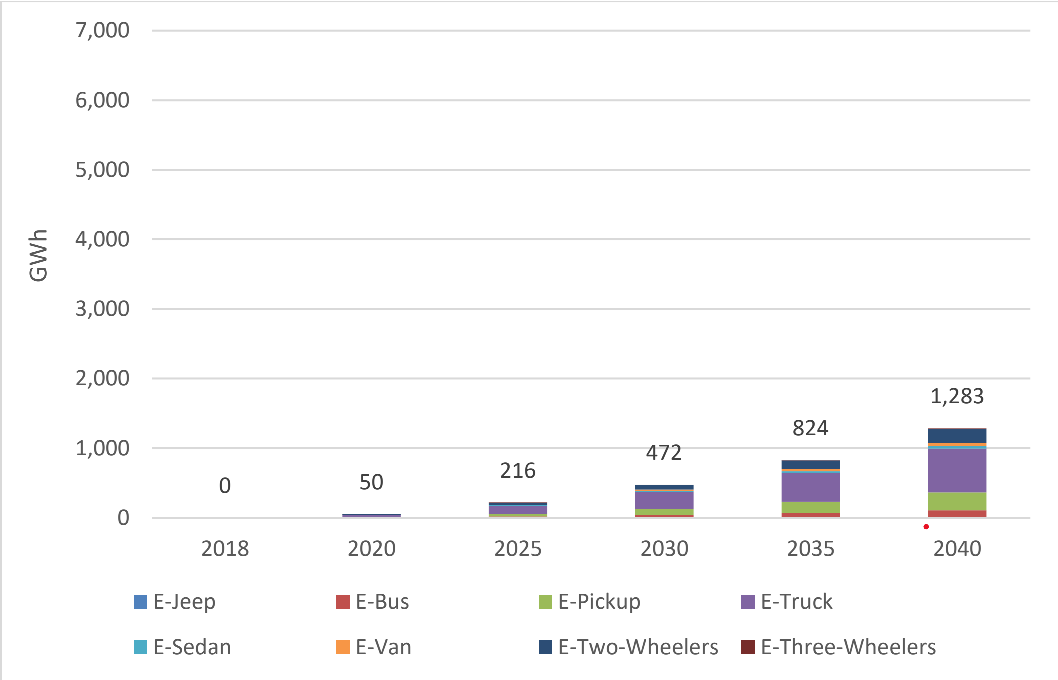
$$\boldsymbol{TOTNBCHAR = \sum_{charger\ type \in public} NBCHAR_{charger\ type \in public}} \quad \textbf{(6)}$$

3.2. Results

Electricity Demand of Road Transport Vehicles

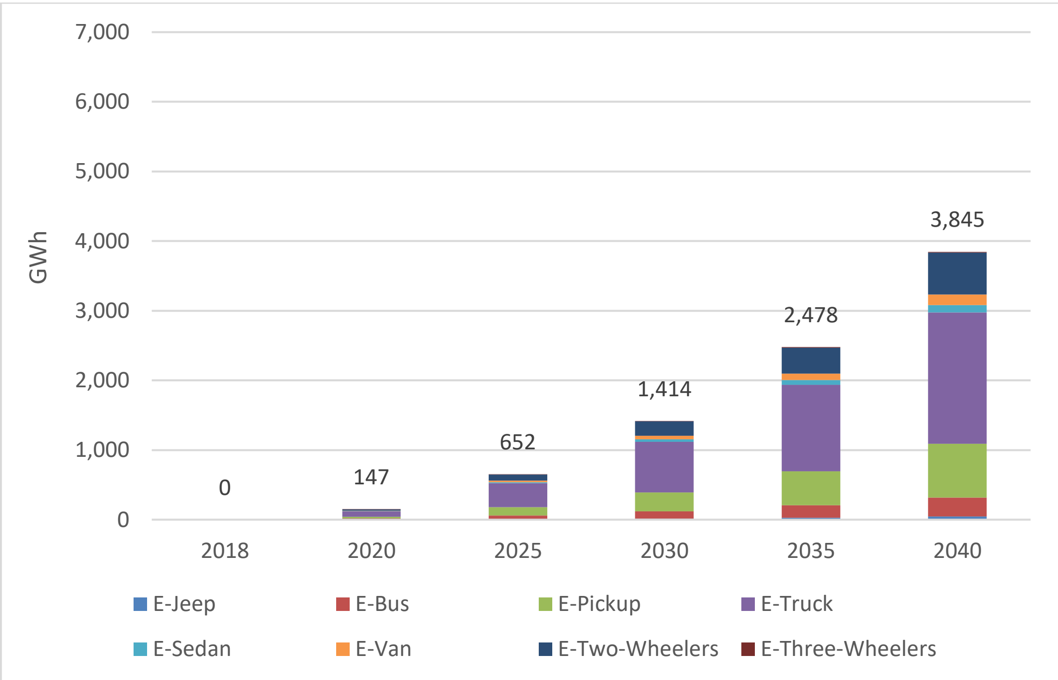
The demand for electric power to feed electric vehicles in three scenarios, i.e., EV10, EV30, and EV50 was calculated in the previous chapter in section 5. Figure 2.3 to Figure 2.5 show the electricity needed in the three scenarios differentiated by electric vehicle types, i.e., e-jeep, e-bus, e-pick up, e-sedan, e-truck, e-van, e-two-two-wheelers, and e-three-three-wheelers. In the three scenarios we can see that e-trucks would need almost 50% of the total electric power and therefore have the lion share of the electricity for the electric vehicles. With around 20%, e-pick ups' electricity demand share would be the second highest, whilst e-two wheelers' share would be the third highest (15%).

Figure 2.3: Electricity Demand of Road Transport Vehicles in EV10 Scenario



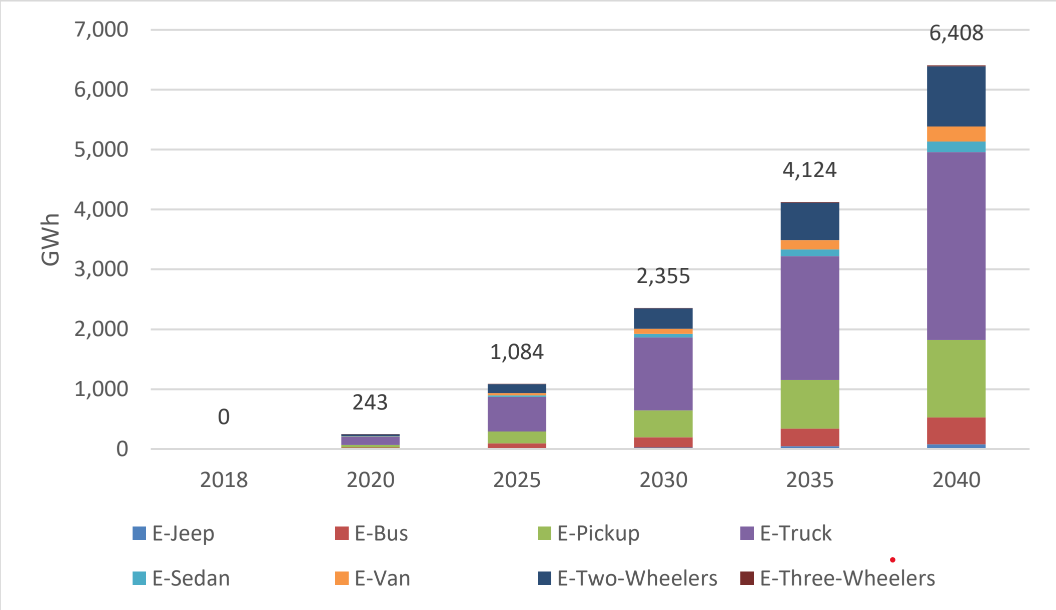
GWh = gigawatt hour.
Source: LEAP Model run (2021).

Figure 2.4: Electricity Demand of Road Transport Vehicles in EV30 Scenario



GWh = gigawatt hour.
Source: LEAP Model run (2021).

Figure 2.5: Electricity Demand of Road Transport Vehicles in EV50 Scenario



GWh = gigawatt hour.
Source: LEAP Model run (2021).

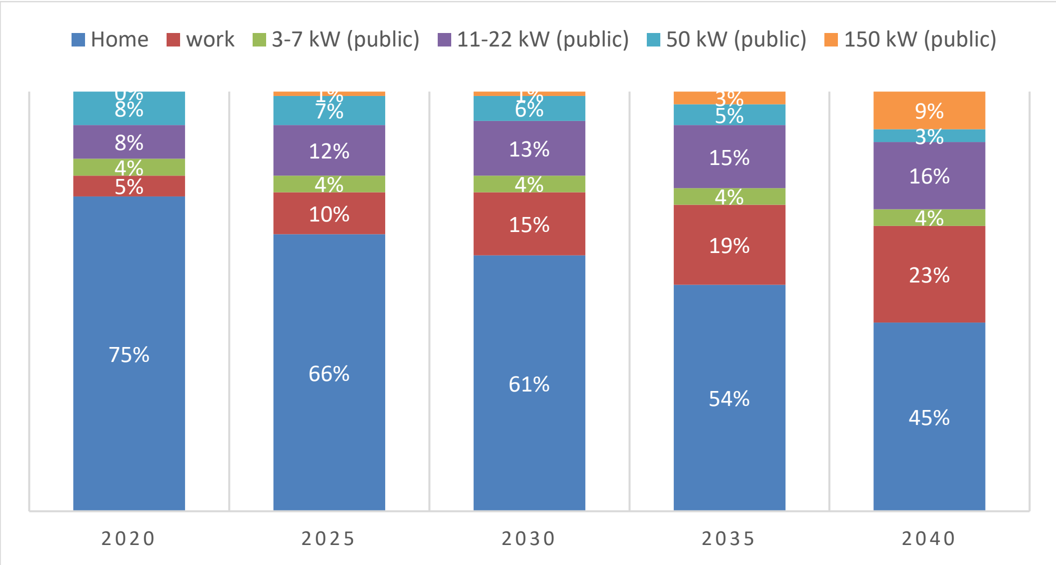
Electricity Demand by Charger Type

To calculate the electricity demand by charger type, as determined by equation (3) we need to have charging behaviour, i.e., the distribution of energy shares amongst the different charger types. As shown in Figure 2.6, we assume that home charging would constitute 75% of the electricity at the beginning of the electric vehicle penetration period and this share would decrease to reach only 45% of the share by 2040. By this time, the power share of faster charger types should grow, and we assume that by 2040, 23% of power would be obtained at work, 4% at 3–7 kW public chargers, 16% in 11–22 kW public chargers, 3% in 50 kW public chargers, and 9% in 150 kW public chargers. The total private (home and work) power share would decrease then from 80% in 2020 to 68% in 2040, whilst that of public charging would increase from 20% in 2020 to 32% in 2040.

For comparison, in 2020, the average charging behaviour in the EU countries as reported in Transport & Environment (2020) consisted of around 45% home charging, 15% charging at work, 10% 3–7 kW public chargers, almost 15% 11–12 kW public chargers, and around 1% 150 kW superfast chargers. By 2030, the estimated average charging behaviour in the EU countries as reported in the same study would consist of around 60% home charging, 30% charging at work, 10% 3–7 kW public chargers, almost 20% 11–12 kW public chargers, and around 3% 150 kW superfast chargers.

The average charging behaviour in the Lao PDR in 2040 was then assumed to be just slightly better than that of the EU countries in 2020 in term of share of private chargers (home and work) and the penetration of superfast 150 kW chargers. The assumption of strong use of 150 kW chargers was taken considering the high demand of electricity of heavy-duty electric vehicles especially e-trucks, penetration in the Lao PDR as shown in Figures 2.3, 2.4, and 2.5. E-trucks should be equipped with big batteries that would need to be charged rapidly using super-fast chargers.

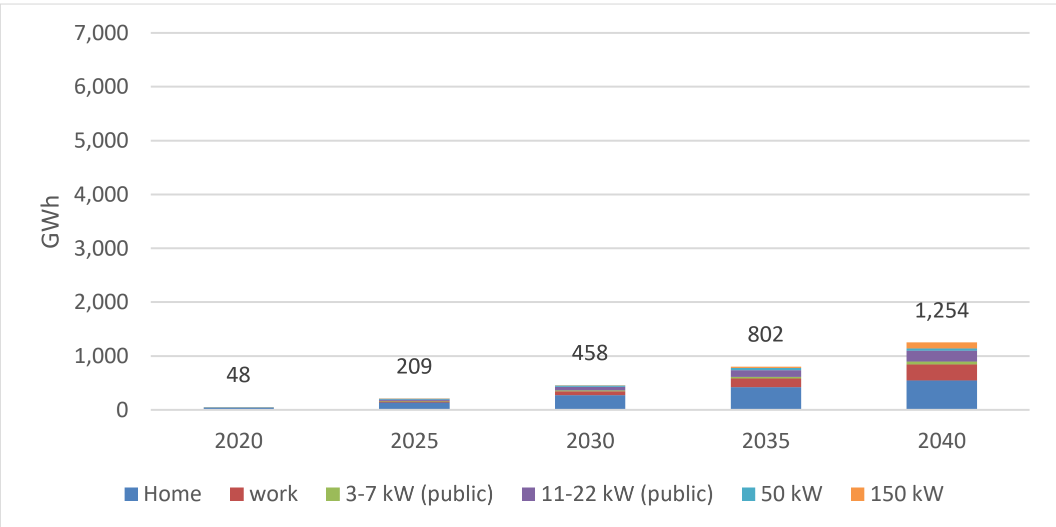
Figure 2.6 :Charging Behaviour Assumption



kW = kilowatt.
Source: Authors' elaboration.

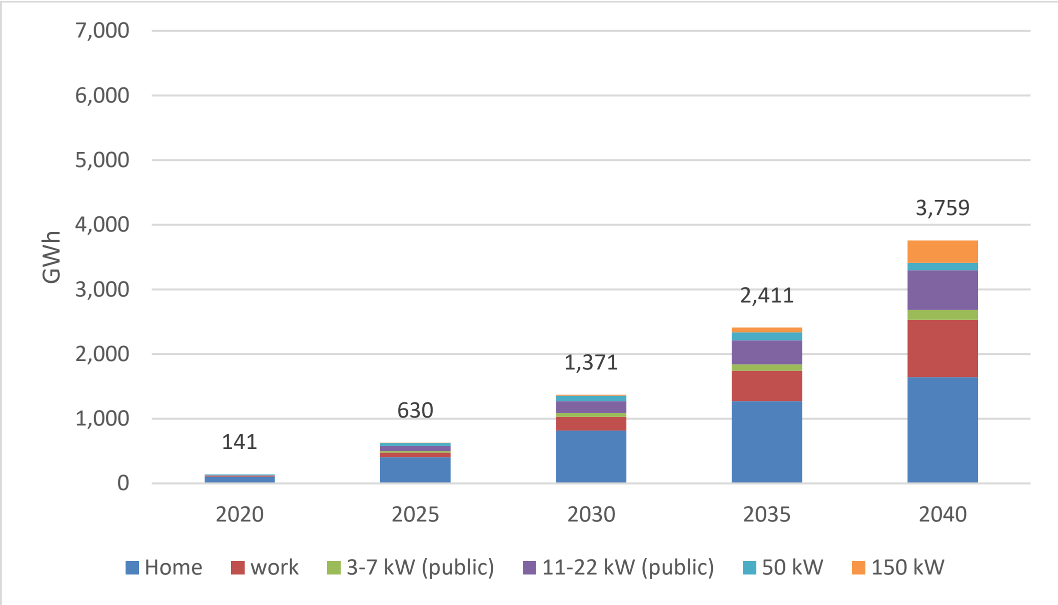
Assuming that public chargers would be 100% accessible and private chargers 95%, the electricity demand by charger types in the three scenarios are given in Figure 2.7, 2.8, and 2.9.

Figure 2.7: Electricity Demand by Charger Type in EV10 Scenario



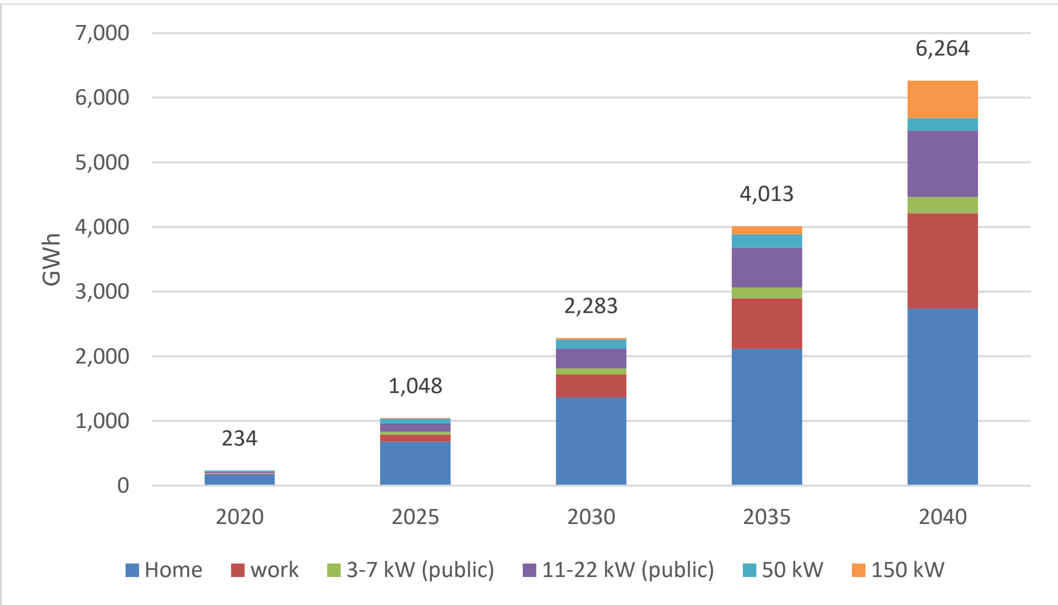
GWh = gigawatt hour, kW = kilowatt.
Authors' calculation.

Figure 2.8: Electricity Demand by Charger Type in EV30 Scenario



GWh = gigawatt hour, kW = kilowatt.
Source: Author's calculation.

Figure 2.9: Electricity Demand by Charger Type in EV50 Scenario



GWh = gigawatt hour, kW = kilowatt.
Source: Authors' calculation.

The 95% accessibility assumption for private home chargers means that not all users live in dwelling units with garages that are equipped with electric plugs that can be used to charge their electric vehicles. Users who do not have a garage or live in flats without individual indoor parking spaces are amongst the 5%. In consequence, the total electric power needed by the electric vehicle fleet given in Figures 2.3, 2.4, and 2.5 are then slightly higher than the total electricity needed by chargers.

Table 2.5 shows three other important assumptions from the supply side, i.e., the availability or uptime of chargers, recharge efficiency or losses from plug to battery, and the average charging power of each charger type.

Uptime of chargers is assumed to increase from 95% in 2020 to 99% in 2040, whilst recharge efficiency is assumed to be constant at 95% during the analysed period.

Table 2.5. Assumptions on Availability (AVAILYEAR), Efficiency (CHAREFF), and Charging Power (CHARPWR)

	2020	2025	2030	2035	2040
Availability (or uptime)	95%	96%	97%	98%	99%
Recharge efficiency (losses from plug to battery)	95%	95%	95%	95%	95%
Average charging power (kW)					
Home	5.0	5.0	5.0	5.0	5.0
work	5.0	5.0	5.0	5.0	5.0
3–7 kW (public)	5.0	5.0	5.0	5.0	5.0
11–2–22 kW (public)	15.0	15.0	15.0	15.0	15.0
50 kW (public)	50.0	50.0	50.0	50.0	50.0
150 kW (public)	150.0	150.0	150.0	150.0	150.0

kW = kilowatt.

Source: Authors’ estimation based on Transport & Environment (2020).

Table 2.6 and Table 2.7 show two distinct assumptions of energy use ratio, which is the ratio of total energy delivered with the total maximum energy capacity, i.e., charger at the maximum power 24 hours x 7 days. Assumption 1 (Table 2.6) signifies that energy ratios of all public chargers would increase gradually from 2020 to 2040. Assumption 2 (Table 2.7) signifies that energy use ratios of public chargers will only increase between 2020 and 2025. From 2025 onwards the energy use ratios of public chargers stay constant.

Table 2.6: Assumption 1: Increasing Energy Use Ratio in Public Charging from 2020 to 2040

	2020	2025	2030	2035	2040
Home	12.0%	12.0%	12.0%	12.0%	12.0%
Work	12.0%	12.0%	12.0%	12.0%	12.0%
3–7 kW (public)	3.0%	5.0%	7.0%	10.0%	14.0%
11–22 kW (public)	1.0%	2.0%	3.0%	5.0%	8.0%
50 kW (public)	1.0%	2.0%	2.0%	4.0%	7.0%
150 kW (public)	0.0%	1.0%	1.0%	3.0%	5.0%

kW = kilowatt.
Source: Authors' assumptions.

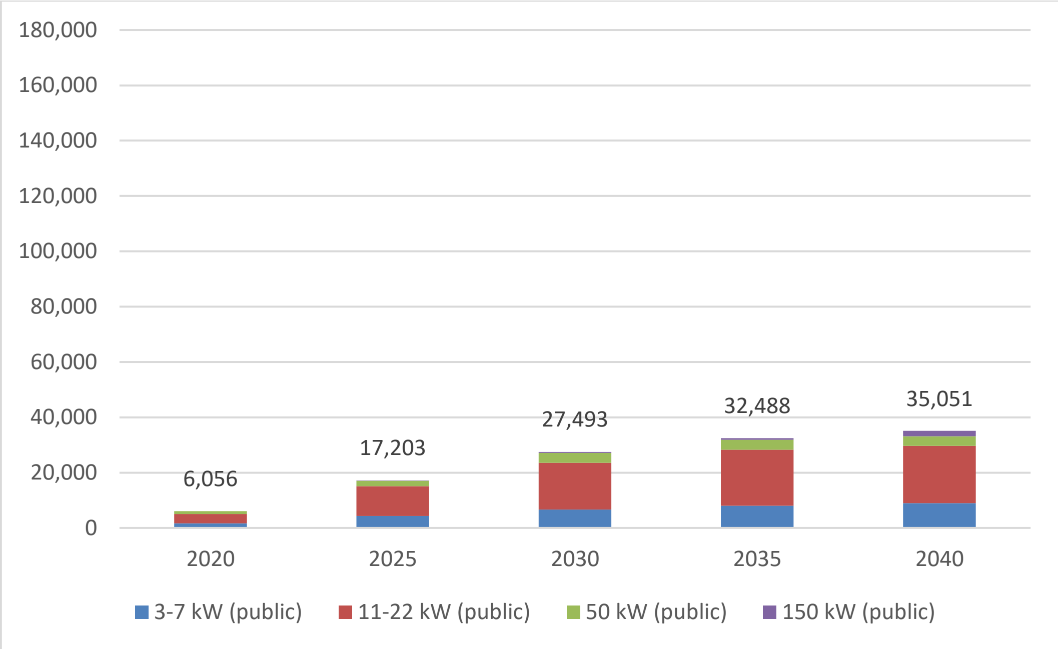
Table 2.7: Assumption 2: Constant Energy Use Ratio in Public Charging from 2020 to 2040

	2020	2025	2030	2035	2040
Home	12.0%	12.0%	12.0%	12.0%	12.0%
Work	12.0%	12.0%	12.0%	12.0%	12.0%
3–7 kW (public)	3.0%	5.0%	5.0%	5.0%	5.0%
11–22 kW (public)	1.0%	2.0%	2.0%	2.0%	2.0%
50 kW (public)	1.0%	2.0%	2.0%	2.0%	2.0%
150 kW (public)	0.0%	1.0%	1.0%	1.0%	1.0%

kW = kilowatt.
Source: Authors' assumptions.

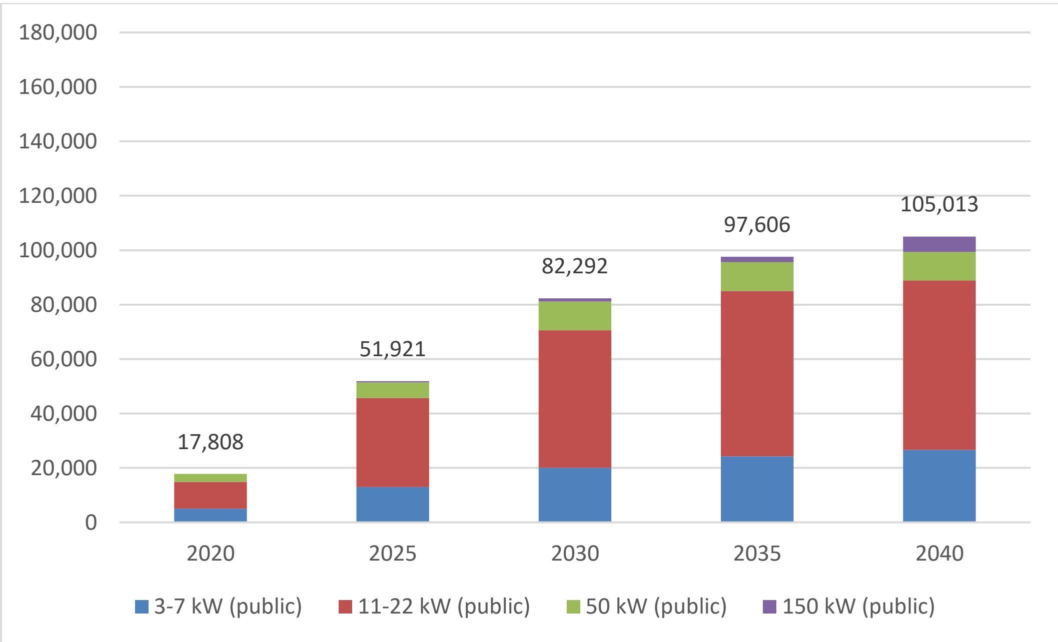
The effects of the two assumptions are seen in the calculated number of public chargers. As shown in Figure 2.10, 2.11, and 2.12, under Assumption 1 where the energy use ratios increase gradually from 2020 to 2040, the total number of public chargers would grow at an annual rate of around 9.3% in the three EV scenarios. By 2040, 11–22 kW chargers would comprise 59% of the total chargers, whilst 3–7 kW chargers would comprise around 25%, followed by 50 kW chargers (10%), and 150 kW chargers (5%).

Figure 2.10: Number of Public Chargers – EV10 Scenario – Energy Use Ratio Assumption 1



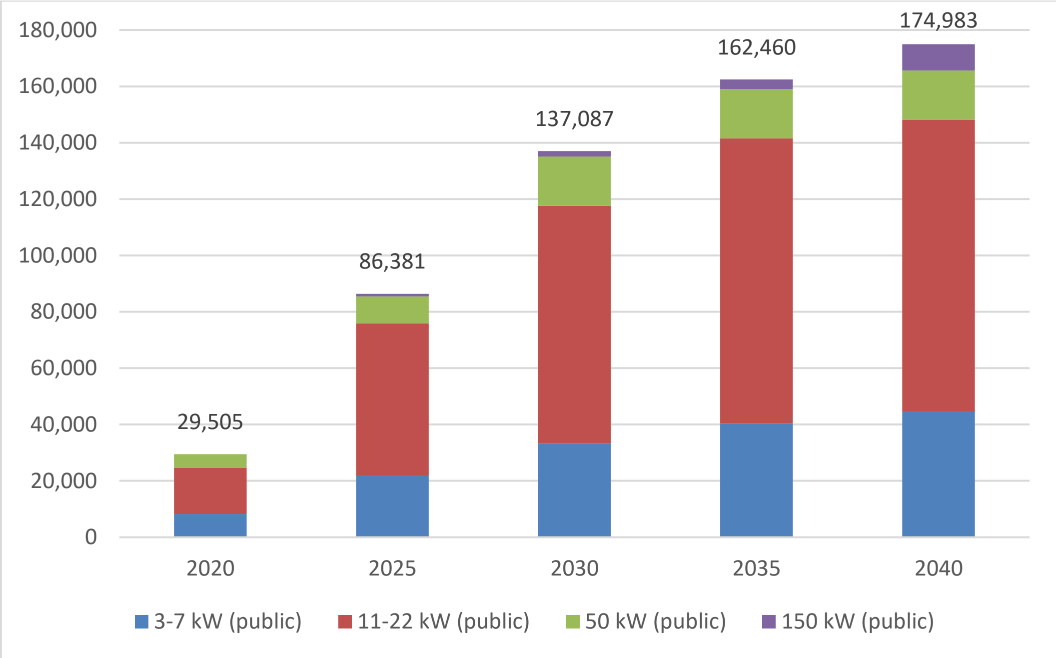
kW = kilowatt.
Source: Authors' calculation.

Figure 2.11: Number of Public Chargers – EV30 Scenario – Energy Use Ratio Assumption 1



kW = kilowatt.
Source: Authors' calculation.

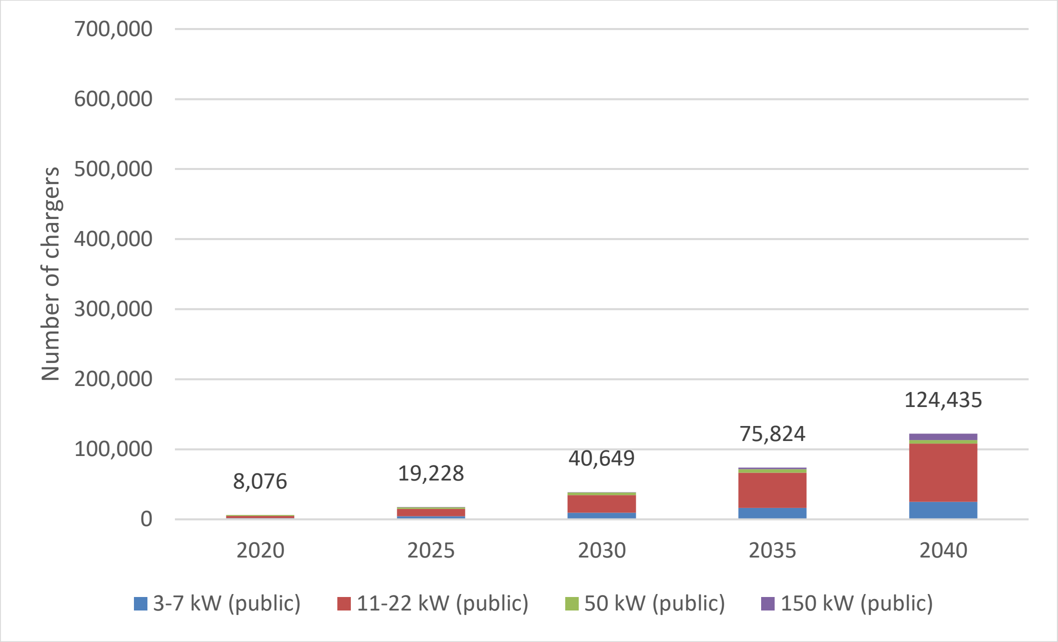
Figure 2.12: Number of Public Chargers – EV50 Scenario – Energy Use Ratio Assumption 1



kW = kilowatt.
Source: Authors' calculation.

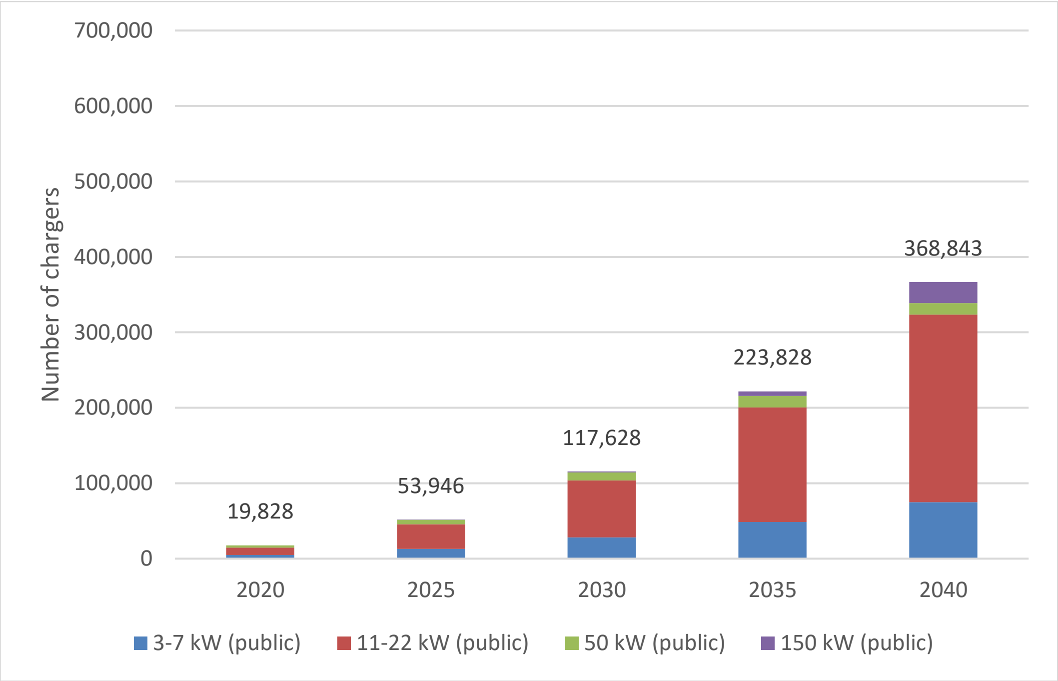
As shown in Figure 2.13, 2.14, and 2.15 , under Assumption 2 where the energy use ratios are assumed to remain the same between 2025 to 2040, the total number of public chargers would grow at an annual rate of around 16.3% in the three EV scenarios, which is faster than that of Assumption 1. By 2040, 11–22 kW chargers would comprise 68% of the total number of chargers, whilst 3–7 kW chargers would comprise around 20%, followed by 50 kW chargers (5%), and 150 kW chargers (8%).

Figure 2.13: Number of Public Chargers – EV10 Scenario – Energy Use Ratio Assumption 2



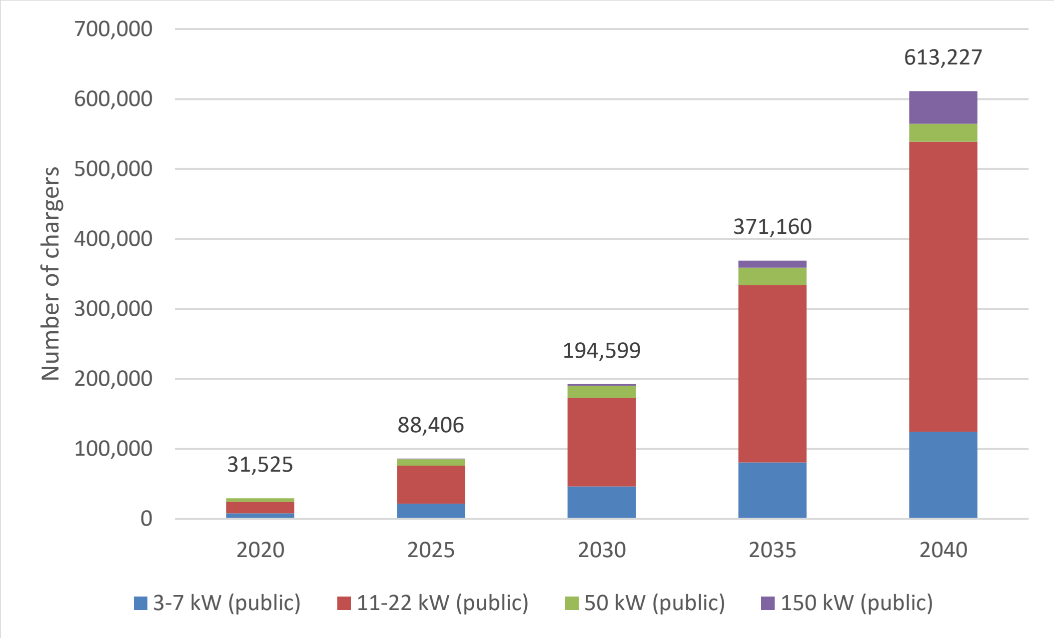
kW = kilowatt.
Source: Authors' calculation.

Figure 2.14: Number of Public Chargers – EV30 Scenario – Energy Use Ratio Assumption 2



kW = kilowatt.
Source: Authors' calculation.

Figure 2.15: Number of Public Chargers – EV50 Scenario – Energy Use Ratio Assumption 2

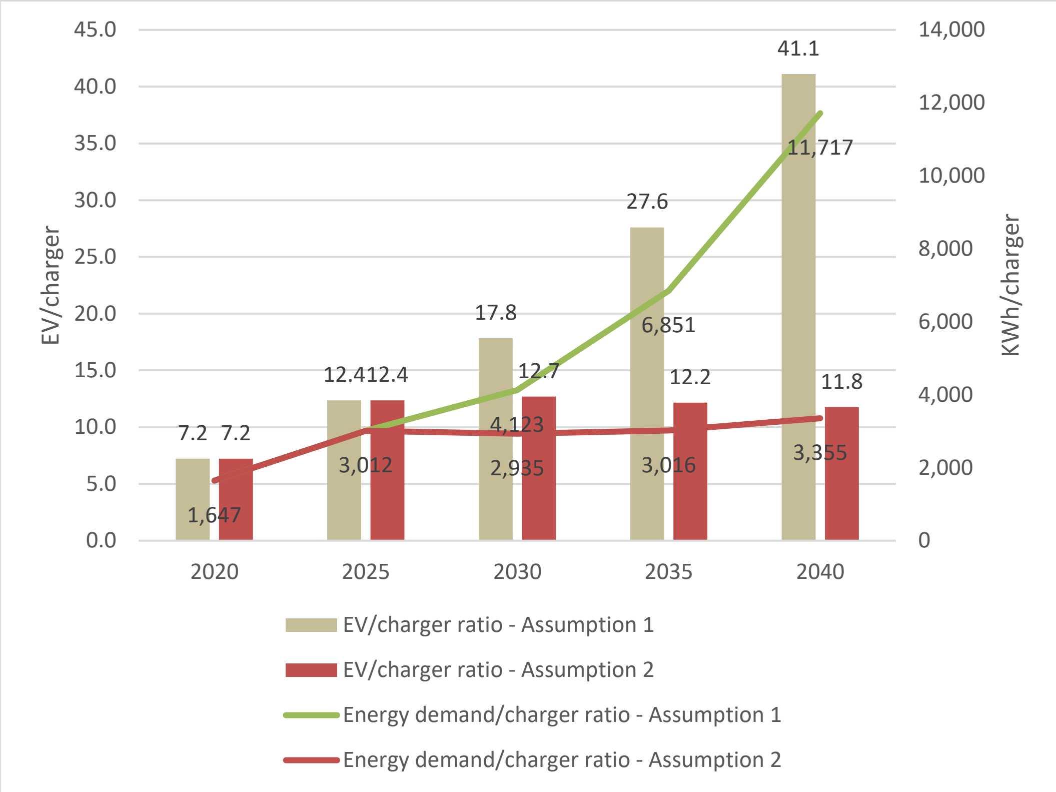


kW = kilowatt.
Source: Authors' calculation.

Figure 2.16 shows two additional indicators, i.e. the ratio of electric vehicles to chargers and the ratio of electric power consumption to charger. The increasing energy use ratios keep the number of chargers relatively low, therefore the ratio of electric vehicles to the number of chargers would increase from 7.2 units of electric vehicle per charger in 2020 to 41.1 units of electric vehicle per charger in 2040. In contrary, the stable energy use ratios between 2025 and 2040 in Assumption 2 means faster growth of the number of chargers and automatically the ratio of the number of electric vehicles to the number of charges remain relatively low, i.e., 12.4 in 2025 to 11.8 in 2040.

The ratio of electric power per charger would also increase in Assumption 1, from 1.647 GWh per charger in 2020 to 11.717 GWh per charger in 2040. In contrary under Assumption 2, the ratio of consumed power would remain relatively constant, i.e. 3.012 GWh per charger in 2025 to 3.355 GWh per charger in 2040.

Figure 2.16: Two Indicators of Charging Infrastructure



EV = electric vehicle, kWh = kilowatt hour.
Source: Authors' calculation.

Increasing energy use ratios would avoid the need for constructing more charging infrastructure. However, fewer chargers would also mean more power load on each charger, and this might also trigger less comfort for users such as longer waiting times or longer queues in charging stations or even longer travel distances and times to reach those stations.

In the other direction, building more chargers would avoid high power load on chargers and increase comfort for users. However, building more chargers means the need for more costly investment.

We took some installation costs per charger from various sources in Table 2.8 to calculate the total costs of installing chargers in the two assumptions for each of the three scenarios.

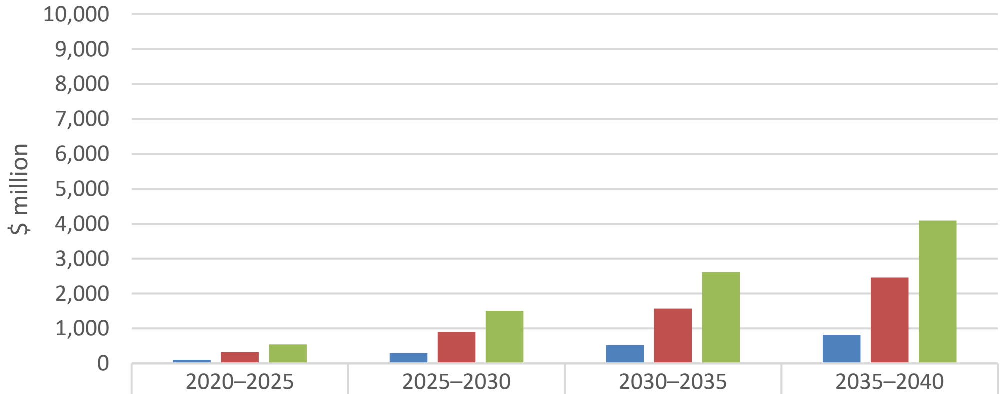
Table 2.8: Assumed Installation Costs

Power (kW)	**Installation cost per charging point**	**Currency**	**Country**	**Sources**	**$**	**Kip** (million)
7.2	69,000	฿	Thailand	https://www.futurecharge.co.th/	2,154	20
22	95,000	฿	Thailand	https://www.futurecharge.co.th/	2,966	28
50	25,000	€	Germany	NPE (2018)	29,769	282
150	50,000	€	European Union	Spöttle et al. (2018)	59,538	565

kW = kilowatt.
Source: Authors' compilation.

Under Assumption 1 where energy ratios are increased to keep the number of chargers relatively low, the accumulative costs might reach from around $819 million to $4,092 million by 2035–2040 (Figure 2.17). Under Assumption 2 as shown in Figure 2.18, where the number of chargers increases, total cumulative costs by 2035–2040 would reach between $1,794 million to $8,965 million. The accumulative costs of Assumption 2 are therefore more than double Assumption 1 in each scenario.

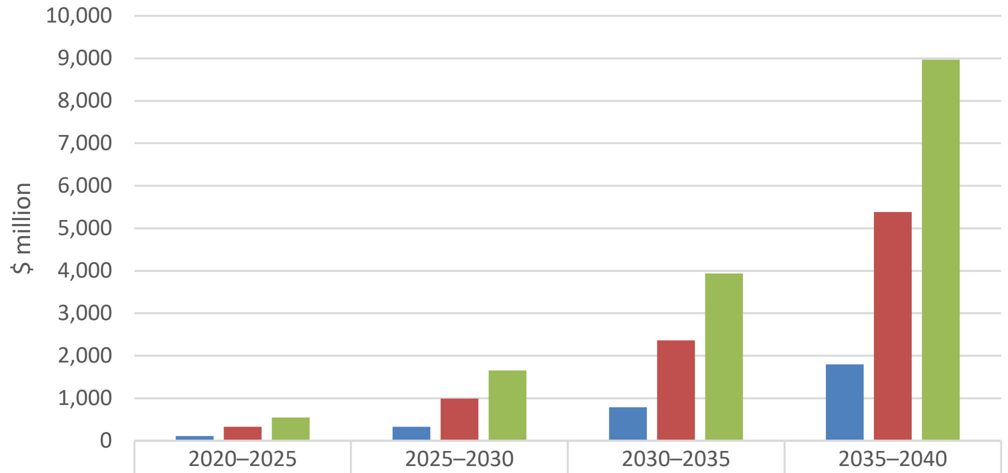
Figure 2.17: Accumulative Cost – Energy Ratio Assumption 1



	2020–2025	2025–2030	2030–2035	2035–2040
EV10	108	301	523	819
EV30	327	903	1,569	2,457
EV50	544	1,503	2,612	4,092

Source: Author's calculation.

Figure 2.18: Accumulative Cost – Energy Ratio Assumption 2



	2020–2025	2025–2030	2030–2035	2035–2040
EV10	108	331	787	1,794
EV30	327	995	2,364	5,383
EV50	544	1,657	3,936	8,965

Source: Authors' calculation.

4. Optimal Deployment of Charging Infrastructure

The public charging supply-cost model as demonstrated in section 3 is a simple method to determine the number of chargers needed in a region at a highly aggregated spatial level such as country, the type of charger needed, and the impacts of the possible solutions to the demand side as indicated by the ratio of electric vehicles per charger, to the supply side as indicated by the electricity consumption per charger and to the cost of charger roll-out.

To deploy electric vehicle charging infrastructure at the lower spatial level such as cities or municipalities, we need to determine not only the number of chargers, their required type, but also the spatial distribution of those chargers in a determined period. The research questions are then how many chargers should be built, the required type, and where.

Many types of approach exist to locate and optimise EV charge point locations answering the above research questions. Most studies focus on demand modelled by demographic, traffic, or individual trip data. Two types of approach are usually combined to answer those questions. The first type is the transportation approach that focuses on the transportation perspective such as mobility flows, road network configuration, and travel demand. The second type is the electric approach that considers factors such as demand from electric vehicles, user behaviour patterns, electric grid infrastructure, aim to locate charging stations in power systems such that their capacity and security requirements are satisfied, and the investment costs needed to upgrade them are minimised The following paragraphs illustrate some recent research work that looks for deploying optimally electric vehicle charging infrastructure.

Wagner, Götzinger, and Neumman (2013) for example is based on a transportation approach. Using data from Amsterdam, amongst the cities in the world with the highest number of EV users, the research first investigated the influence of possible local trip destinations of EV owners on charging point usage. The trip destinations, so called ‘points of interest’ (POI), were grouped in 92 different categories, and proved that these POIs have significant influence on the actual charging behaviour of EV owners in Amsterdam. A ranking procedure to rate individual POIs based on the surrounding charge point usage behaviour was developed and the individual POI ranking contributed to the POI category ranks, which in turn was used to assess the ‘charge point attractiveness’ of selected urban areas.

A location model was finally built to provide city planners with the optimal locations for new charging point infrastructure not only based on POI locations but also, spatially, in demand coverage.

Tian et al. (2018) proposed an optimisation model of charging stations that was based on waiting time. The target of this optimisation model was to minimise the time cost to electric vehicle drivers. Even if their main objective is from the transportation perspective, i.e. reduction of driver’s time cost, Tian et al. (2018) proved the necessity of EV driver behaviour prediction, i.e., the estimation whether drivers choose to charge EVs at a point in time. When the EV driver chooses to charge his vehicle, there are several optional charging stations in the range of the distance that the remaining power can support.

EV drivers might go to the nearest charging station, but they might need to wait to charge. The waiting time might be lower if they chose to go to the second nearest and the total time cost for charging would be less than that for the nearest station.

The total time cost without behaviour prediction of EV drivers is 27.28% more than the total time cost in driver behaviour prediction mode, and the average waiting time is 1.68 minutes more.

Tian et al. (2018) built a queuing model based on the number of drivers (vehicles) that are predicted to go to each station and the station capacity, based on which the waiting time is calculated. Finally, an optimisation model is built to determine the location of charging stations based on the minimised charging time cost.

The last example, i.e. Mourad and Hennebel (2020) developed a mathematical formulation aiming at maximising the covered recharging demand, whilst respecting investment budget limits and the available capacities provided by the electric grid. With the main objective at finding the optimal locations for deploying EV charging stations and finding the number of chargers that need to be installed at each charging station, they considered the different mobility flows and recharging demands as well as the constraints imposed by the available electric grid and the availability of alternative energy sources, i.e., photovoltaic.

Having the maximisation of the total covered charging demand based on the covered paths as the objective function, Mourad and Hennebel's mathematical model had several constraints:

- the sum of location costs and charger installation costs does not exceed total budget limit
- a minimum of the overall charging demand must be satisfied
- charging demands for vehicles and trucks at each path must be satisfied
- the number of fast chargers (for vehicles and trucks) to be installed must be within the specified limits at each charging location
- the electric power required to operate the installed chargers does not exceed the available electric capacity at the charging locations

Mourad and Hennebel (2020) started by defining a set of coupling nodes, a set of potential charging locations, and a set of mobility paths that represented electric vehicle flows and their recharging demands. Through a case study on the Paris Saclay area in the Île-de-France region in France, the research obtained the optimal locations for deploying EV charging stations as well as the number of chargers that need to be installed at each charging station.

5. Facilitating Charging Infrastructure Investment

Developing charging infrastructure needs significant investment. The public sector cannot bear the total burden and needs to attract private investors. The main challenge is convincing investors that the investment will be profitable as there are not yet enough EVs on the road.

Some EV front-runner country strategies for rolling-out charging facilities are summarised below.

5.1. China

The world leader in the number of EVs sold, China started in 2009 with the '10 cities, 10,000 vehicles' business model to promote EV development, but established targets only in June 2012: 500,000 vehicles by 2015 and 5 million by 2020.

The programme's first step was top-down selection of experimental sites where the central government could either test policy or try out innovative practices. The second step – evaluation and absorption – combined bottom-up and top-down approaches. Central government agents evaluated the performance of pilot projects, whilst local participants reported their progress to the central authorities, documenting the most advanced practices for wider diffusion. The third step – diffusion by the central government – popularised successful practices through the media and endorsement by leading politicians. The final step was the learning and feedback loop (Marquis, Zhang, and Zhou, 2013).

Five models were created in the pilot cities: state leadership in Beijing based on public sector support; platform-led business in Shanghai replicating international models; cooperative commercialisation in Shenzhen based on a leasing model through strategic partnership; flexible rental in Hangzhou; and fast-charging models in Chongqing, which is close to the Three Gorge Power Grid.

The city-based pilot programmes, however, focused on local goals and firms rather than a long-term national agenda. Competition for central government support eroded cities' willingness to cooperate with each other on setting national or international standards and goals; manufacturers or players were barred from entering other cities.

5.2. United States

EVs are becoming more popular in the US. California leads with 2% PEV share of total road vehicles, followed by Hawaii (1.2%), Colorado (0.56%), Texas (0.23%), and Ohio (0.15%). Measures in urban areas promoted PEV charging facilities include:

- development of make-ready locations by utilities that would support a variety of third-party charging stations (California, Colorado);
- implementation of TOU rates that encourage users to charge during off-peak periods (California, Ohio, Hawaii);
- provision of significant rebates of charging development for the private sector (Colorado, Texas); low-interest loans for businesses, non-profit organisations, public schools, and local governments for installing charging stations (Ohio); and grants to build stations (Texas);
- legal framework that favours private ownership of charging stations by allowing private companies to resell electricity supplied by a public utility to charge EVs (Colorado);
- partnership between public utilities and private companies in developing and operating charging stations (Texas); and
- explicit right to site charging on premise for multifamily dwellings and townhouses (Hawaii) (Fitzgerald and Nelder, 2017).

5.3. Europe

Measures taken by two PEV front-runner European countries – the Netherlands and Germany – are summarised below:

- **The Netherlands**. Between 2010 and 2014, seven grid operators (state owned and regional) invested in developing charging infrastructure (Living Lab Smart Charging, 2017), which was later included in the Green Deal Electric Driving Programme (2016–2020) backed by a consortium of central and regional governments, grid operators, the automotive sector, and universities. The programme provides funding for public charging poles equally from government, municipalities, and market players, and for installation of the Netherlands Knowledge Platform on Public Charging Infrastructure (Hamelink, 2016). The programme not only develops charging facilities but also the roaming system and implements international protocol standards.

- **Germany**. The country has several financial support programmes at different government levels. The Federal Ministry of Transport's programme for EV charging infrastructure and the regional model of electromobility finance and/or subsidising development of charging infrastructure that require local or private investment.

In other European countries – front-runners or followers – state-owned agencies, with or without big private partners such as grid operators, first financed or organised deployment of charging infrastructure. Agencies or consortia then offered financing programmes to the private sector or local government to develop charging infrastructure.

6. Charging Scheme Strategy

The expansion of PEVs and their demand for charging facilities have become increasingly important. The associated electricity demand will affect energy markets and the grid infrastructure. Studies on Portugal (Nunes, Farias, and Brito, 2015) and the European Union (Kasten et al., 2016) show the impact of EVs once they make up 5%–10% of total road vehicles.

The amount of electricity needed to meet additional demand and the greenhouse gas emissions produced to generate electric power are calculated based on the average of total power plant mix. PEVs' environmental performance would be better than conventional vehicles' performance if additional demand was met by a low-carbon intensive energy mix. Even if there were 300 million electric cars, if power generation was not decarbonised, CO_2 emissions would be insignificantly reduced by less than 1% (Sauer, 2019). Electric vehicles may reduce local pollution but not global emissions.

China, the EV front-runner in Asia, is struggling to curb the share of coal-fired-based electric energy from 75% to 50% and to increase that of renewable sources from 25% to 50% in 2030, bringing down power generation carbon intensity by one-third and ensuring that EVs will be less carbon intensive than they are now. China uses more electricity from coal-fired generating plants during fast charging peak demand periods and after working hours in the evening. Slow charging during off peak hours, when energy from renewables such as wind turbines is available, would reduce CO_2 emissions (Chen et al., 2018).

When and how PEVs are charged determine which generation plants satisfy additional electricity demand and have an impact on emissions. Depending on their total system and marginal costs, different types of power plants may increase production. Including this charging scheme in the analysis might change the calculation results.

Uncontrolled or user-driven charging occurs mostly after work in the evening, when electricity demand is already high, increasing system load and costs of utilities (Brandmayr et al., 2017).

User-driven charging would raise severe concerns about generation adequacy and may jeopardise the stability of the power system (Schill and Gerbaulet, 2015). Fast-charging stations use large amounts of power for short periods of time, meaning that expensive upgrades will be needed for a relatively low use rate (Hall and Lutsey, 2017). In the US, if EVs constitute 25% of all road vehicles, uncontrolled charging would increase electricity peak demand by 19%, but spreading charging over the evening hours would increase demand by only 6% (Fitzgerald and Nelder, 2017).

Reducing carbon emissions and the load on the local grid will be solved only by charging management schemes, some of which are described below.

- **Off-peak or network-oriented charging** includes policies and structures that encourage off-peak-period charging, including workplace or daytime charging and night-time home charging, to avoid network congestion and physical capacity constraints. This strategy should increase system stability and grid functioning but producing electricity during low-demand periods using conventional energy sources might have negative environmental effects.
- **Cost-oriented charging**. This strategy aims to reduce EV charging cost by shifting the charging time to periods of low energy prices. EV owners could benefit from low energy costs, and load patterns might be smoothed as the low charging cost period coincides often with low demand. Additional conventional production during low-cost periods could have negative environmental effects. Some findings are the following (Schill and Gerbaulet, 2015). First, cost-driven charging promotes renewable energy more than user-driven charging, but cost-driven charging might also increase the use of the emissions-intensive lignite power generation. Germany, for example, has the lowest marginal costs for thermal technology and uses more hard coal than user-driven strategies. Second, cost-driven charging reduces unused generated power more than uncontrolled charging. The opposite happens in countries with a high share of renewables, such as Denmark, which has a low share of emissions-intensive generators and a high share of wind power. Using a cost-driven charging system, Germany and the Association of Southeast Asian Nations (ASEAN) countries will reduce CO_2 emissions only if they build more renewable-energy generators. Cost-driven charging will work only if emissions externalities are correctly priced.
- **Smart charging** includes controlled charging and demand response. A simpler solution such as the use of in-vehicle timers to take advantage of TOU rates could help minimise stress on the electrical grid, whilst also saving money for consumers. Smart charging strategies are less practical for DC fast charging than for level-2 charging as drivers expect fast charging to be available on demand (Hall and Lutsey, 2017). As the fast-changing market continues to grow, fast chargers should be placed near adequate high-capacity electrical infrastructure.

- **Combined smart and cost-oriented charging.** Decreasing real time price increases renewable energy share, such as wind as it is available during that period. The variability of wind power drops as its share increases. In this situation, CO2 emissions could be higher than the average of the total power plant energy mix, if coal, for example, due to its low marginal costs, dominates the lower price part of the merit order (Dallinger, Wietschel, and Santini, 2012).
- **Renewable energy-oriented charging** or **low emissions-oriented charging** aims to increase environmental performance or avoid negative impact of greenhouse gases and air pollutant emissions. The measure shifts charging times to periods of high or surplus renewable energy generation, resulting in reduced additional production by conventional plants. However, conditions vary in different energy systems and this strategy requires sufficient renewable power generation to meet additional electricity demand.

Chapter 3

Analysis on Impacts to Energy Demand and Supply Situation

As mentioned in Chapter 1, electric vehicle (EV) penetration will bring a change in the energy demand supply situation of the Lao People's Democratic Republic (Lao PDR). The change will see a decrease in demand for gasoline and transport diesel oil and an increase in electricity demand for EVs. Thus in this chapter, reflecting this change into the Energy Balance Table (EBT) of the Lao PDR in 2040 by Kimura and Phoumin (2021) which is also in line with the Ministry of Energy and Mines Lao PDR and ERIA (2018 and 2020b), we analysed the impacts to energy demand supply to be brought by EV penetration.

1. Changes in Energy Demand from Penetration of Electric Vehicles

The changes in energy demand from the penetration of EVs in 2040 are summarised in Table 3.1. The changes depend on the scenarios with EV penetration ratio of 10% (10% of vehicle stock will be shown as EV10%), 30%, and 50%. The balance defined as the increase in electricity demand minus the decrease in oil demand will be minus in the three scenarios, in other words, energy consumption will be saved.

Why will the decrease in petroleum consumption be larger than the increase in electricity demand? For example, in the case of the Nissan LEAF, 40 kilowatt hours (kWh) of electricity can run for 400 kilometres (km) according to Nissan's catalogue, so that necessary electricity of thermal basis is estimated as 40 kWh * 860 kilocalories (kcal)/kWh = 34.4 megacalories (Mcal). On the other hand, in the case of the Toyota Prius, its fuel economy as noted in its catalogue is around 35 km/litre, so that necessary gasoline is estimated as 400 km/35 km/litre * 7,970 kcal/litre = 91.1 Mcal. This is one reason why we can expect a large decrease in petroleum demand due to the penetration of EVs.

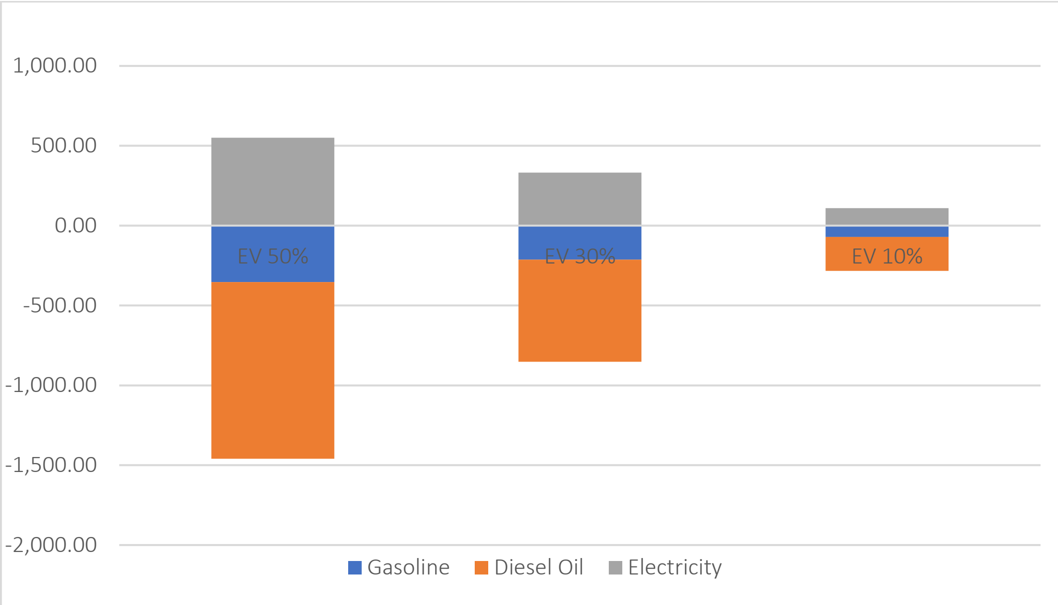
Table 3.1: Changes in Energy Demand from EV Penetration in 2040 (ktoe)

	Gasoline	Diesel Oil	Electricity	Balance
EV 50%	-353.82	-1105.87	551	-908.69
EV 30%	-212.29	-640.347	331.1	-521.537
EV 10%	-70.76	-213.449	110.08	-174.129

ktoe = kiloton of oil equivalent.

Source: Authors' calculation.

Figure 3.1: Changes in Energy Demand by Penetration of EVs in 2040 (ktoe)



ktoe = kiloton of oil equivalent.
Source: Author's calculation.

2. New Energy Balance Table 2040 to Incorporate Impacts of Electric Vehicle Penetration

Based on the Lao PDR's Energy Balance Table (EBT) of the business-as-usual (BAU) scenario in 2040 (shown in Table 3.2), a new EBT will be produced to reflect the changes of energy demand shown in Table 3.3. As power generation assumption, 100% of electricity will come from hydropower plants. The Lao PDR's EBT of EV penetration scenario in 2040 is shown in Table 3.2.

Table 3.2: Lao PDR Energy Balance Table of BAU Scenario in 2040

Lao PDR Energy Balance Table 2040 Unit: ktoe	Coal	Petroleum Products							Hydro	Solar etc	Others	Electricity	Total
		Total	Motor Gasoline	Jet Fuel	Gas/Diesel Oil	Fuel Oil	LPG	Other Petroleum Products					
Indigenous Production	9,654	0							4,004	258	1,819		15,735
Imports		1,836	353	50	1,348	44	40	1				26	1,862
Exports		0										-3,783	-3,783
International Marin Bunkers		0											0
International Aviation Bunkers		-41		-41									-41
Stock Changes		0											0
Total Primary Energy Supply	9,654	1,795	353	9	1,348	44	40	1	4,004	258	1,819	-3,757	13,773
Transfer		0											0
Total Transformation Sector	-9,182	0	0	0	0	0	0	0	-4,004	-258	-246	6,752	-6,937
Main Activity Producer	-9,182	0							-4,004	-258	-246	6,752	-6,937
Charcoal Processing		0											0
Loss & Own use		0										-366	-366
Discrepancy	1	0	0	0	0	0	0	0	0	0	-1	0	0
Total Final Energy Consumption	471	1,795	353	9	1,348	44	40	1	0	0	1,574	2,629	6,469
Industry sector	471	249			205	44					44	1,188	1,952
Transport sector	0	1,469	353	9	1,106	0	0	1	0	0	0	580	2,049

Domestic Air Transport		9		9									9
Road		1,460	353		1,106			1				551	2,011
Railway		0										29	29
Other sector	0	77	0	0	37	0	40	0	0	0	1,530	861	2,468
Residential sector		27					27				1,145	484	1,656
Commercial sector		13					13				385	377	775
Agriculture sector		37			37								37

BAU = business-as-usual.

Source: Kimura and Phoumin (2021).

Table 3.3: Lao PDR Energy Balance Table of EV 50% Scenario with 100% Hydropower in 2040

Lao PDR Energy Balance Table 2040 Unit: ktoe	Coal	Petroleum Products							Hydro	Solar etc	Others	Electricity	Total
		Total	Motor Gasoline	Jet Fuel	Gas/Diesel Oil	Fuel Oil	LPG	Other Petroleum Products					
Indigenous Production	7,326	0							4,632	258	1,819		14,035
Imports		1,836	353	50	1,348	44	40	1				26	1,862
Exports		0										-3,783	-3,783
International Marine Bunkers		0											0
International Aviation Bunkers		-41		-41									-41
Stock Changes		0											0
Total Primary Energy Supply	7,326	1,795	353	9	1,348	44	40	1	4,632	258	1,819	-3,757	12,073
Transfer		0											0
Total Transformation Sector	-6,854	0	0	0	0	0	0	0	-4,632	-258	-246	6,752	-5,238
Main Activity Producer	-6,854	0							-4,632	-258	-246	6,752	-5,238
Charcoal Processing		0											0
Loss & Own use		0										-366	-366
Discrepancy	1	0	0	0	0	0	0	0	0	0	-1	0	0
Total Final Energy Consumption	471	1,795	353	9	1,348	44	40	1	0	0	1,574	2,629	6,469
Industry sector	471	249			205	44					44	1,188	1,952
Transport sector	0	1,469	353	9	1,106	0	0	1	0	0	0	580	2,049

Domestic Air Transport		9		9									9
Road		1,460	353		1,106			1				551	2,011
Railway		0										29	29
Other sector	0	77	0	0	37	0	40	0	0	0	1,530	861	2,468
Residential sector		27					27				1,145	484	1,656
Commercial sector		13					13				385	377	775
Agriculture sector		37			37								37

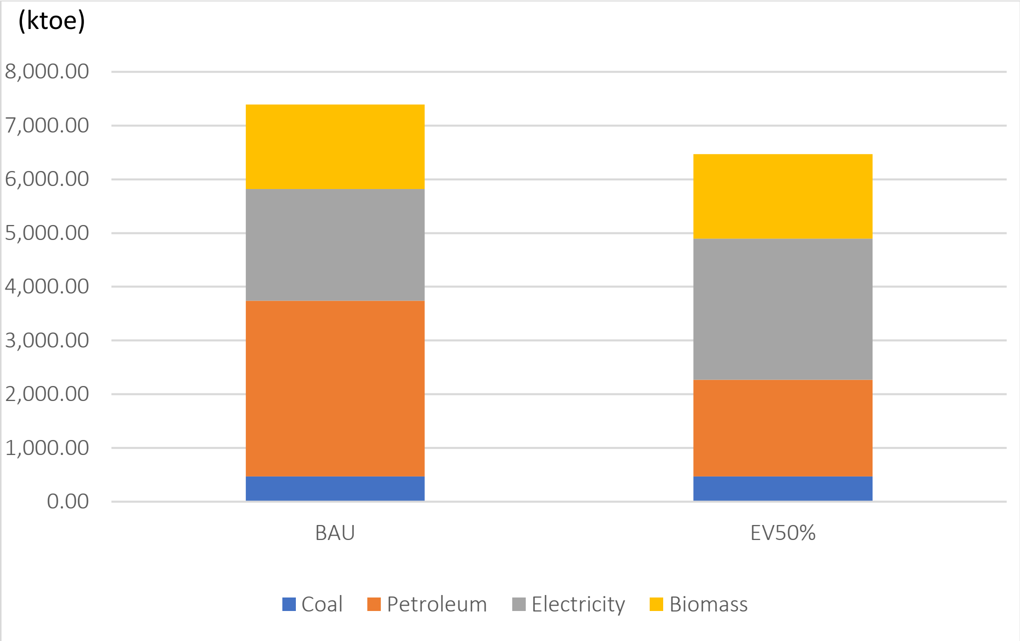
ktoe = kiloton of oil equivalent.

Source: Author's calculation.

3. Impact on Total Final Energy Consumption

The total final consumption (TFEC) of the EV penetration scenario is much lower than in the BAU scenario (Figure 3.2). Thus, EV penetration will bring the Lao PDR significant energy savings.

Figure 3.2: Comparison of TFEC Between BAU and EV 50% in 2040



BAU = business-as-usual, ktoe = kiloton of oil equivalent, TFEC = total final energy consumption.
Source: Author’s calculation.

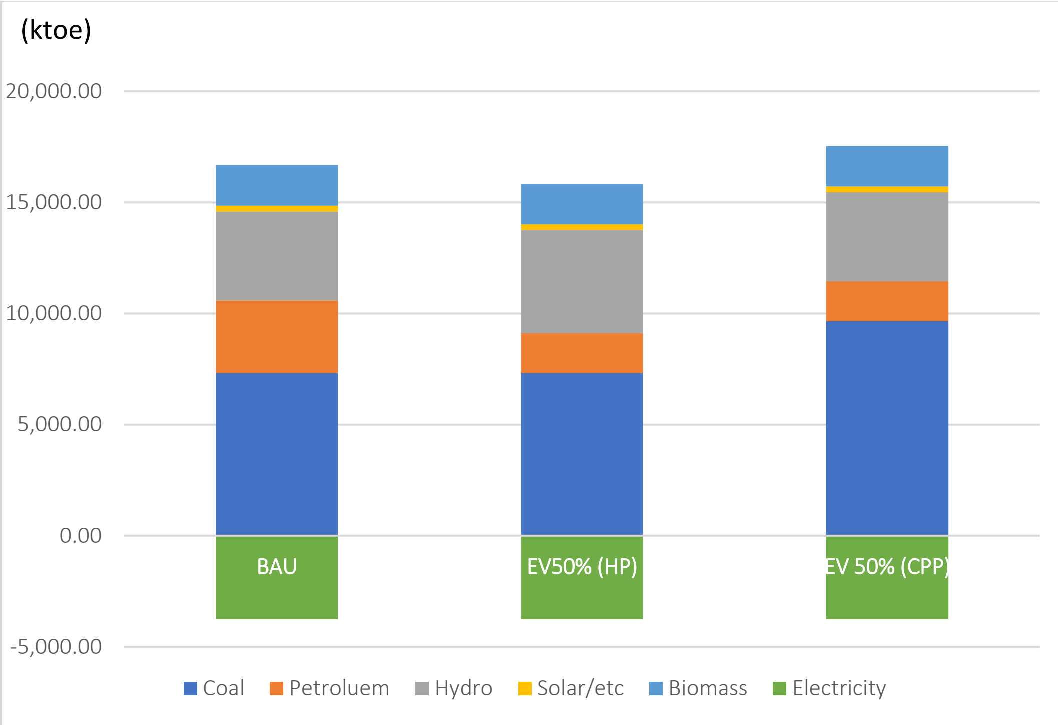
4. Impact on Total Primary Energy Supply

If we analysed the impact of EV total primary energy supply (TPES), we need to assume that the power generation mix to meet additional electricity demand comes from EVEV penetration. Referring to the current power generation mix in the Lao PDR; the following two cases are assumed:

- 100% hydropower generation
- 100% coal-fired power generation

Based on the new EBT of EV 50% shown in Table 3.3, the two cases mentioned above are incorporated into the new EBT and the results including BAU are show in Figure 3.3.

Figure 3.3: Impact on TPES by EV Penetration in 2040



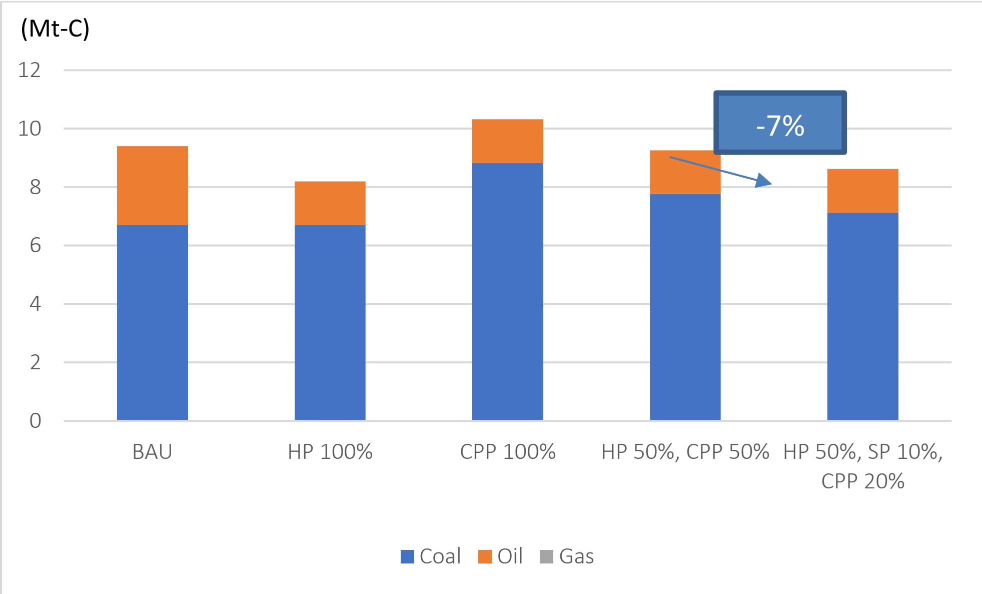
BAU = business-as-usual, CPP = coal-fired power plant, HP = hydropower plant, ktoe = kiloton of oil equivalent, TPES = total primary energy supply.
Source: Author's calculation.

If the Lao PDR generates the additional electricity for EVEV penetration from hydropower plants, the TPES will decrease from the BAU scenario of around 850 ktoe. But if it generates the electricity from coal-fired power plants, the TPES from BAU is around the same amount of 850 ktoe due to different thermal efficiencies – 100% for hydropower, and 27% for coal-fired power generation. In other words, coal-fired power generation needs lots of coal for heating boilers.

5. Impact on CO_2 Emissions

The penetration of EVs will also impact CO_2 emissions in the Lao PDR in 2040 but it depends on the power generation mix. Figure 3.4 shows CO_2 emissions of BAU, EV 50% with hydropower generation, EV 50% with coal-fired power generation, EV 50% with 50% hydropower generation and 50% coal-fired power generation, and finally EV 50% with 70% hydropower, 10% solar power, and 20% from coal-fired power generation.

Figure 3.4: Comparison of CO_2 Emissions amongst Four Cases in 2040



BAU = business as usual, CPP = coal-fired power plant, HP = hydropower, ktoe = kiloton of oil equivalent, Mt-C = million ton of carbon.
Source: Authors' calculation.

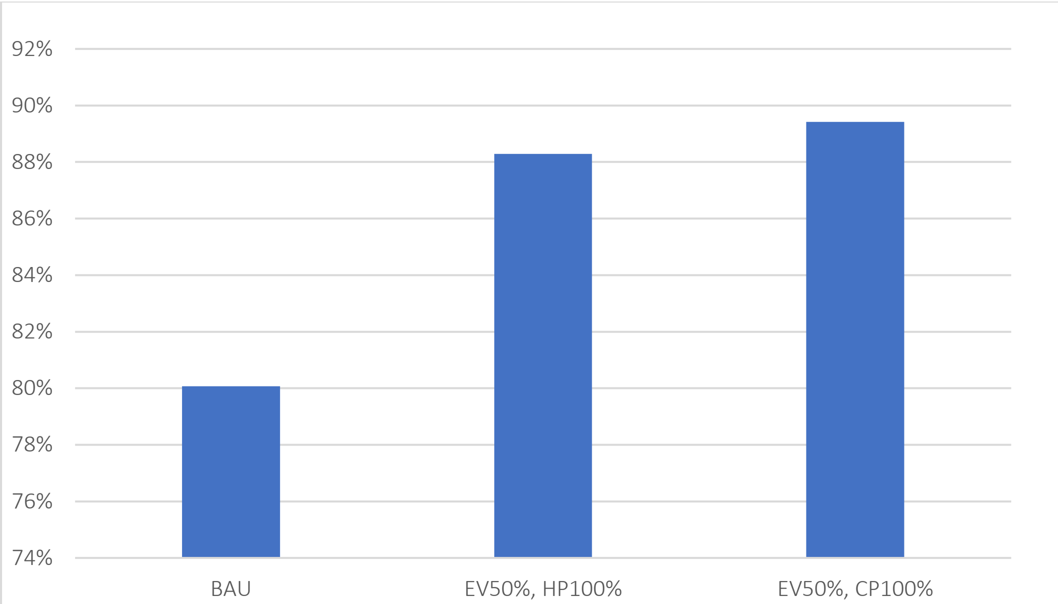
CO_2 emissions in the case of 100% hydropower generation is forecast as 8.2 million tons of carbon (Mt-C), which will be lower than BAU (9.4 Mt-C), but CO_2 emissions to apply 100% coal-fired power generation will increase to 10.3 Mt-C from BAU. In the case of 50% hydropower and 50% coal-fired power, CO_2 emissions will slightly decrease to 9.2 Mt-C compared to BAU. Thus, in terms of CO_2 emissions, hydropower generation is a good option for the Lao PDR.

We need also to pay attention to the different capacity factors of hydropower in the wet and dry seasons. Usually, the capacity factor of hydropower in the dry season is much lower than in the wet season, thus the Lao PDR imports electricity from Thailand due to electricity supply shortages every year. Consequently, the selection of 100% hydropower generation is risky for the Lao PDR.I. In this regard mixing power generation using hydropower and coal-fired power is recommended with attention paid to maximising hydropower with a range of round 50%.

6. Impact on Energy Supply Security

Finally, we analyse how EVEV penetration will contribute to energy supply security in the Lao PDR. Usually, we apply an import dependency ratio for analysing energy supply security level, which is defined as indigenous production/total supply. Total supply is also defined as indigenous production plus imports. Figure 3.5 shows the import dependency ratio of the three cases which are BAU, EV 50% with hydropower 100%, and EV 50% with coal-fired power 100%.

Figure 3.5: Domestic Energy Dependency Ratio of the Three Cases



BAU = business as usual, CPP = coal-fired power plant, HP = hydropower.
Source: Authors' calculation.

The penetration of EVs will contribute to improving the domestic energy dependency ratio and it means EVs will increase the demand for domestic energy supply such as hydropower generation and coal consumption, and decrease petroleum imports such as gasoline and diesel oil.

7. Conclusions

The penetration of EVs in the Lao PDR will, on the one hand, decrease gasoline and diesel oil consumption and on the other hand, increase electricity consumption. As a result, the TFEC of the Lao PDR will decrease. Thus, the penetration of EVs will contribute to the energy savings of the road transport sector.

If electricity to be consumed by EVs will be generated by hydropower plants, CO_2 emissions will largely decrease 13% from the BAU scenario. But if the electricity will be generated by coal-fired power plants, CO_2 emissions will increase 9.8% from BAU. Thus, the Lao PDR has to consider increasing the hydropower capacity to meet the additional electricity demand for EVs. However, it is true that hydropower's output in the dry season declines due to lack of water flow, thus a power generation mix of hydropower and coal-fired power is strongly recommended and the appropriate ratio of both capacity factors will be around 70% and 30%, respectively.

EVEV penetration will also contribute to improve energy supply security of the Lao PDR. A decrease in transport fuel consumption such as gasoline and diesel oil will decrease oil imports into the Lao PDR and in parallel, an increase of hydropower and coal-fired power will increase the supply of domestic energy. Thus, energy supply security of the Lao PDR will improve if EV penetration proceeds in the Lao PDR.

Chapter 4

Analysis on Impacts to the National Economy and the Oil Industry

Chapter 4 clarifies the impacts to the national economy and oil industry by electric vehicle (EV) penetration scenarios. EV penetration will decrease the demand of gasoline and diesel oil in 2040 compared with BAU scenario (which means without EV penetration), and the decreased volume of demand increases as the EV penetration rate increases.

Decreasing oil demand will reduce oil imports and contribute to improving the trade balance. In addition, the decrease in oil imports has the effect of boosting the gross domestic product by 0.5%–2.4% depending on the EV penetration rate. These are a positive impact for the national economy. On the other hand, declining oil demand will reduce government revenues and adversely affect the oil industry, including a decrease in sales amount, number of employees, and number of service stations compared with BAU in 2040. However, oil demand will increase from the current level even if EV penetration proceeds, so the EV 10% and EV 30% scenarios are unlikely to have a serious impact. However, in the EV 50% scenario, the impact could be significant as oil demand growth flattens towards 2040.

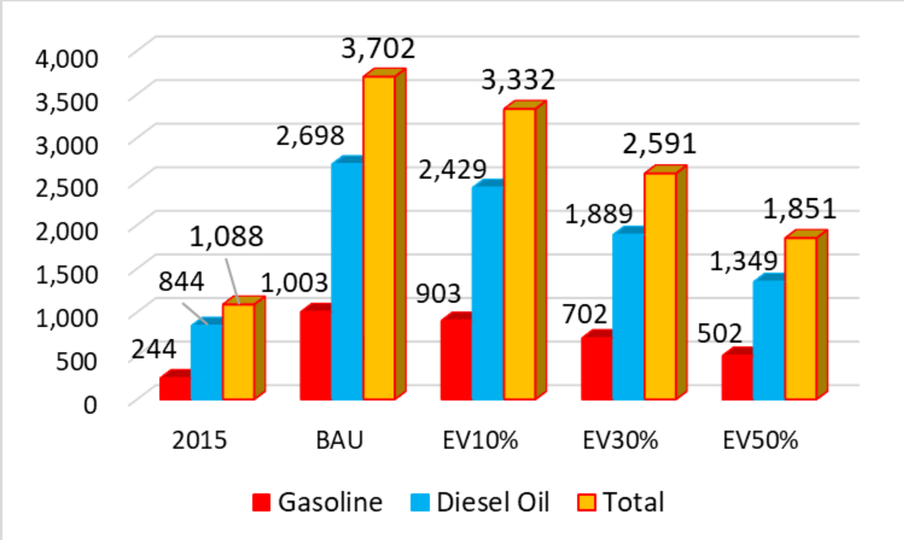
In addition, it should be noted, in this chapter, the unit of oil demand is expressed in kilolitres (kl), which is suitable for analysing the impact to oil industry.

1. Impact on the National Economy

1.1. Decreased Demand for Gasoline and Diesel Oil for Transportation

The demand for gasoline and diesel oil for transportation in 2040 are estimated in ERIA Outlook: 1,003 thousand kilolitres (kl) and 2,698 thousand kl, respectively. The total demand for gasoline and diesel oil for transportation is 3,702 thousand kl (Kimura and Phoumin, 2021). This is the BAU case. Through the EV penetration scenario, the demand for gasoline for transportation will decrease to 903 thousand kl in the EV 10% scenario, 702 thousand kl in the EV 30% scenario, and 502 thousand kl in the EV 50% scenario, whilst the demand for diesel oil for transportation will decrease to 2,429 thousand kl in the EV 10% scenario, 1,889 thousand kl in the EV 30% scenario, and 1,349 thousand kl in the EV 50% scenario.

Figure 4.1: Demand for Gasoline and Diesel Oil in 2040 for Transportation (1,000 kl)



BAU = business-as-usual, kl = kilolitre.
Source: Author's calculation.

The demand for gasoline and diesel oil in the BAU scenario compared to the EV penetration scenarios are shown Table 4.1.

Table 4.1: Estimation of Demand for Gasoline and Diesel Oil by EV Penetration Scenario Compared to BAU in 2040 (1,000 kl)

	2015	BAU	EV 10%		EV 30%		EV 50%	
Gasoline	244	1,003	903	–10.0%	702	–30.0%	502	–50.0%
Diesel Oil	844	2,698	2,429	–10.0%	1,889	–30.0%	1,349	–50.0%
Total	**1,088**	**3,702**	**3,332**	**–10.0%**	**2,591**	**–30.0%**	**1,851**	**–50.0%**

BAU = business-as-usual, kl = kilolitre.
Source: Authors' calculation.

1.2. Decreased Import Value of Gasoline and Diesel Oil

Result in 2015

The total import value of the Lao PDR in 2015 was $6,462 million with the total import value of gasoline and diesel oil estimated at $672 million. It is 10.4 % of the total.

Table 4.2: Total Import Value of Lao PDR in 2015

Items	$1,000	%
Machines/parts	1,368,000	21.2
Vehicles/parts	1,127,000	17.4
Fossil fuel/electricity	969,000	15.0
Agriculture, livestock, food	833,000	12.9
Steel	654,000	10.1
Others	1,511,000	23.4
Total	**6,462,000**	**100.0**

Source: Laos Japan External Trade Organization Annual Report 2015.

Table 4.3: Import Value of Gasoline and Diesel Oil in 2015

	Import Volume (1,000 kl)	CIF Price $/kl	Import Value ($1,000)
Gasoline	255	577	147,263
Diesel Oil	889	590	524,734
Total	**1,145**	**-**	**671,997**

CIF = cost, insurance, and freight.

Source: Lao State Fuel Oil Company. Lao PDR Energy Statistics (2018).

Estimation of Import Value of Gasoline and Diesel Oil in 2040

The import value of gasoline and diesel oil in 2040 is estimated by using the cost, insurance, and freight price of each product in 2015 and import volume of each product by EV penetration scenario.

In the BAU case, the total import value of gasoline and diesel oil in 2040 is estimated at $2,170,993 thousand. The in the BAU case and the EV10, EV30, EV 50 scenarios are shown in Table 4.4.

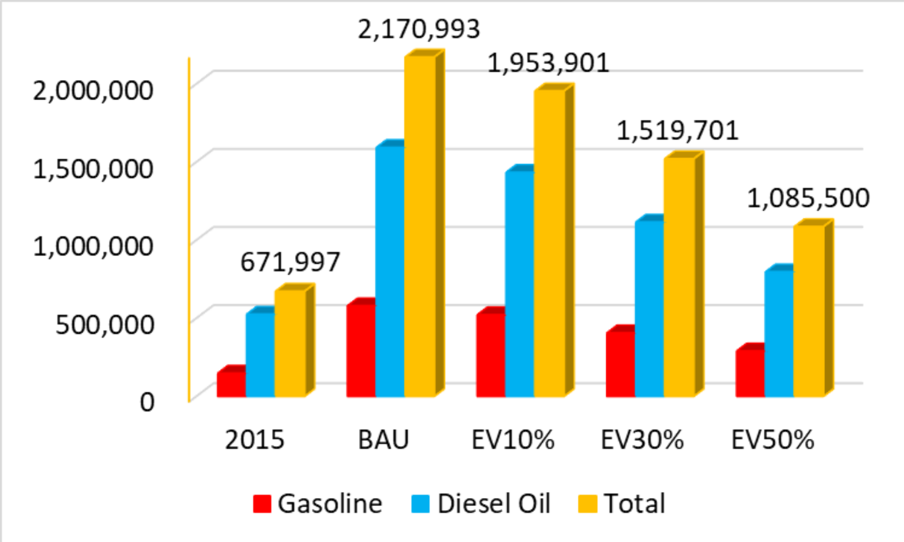
Table 4.4: Import Value in 2040 by EV Penetration Scenario ($1,000)

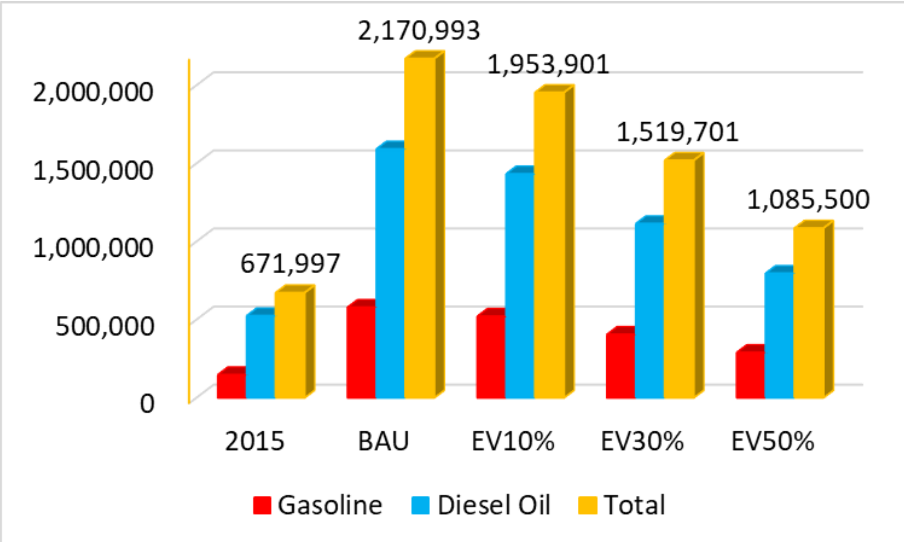
	BAU	EV 10%	EV 30%	EV 50%
Gasoline	578,945	521,053 (–10%)	405,263 (–30%)	289,472 (–50%)
Diesel Oil	1,592,049	1,432,847 (–10%)	1,114,438 (–30%)	796,028 (–50%)
Total	**2,170,993**	**1,953,900 (–10%)**	**1,519,701 (–30%)**	**1,085,500 (–50%)**

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

Source: Authors' calculation.

Figure 4.2: Import Value of Gasoline and Diesel Oil by EV Penetration in 2040 ($1,000)




2,170,993
1,953,901
1,519,701
1,085,500
671,997
2,000,000
1,500,000
1,000,000
500,000
0
2015
BAU
EV10%
EV30%
EV50%
Gasoline
Diesel Oil
Total

BAU = business-as-usual, EV = electric vehicle.
Source: Authors' calculation.

Decreased Import Value of Gasoline and Diesel Oil from BAU

The decreased import value of gasoline and diesel oil by EV penetration scenario from the BAU case is shown in Table 4.5.

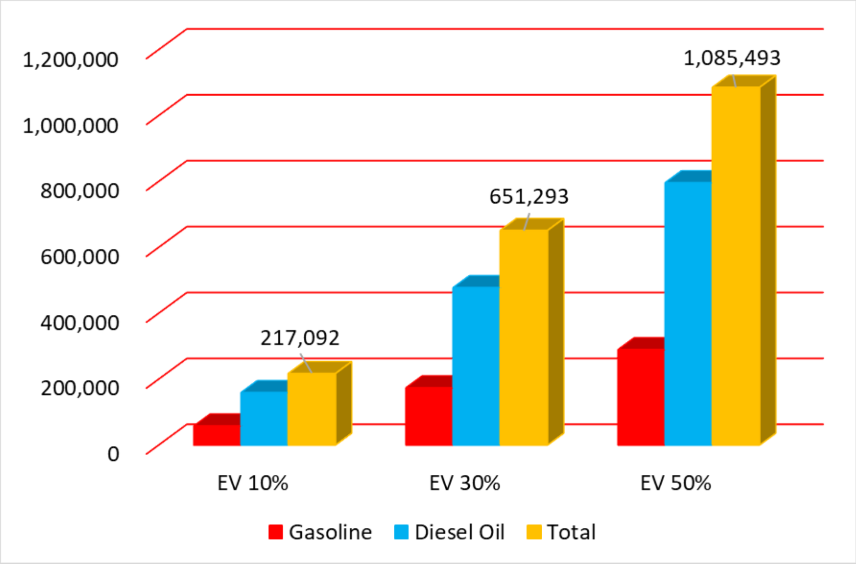
Table 4.5: Decreased Import Value of Gasoline and Diesel Oil in 2040 Compared with BAU ($1,000)

	EV 10%	EV 30%	EV 50%
Gasoline	57,891	173,682	289,472
Diesel Oil	159,201	477,611	796,021
Total	**217,092**	**651,293**	**1,085,493**

BAU = business-as-usual.

Source: Authors' calculation.

Figure 4.3: Decreased Import Value of Gasoline and Diesel Oil in 2040 with BAU ($1,000)



Source: Authors' calculation.

1.3. Decrease of Government Revenue Compared with BAU Case

Government revenues are taxes and duties, road fees, and the government reserve fund.

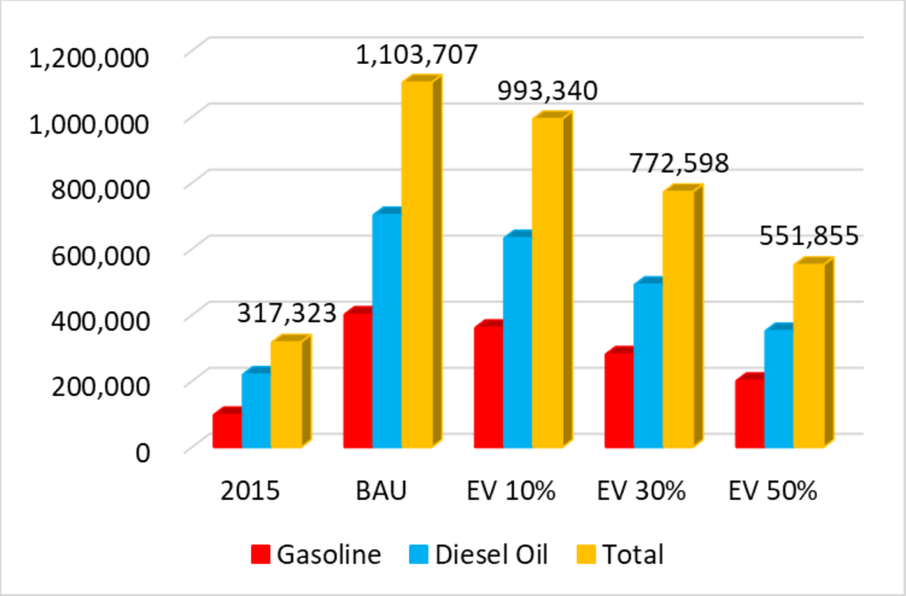
Table 4.6: Government Revenue ($/litre)

	Gasoline	Diesel Oil
Taxes and Duties	0.3133	0.1740
Road Fee	0.0494	0.0494
Government Reserve Fund	0.0370	0.0370
Total	**0.3997**	**0.2604**

Source: Lao State Fuel Oil Company.

As shown in Tabl, government revenue in 2040 by EV penetration scenario can be estimated and decrease of Government revenue by EV penetration scenario can be estimated compared with BAU case.

Figure 4.4: Government Revenue in 2040 by EV Penetration Scenario ($1,000)



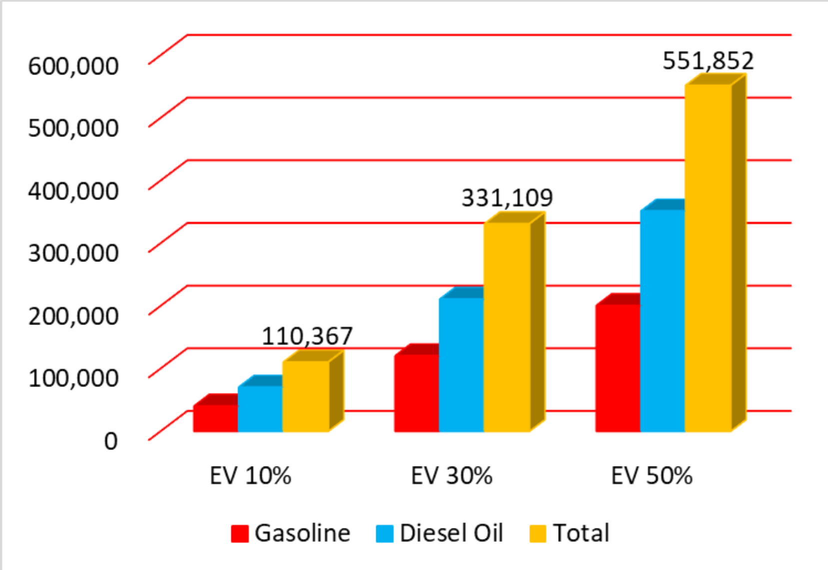
BAU = business-as-usual, EV = electric vehicle.
Source: Authors' calculation.

Table 4.7: Government Revenue in 2040 by EV Penetration Scenario ($1,000)

	2015	BAU	EV 10%		EV 30%		EV 50%	
Gasoline	97,479	401,047	360,945	–10%	280,734	–30%	200,524	–50%
Diesel Oil	219,844	702,660	632,396	–10%	491,864	–30%	351,332	–50%
Total	**317,323**	**1,103,707**	**993,340**	**–10%**	**772,598**	**–30%**	**551,855**	**–50%**

BAU = business-as-usual, EV = electric vehicle.
Source: Authors' calculation.

Figure 4.5: Decrease of Government Revenue Compared with BAU Case



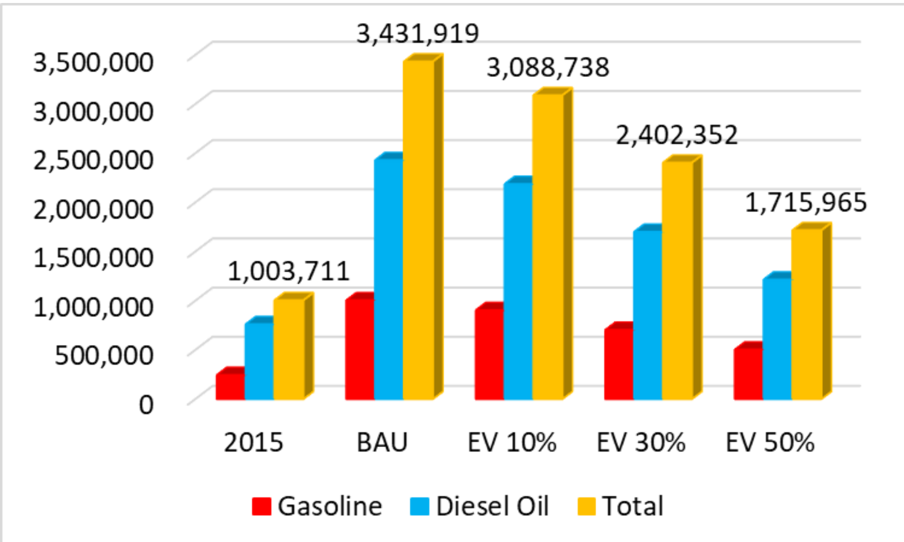
BAU = business-as-usual.
Source: Authors' calculation.

2. Impact on Oil industry

2.1. Decreased Sales Amount of Gasoline and Diesel Oil

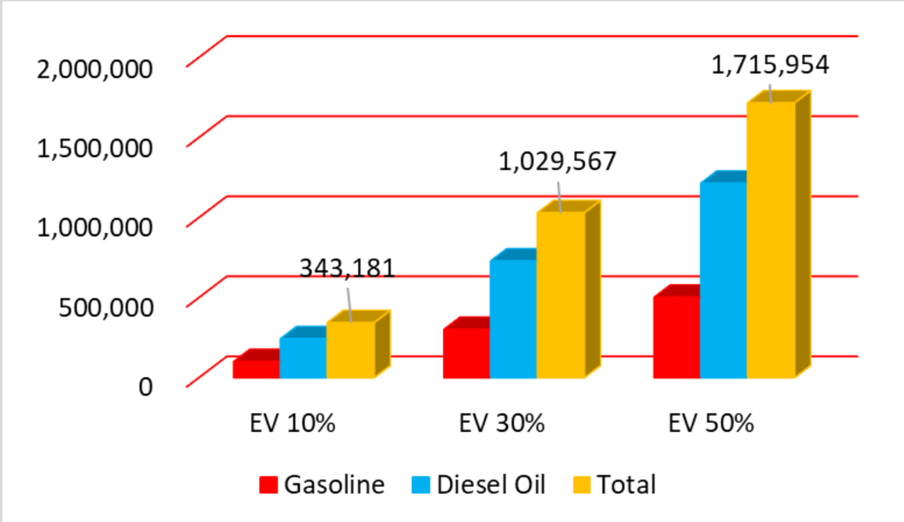
In the BAU case of 2040, the sales amount will expand to about $3,432,000,000, but in the EV 50% case it will be half, but 1.7 times that of 2015. The retail price is set at $1.0re/litre for gasoline and $0.9re/litre for diesel oil.

Figure 4.6. Sales Amount in 2015 and 2040 ($1,000)



BAU = business-as-usual.
Source: Authors' calculation.

Figure 4.7: Decreased Sales Amount Compared with BAU Case ($1,000)



BAU = business-as-usual.
Source: Authors' calculation.

Table 4.8: Sales Amount by EV Penetration Scenario in 2040 ($1,000)

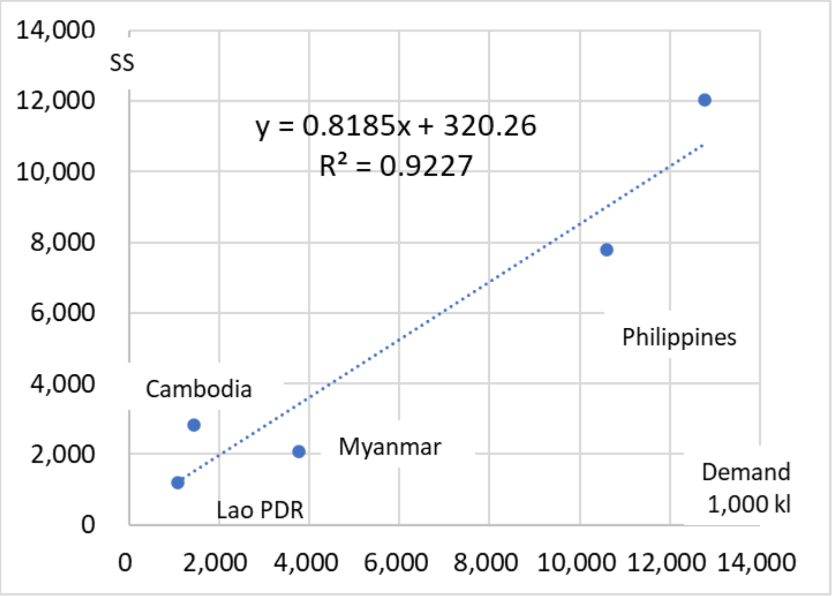
	2015	BAU	EV 10%		EV 30%		EV 50%	
Gasoline	243,881	1,003,370	903,039	–10%	702,362	–30%	501,685	–50%
Diesel Oil	759,831	2,428,549	2,185,700	–10%	1,699,990	–30%	1,214,280	–50%
Total	**1,003,711**	**3,431,919**	**3,088,738**	**–10%**	**2,402,352**	**–30%**	**1,715,965**	**–50%**

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

2.2. Decrease in Number of Service Stations by EV Penetration

The number of service stations in the Lao PDR in 2015 was 1,200. The number of service stations depends on the demand for gasoline and diesel oil. Figure 4.8 shows the relation between the number of service stations and the demand in neighbouring countries.

Figure 4.8: Relation Between Number of Service Stations and Demand



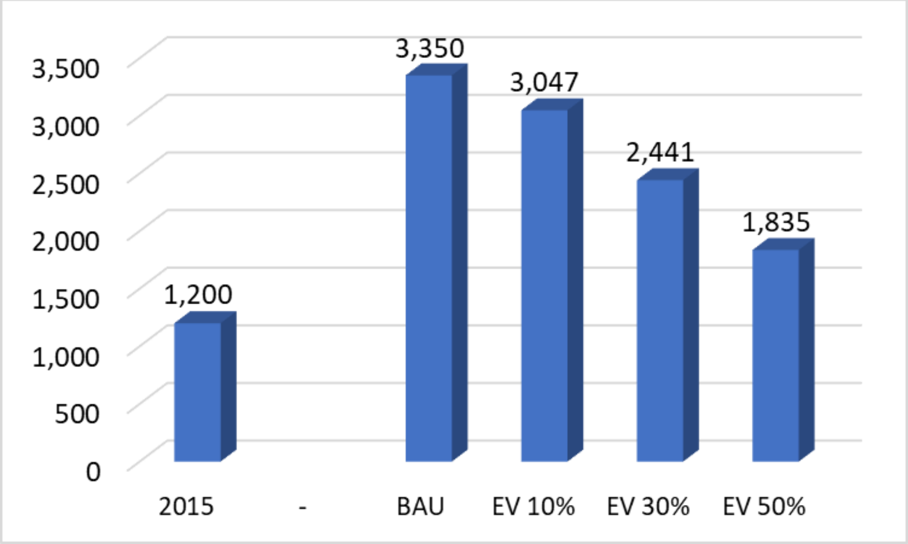
kl = kilolitre, SS = service station.

Note: Demand = Gasoline + Diesel Oil.

Source: Authors' calculation.

The approximate line is estimated. Using this formula, the number of service stations in 2040 by EV penetration can be estimated.

Figure 4.9: Estimation of Number of Service Stations in 2040 by EV Penetration

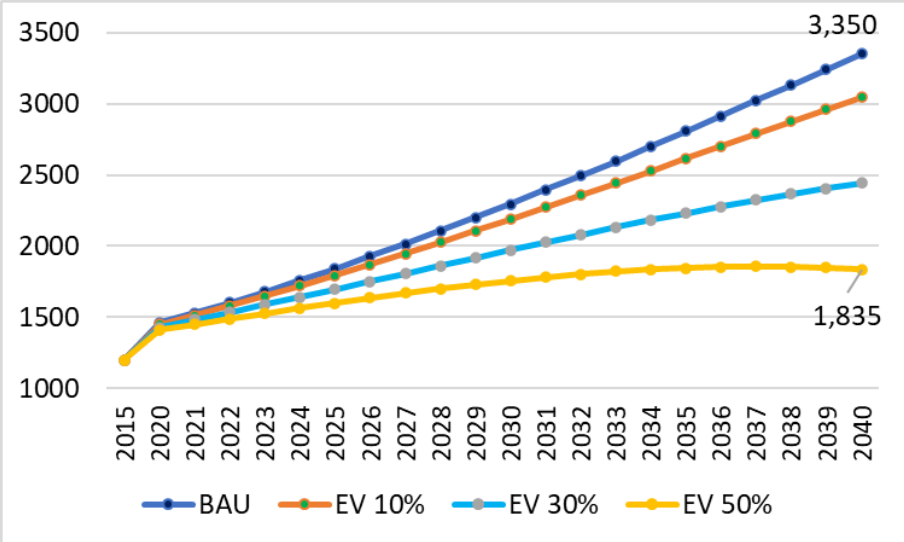


BAU = business-as-usual, EV = electric vehicle.

Source: Authors' calculation.

The number of service stations in 2040 in the BAU case is 3,350, in the EV 10% case is 3,047, in the EV30% case is 2,441, and in the EV 50% case is 1,835 (Figure 4.9). The trend in the number of service stations from 2015 to 2040 in the EV 50% case shows a very small decrease, and it will be almost flat from 2035 (Figure 4.10).

Figure 4.10: Trend in Number of Service Stations, 2015–2040



BAU = business-as-usual.
Source: Authors' calculation.

2.3. Decrease in Number of Employees in the Oil Industry

There are no official statistics of the number of employees in the oil industry. Therefore, the number of employees is estimated based on the information obtained from the website of oil companies in the Lao PDR.

Company P:

(1) 138 service stations in 2014 — estimated 1,380 people

(2) 5 depots and 3 terminals — estimated 140 people

(3) 300 tank-trucks — estimated 300 people

(4) Control section (10%) — estimated 180 people

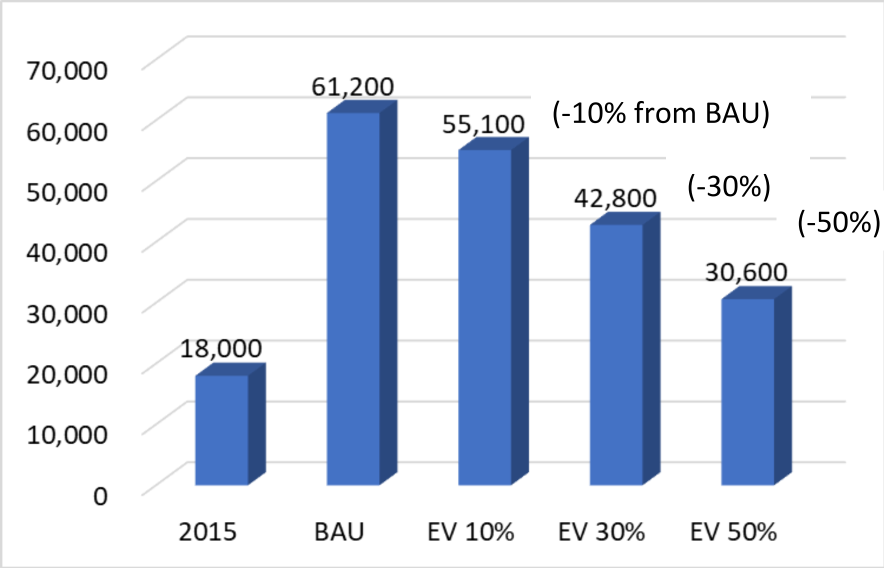
Total = 2,000 people

Company P has stated on its website that it has 2,000 employees.

Since Company P's share is about 11%, the total number of employees in the oil industry in 2015 is estimated to be 18,000.

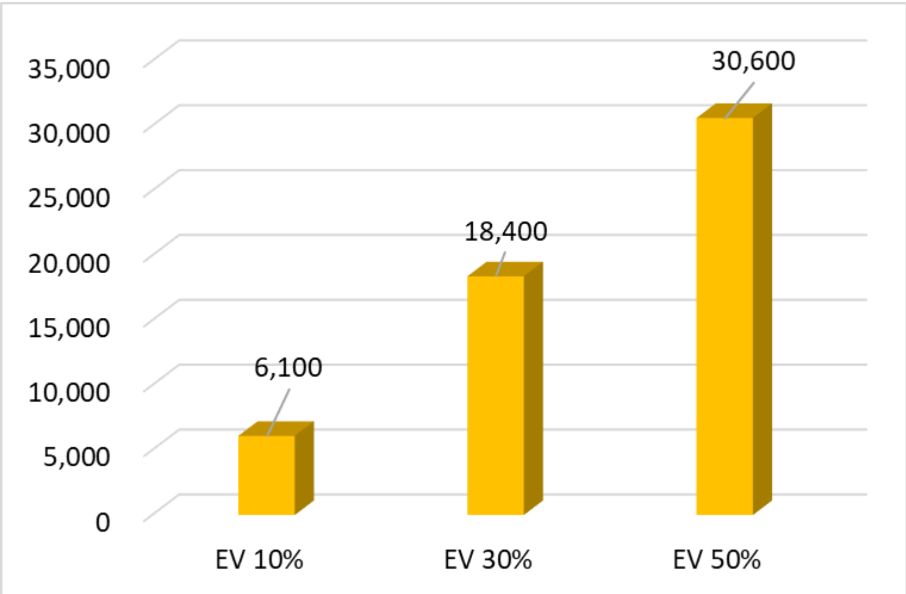
Assuming that the number of employees in the oil industry increases in proportion to the demand for oil, the number of employees by scenario in 2040 is shown in Figure 4.11 and Figure 4.12.

Figure 4.11: Estimation of Number of Employees in Oil Industry



BAU = business-as-usual.
Source: Authors' calculation.

Figure 4.12: Decrease in Number of Employees Compared with BAU Case



BAU = business-as-usual.
Source: Authors' calculation.

3. Positive and Negative Impacts

3.1. Positive Impact

Since the demand for gasoline and diesel oil will expand 3.4 times in 2040 from 2015 in the BAU case, the import value of gasoline and diesel oil will be 3.4 times.

However, the penetration of EVs will improve the trade balance due to the decrease of import of gasoline and diesel oil. The import value of gasoline and diesel oil was 10.4 % of the total import value of the Lao PDR in 2015. Although imports and exports will increase due to economic development in 2040, it is certain that the decrease in imports of petroleum products will contribute to the improvement of the trade balance.

In addition, the decrease in oil imports has the effect of boosting gross domestic product (GDP). According to the ERIA Outlook (Kimura and Phoumin, 2021), the of GDP of the Lao PDR in 2040 is projected to be $$46 billion (2010 price). The decrease in import value by EV penetration scenario in 2040 is estimated at $217 million in the EV 10% case, $651 million in the EV 30% case, and $1,085 million in the EV 50% case.

Therefore, the effect of boosting the GDP due to the decrease in import value is estimated to be 0.5% in the EV 10% case, 1.4% in the EV 30% case, and 2.4% in the EV 50% case.

Government revenues will decrease due to EV penetration scenarios. However, government revenues may be recovered by revenues such as taxes from the electricity sector.

On the other hand, there is no positive impact for the oil industry. However, if the long-term outlook for EV penetration is clarified, there is a possibility of business opportunities other than oil, such as entry into EV-related businesses.

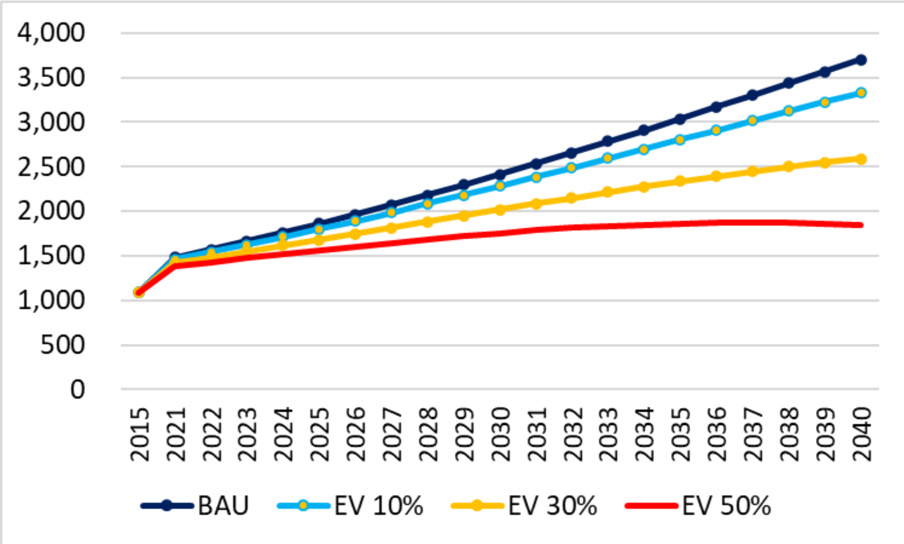
3.2. Negative Impact

Depending on the EV penetration scenario, it will have a negative impact on the oil industry. Demand for gasoline and diesel oil from 2015 to 2040 in the EV 10% case and the EV 30% case will increase by an average of 4.6% and 3.5% annually, respectively. That is not such a serious impact. However, in the EV 50% case, the annual growth rate of demand for gasoline and diesel oil will be only 2.1%, and almost flat from 2035.

There will be a negative impact on the oil industry in the EV 50% scenario.

Figure 4.13: Demand for Gasoline and Diesel Oil in 2040 by EV Penetration Scenario

(1,000 kl)



AGR = annual growth rate, BAU = business-as-usual, EV = electric vehicle.
Source: Author's calculation.

In Japan's experience, oil demand will level off, and if service station sales stop growing, there will be fierce competition in a non-expanding market. This is because service station labour costs and overheads will increase due to consumer price increases, but profits will decrease because the sales amount will not increase.

Under these circumstances, it is expected that service stations that try to increase sales volume with a low-price strategy will appear and will develop into price competition nationwide. Price competition can result in lower profit and create a situation where more service stations go bankrupt.

The government may need to consider ways to avoid such a situation. Possible measures include a law prohibiting unfair bargaining and a law prohibiting radical methods of attracting customers. In addition, a system to subsidise the funds for business closure is also effective.

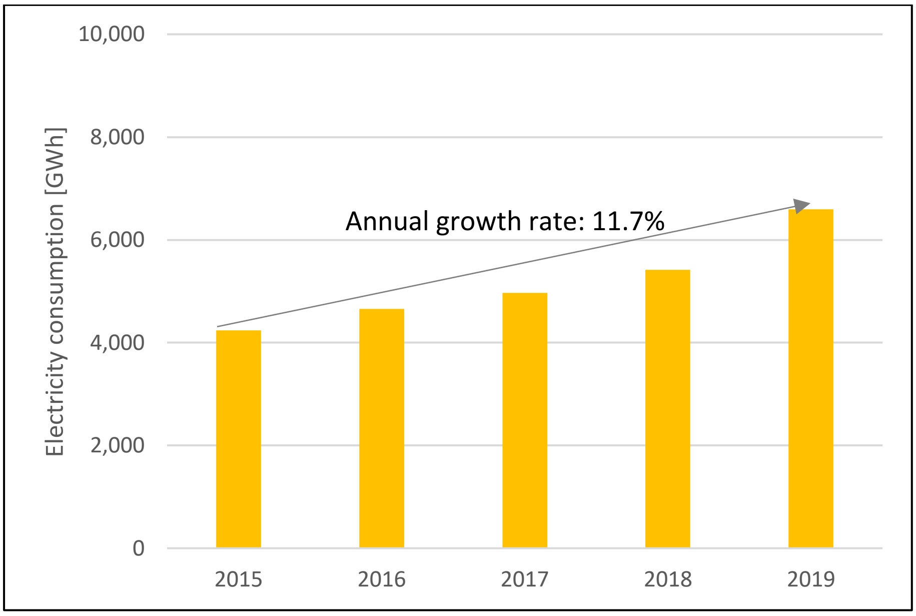
Chapter 5
Analysis on Impacts to the Power Sector

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%.

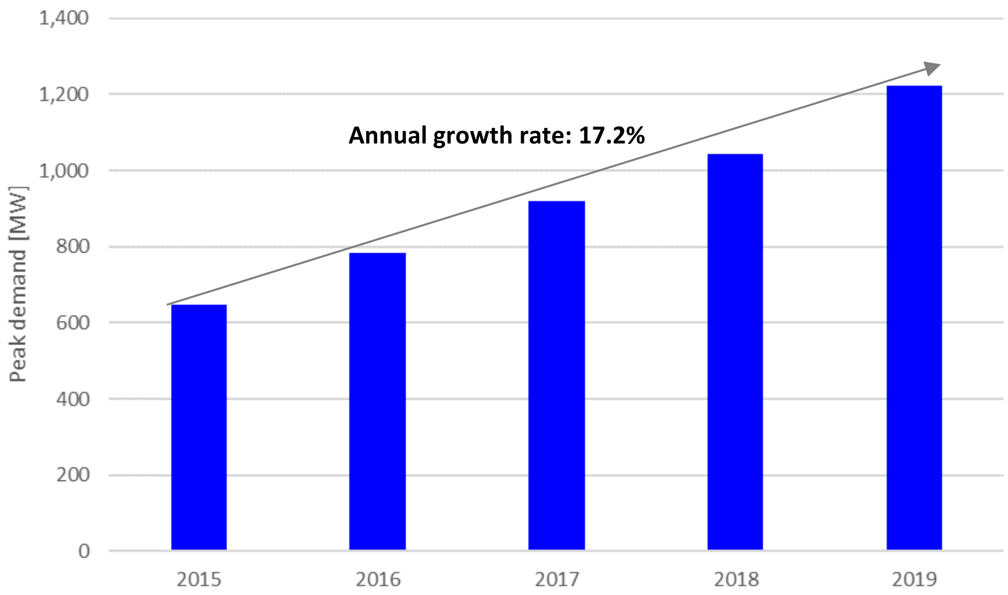
Figure 5.1: Changes in Electricity Consumption in Lao PDR



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%.

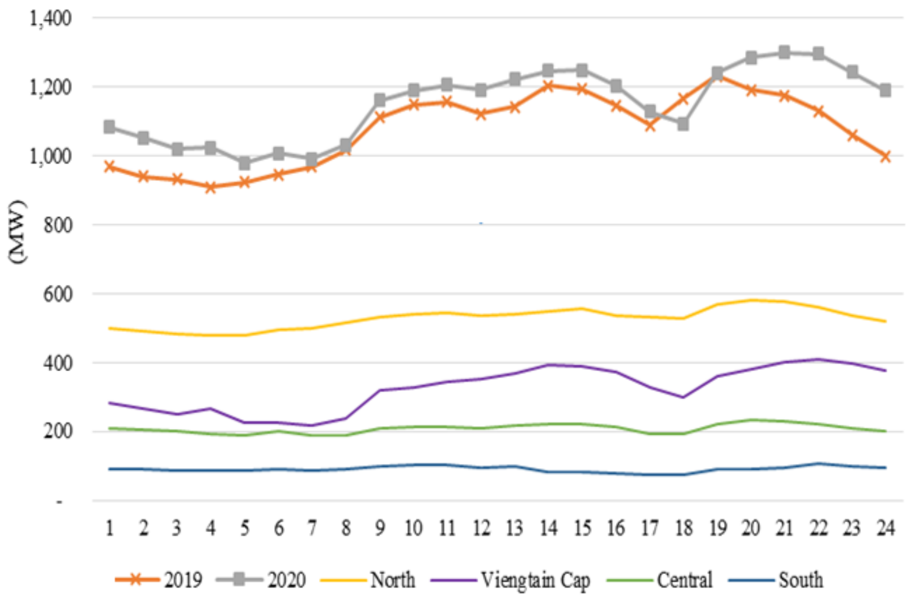
Figure 5.2: Changes in Peak Demand in Lao PDR



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

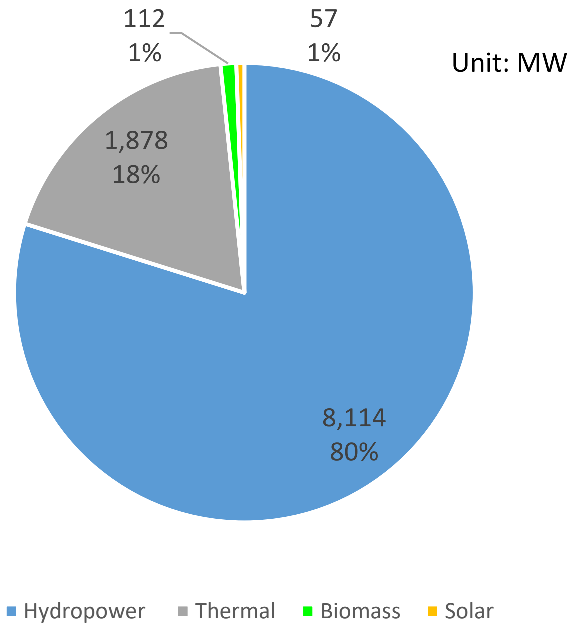


MW = megawatt.
Source: MEM data.

1.2. Power Generation

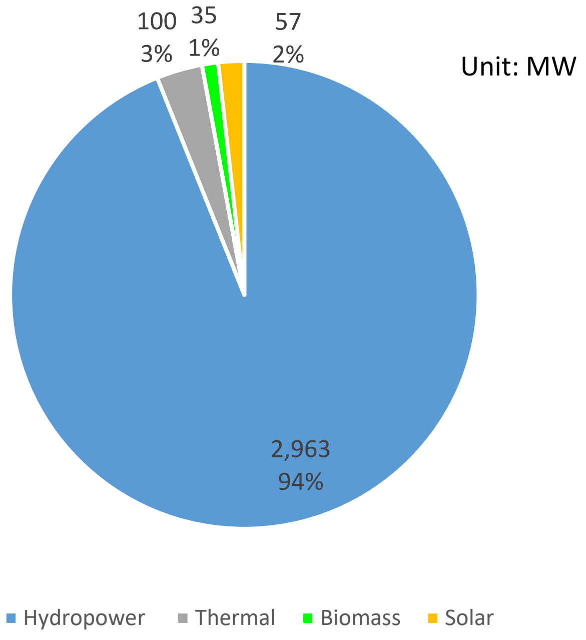
The Lao PDR has a large potential of hydropower generation. As of 2020, the total installed capacity in the Lao PDR was 10,161 MW, of which 3,155 MW was for domestic use. The total installed capacity portfolio in the Lao PDR and the total installed capacity portfolio for domestic use are shown in Figure 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.

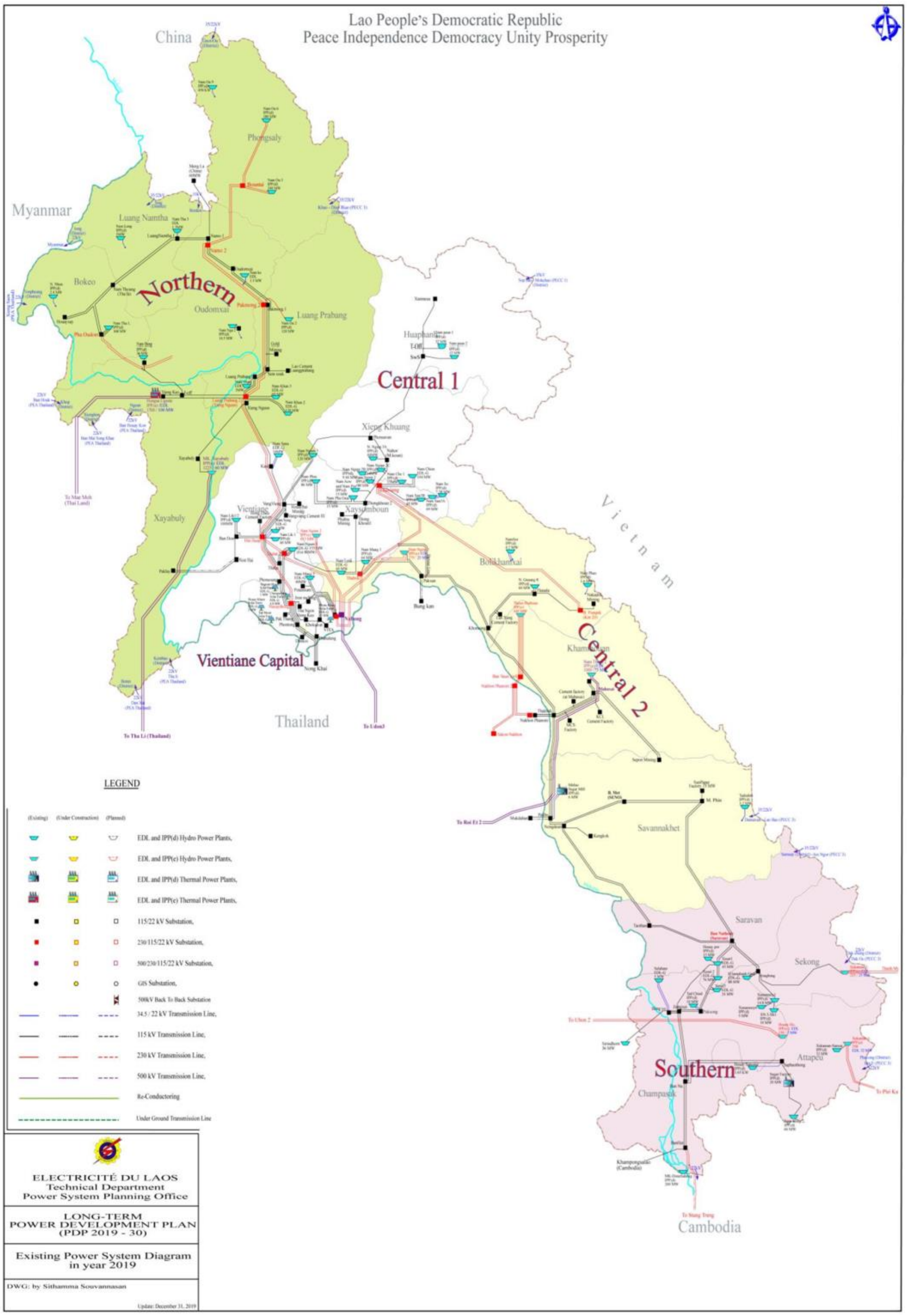
A map of the power system and interconnection lines in Lao PDR as of December 2019 is shown in Figure 5.6: Power Grid Map in Lao PDR. In addition, Table 5.1 shows the EDL transmission line and substation facilities (as of 2020).

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

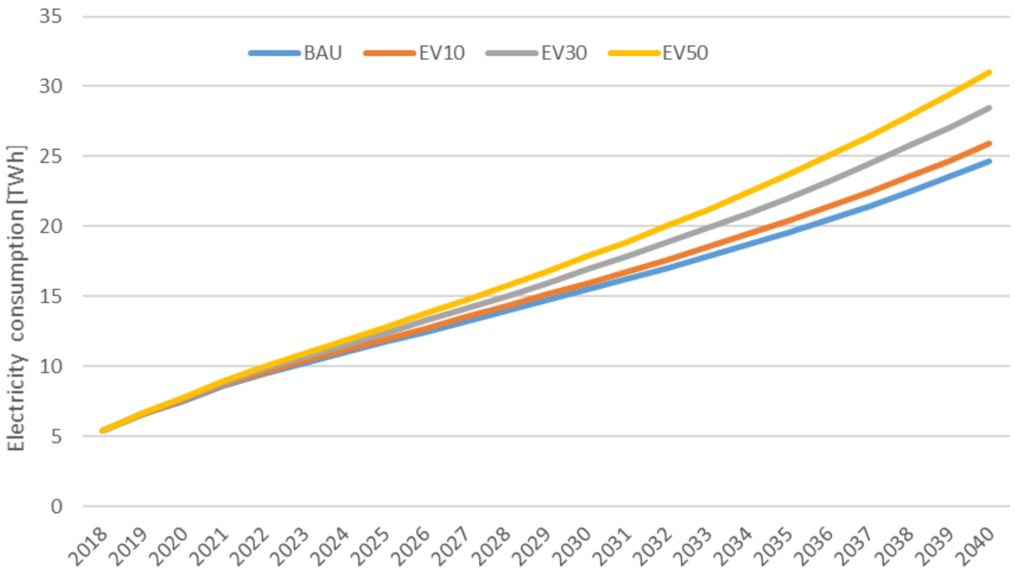


Source: MEM.

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.

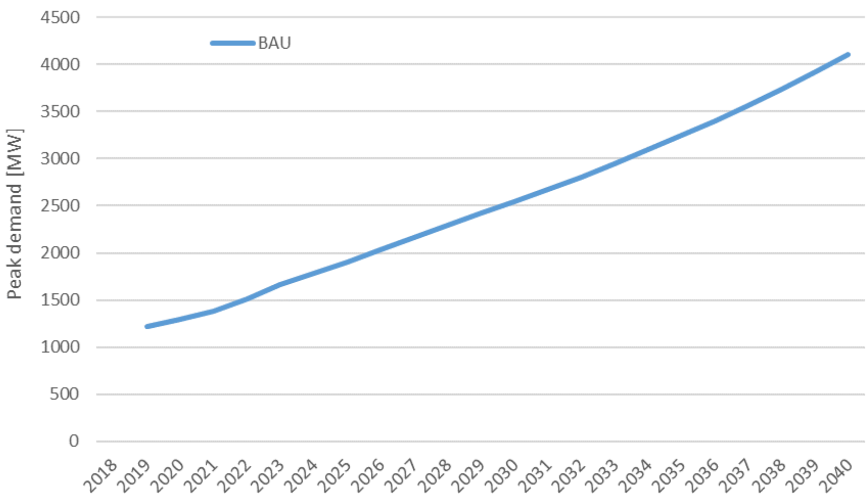
Figure 5.7: Electricity Consumption Forecast up to 2040



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	Hydro	265	Hydro
	200	Solar	200	Solar
2023	305	Hydro	305	Hydro
	30	Solar	30	Solar
2024	52.8	Hydro	52.8	Hydro
	100	Solar	100	Solar
2025	30	Hydro	30	Hydro
	300	Thermal	300	Thermal
2026	290	Hydro	322	Hydro
2027	120	Hydro	120	Hydro
			200	Solar
2028	200	Hydro	200	Hydro
	25	Solar	25	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

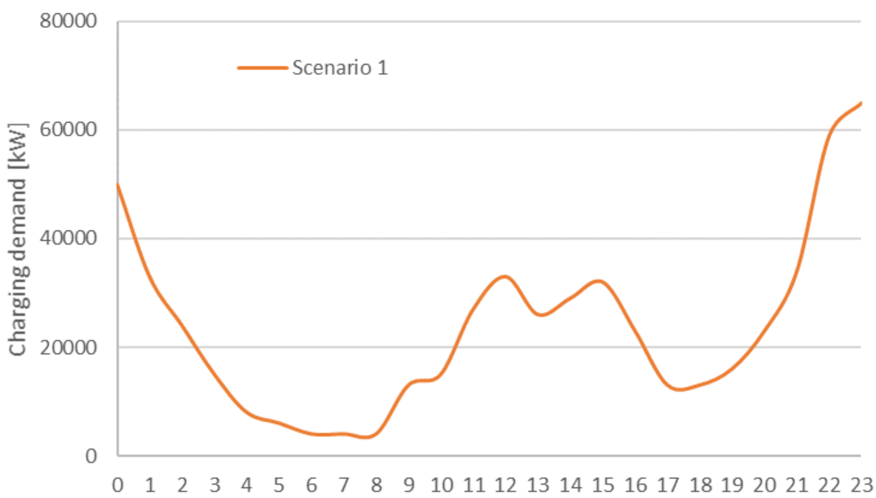
The EV charging power demand changes greatly from hour to hour depending on people's lifestyles. For example, in private cars, people use EVs during the day and charge them after returning home. Thus, the peak charging demand will occur after the evening. Furthermore, if there is a discount on electricity 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.

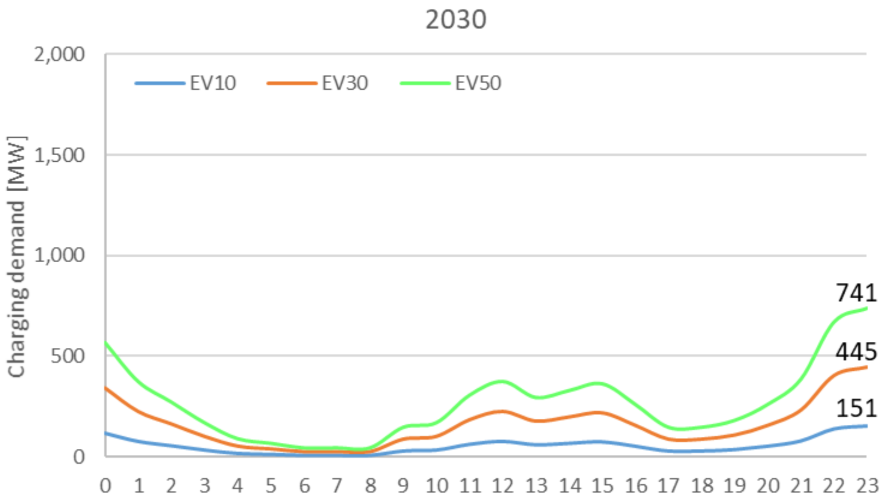
Figure 5.9: Assumed Charging Power Demand Profile



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

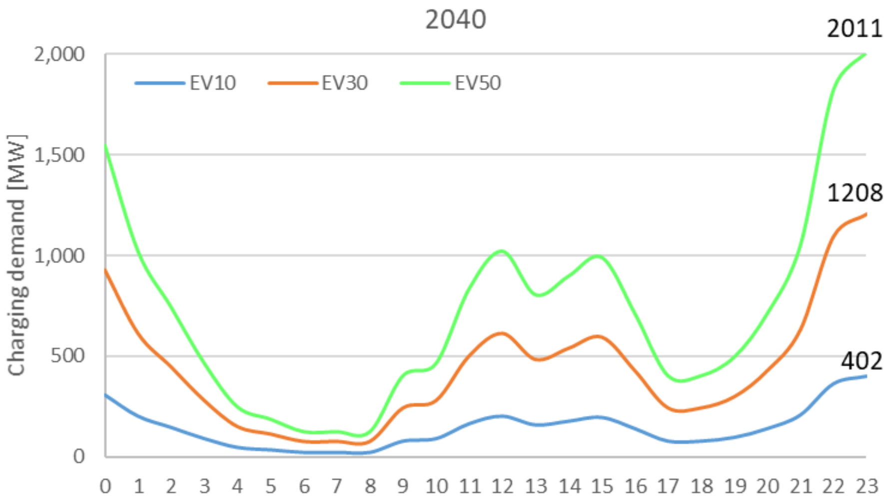
Next, based on the assumed profile, the study estimated the daily charging demand profile in the Lao PDR. The daily charging demand profiles for 2030 and 2040 are estimated as shown in Figure 5.10 and Figure 5.11.

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

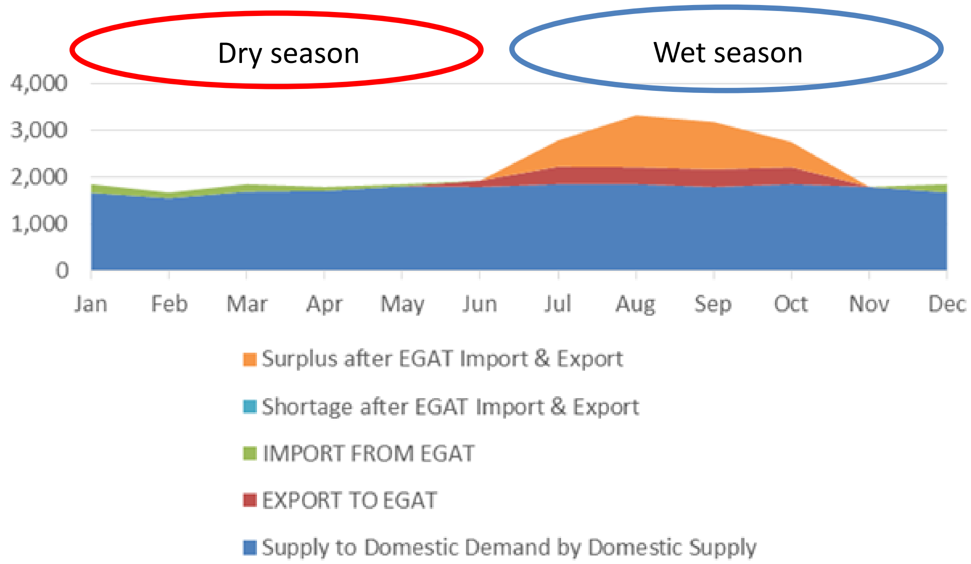
In this section, the study will analyse the required power generation, transmission, and distribution networks to meet the increased power demand due to EV penetration. Then the study will estimate the required cost. In addition, the study will estimate the number of new employment positions expected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

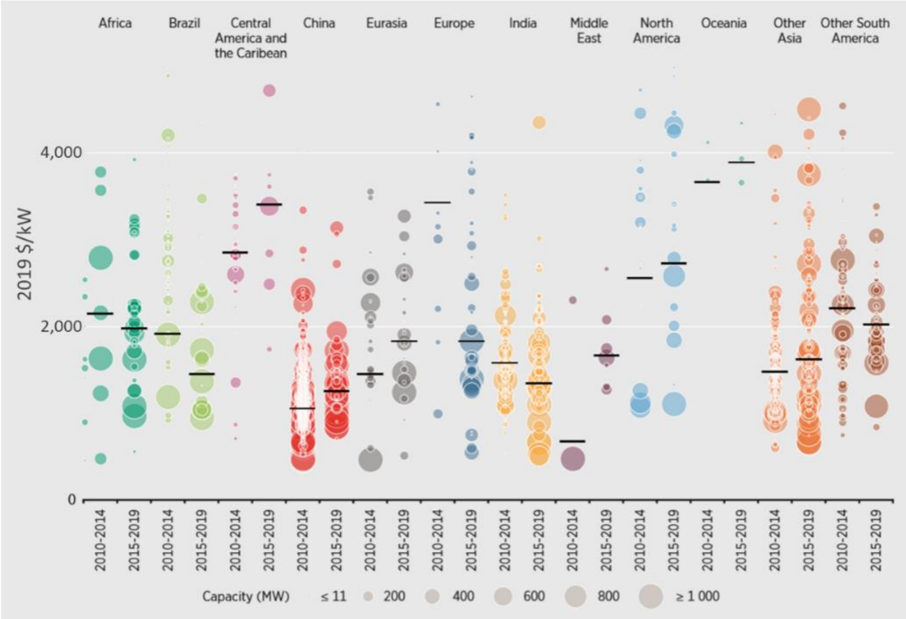
❖ The capacity factor of solar power was 17%. (JICA, 2019)

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).

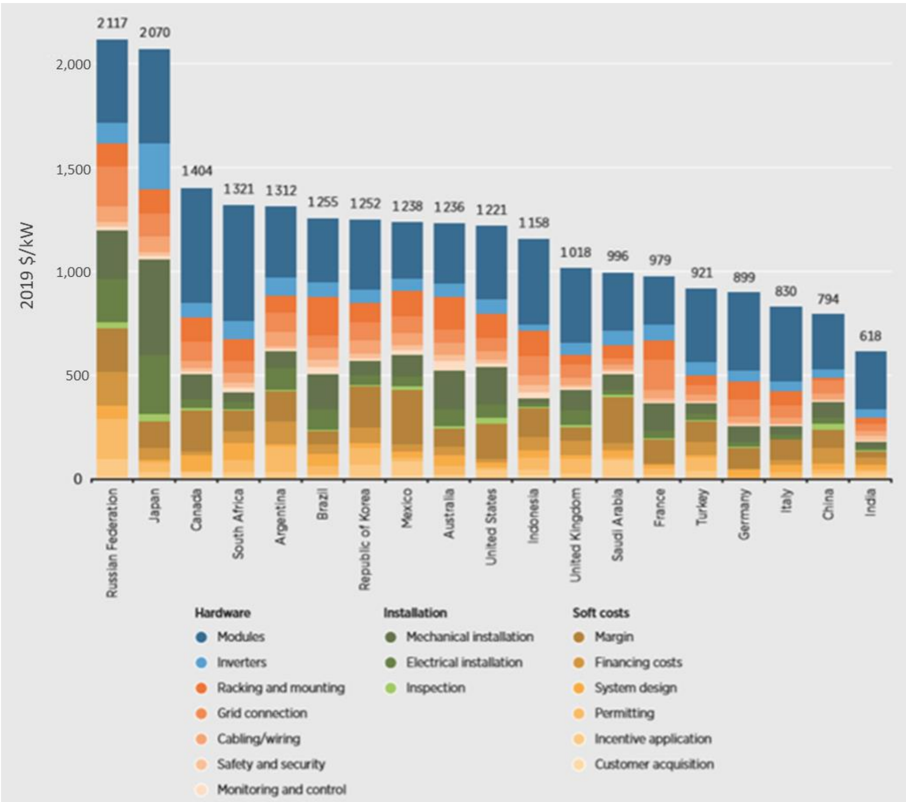
❖ The study referred to the installation cost of China for the calculation of the construction cost of hydropower plants and solar power plants (Figure 5.14).

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

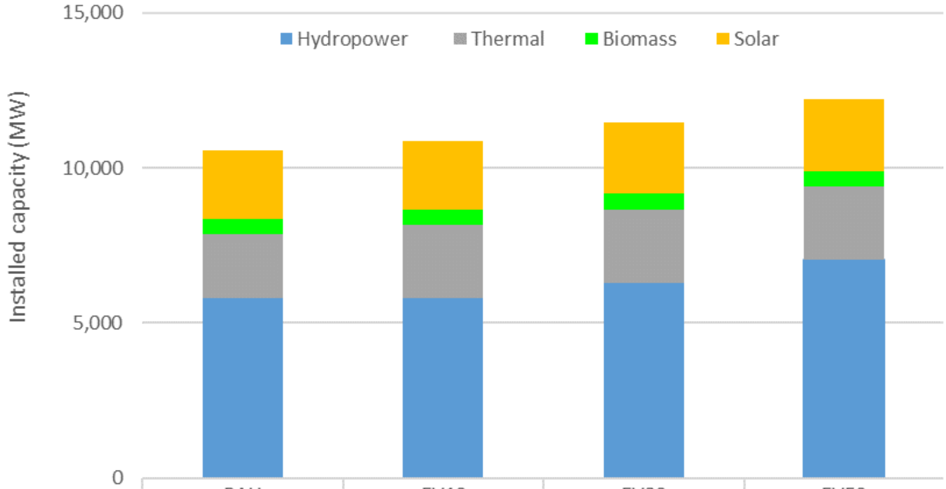
MW = megawatt.
Source: Authors.

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.

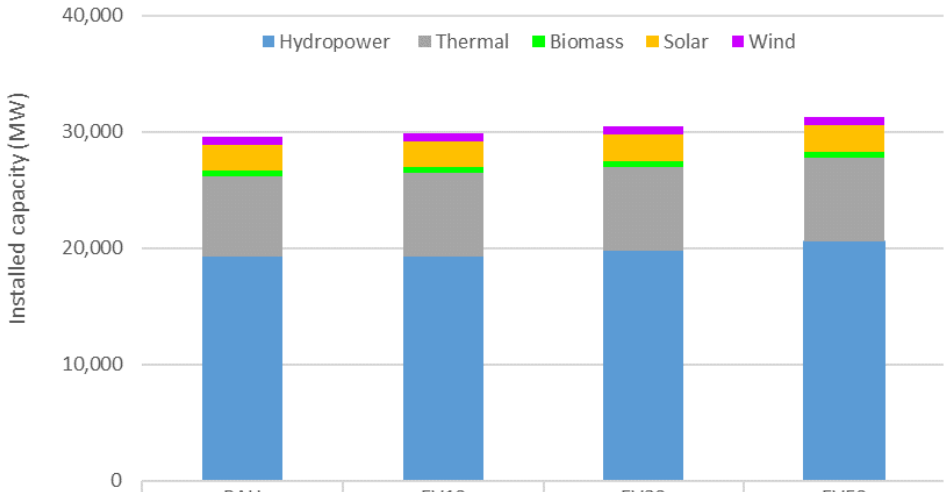
Figure 5.15: Installed Capacity of Case 1 of Domestic Use in 2040



	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.

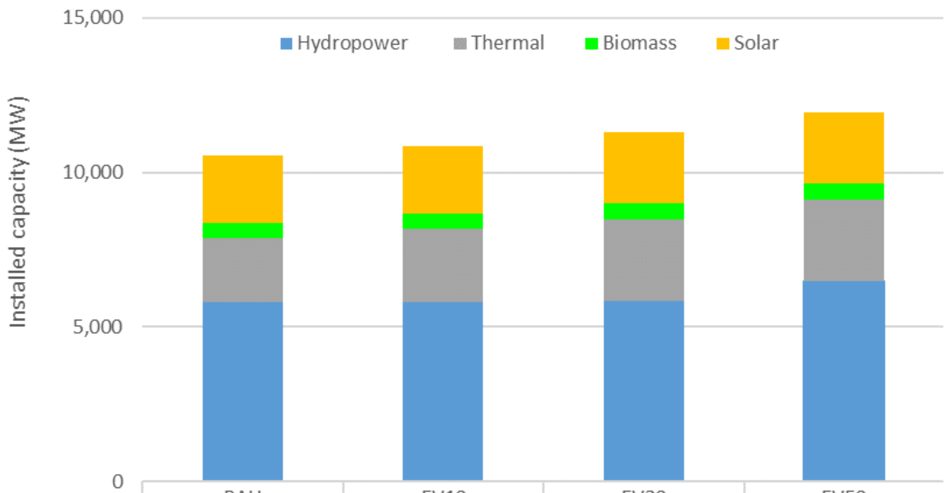
Figure 5.16: Installed Capacity of Case 1 of Whole Country in 2040



	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.

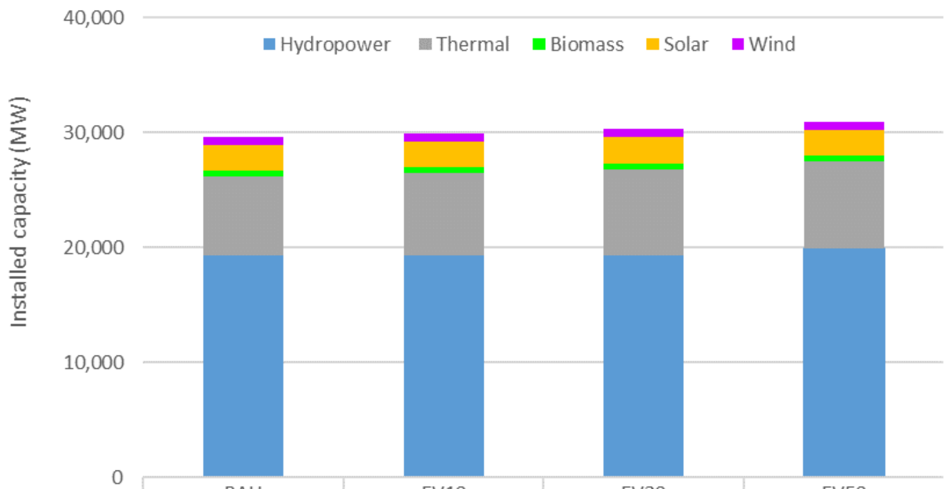
Figure 5.17: Installed Capacity of Case 2 of Domestic Use in 2040



	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.

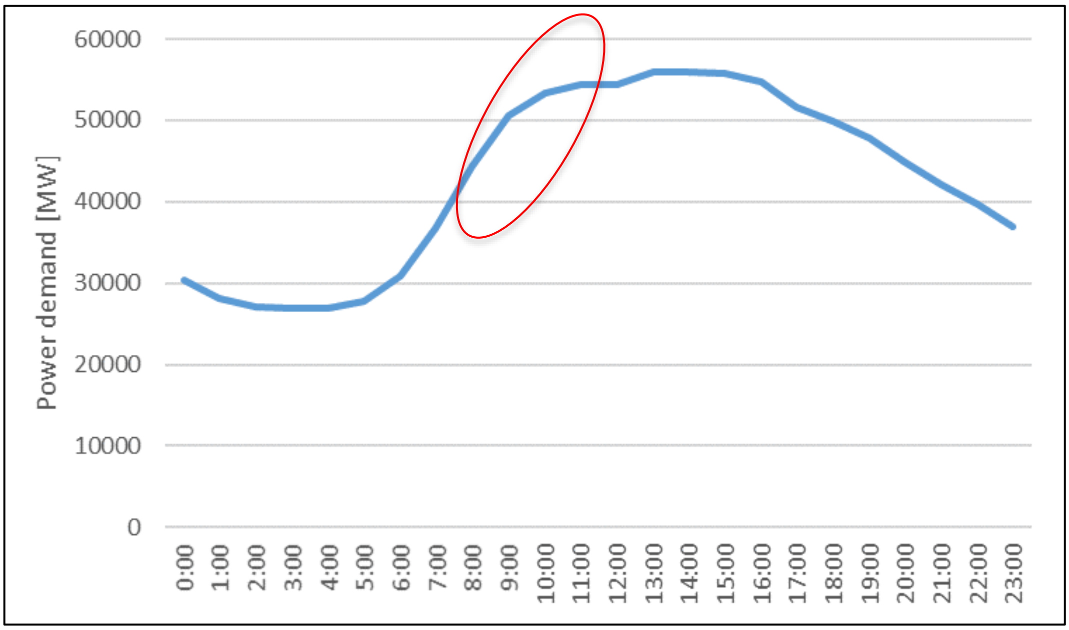
Table 5.22: Ratio of the Change Rate of Charging Power to the Total Demand in Thailand and Lao PDR

	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

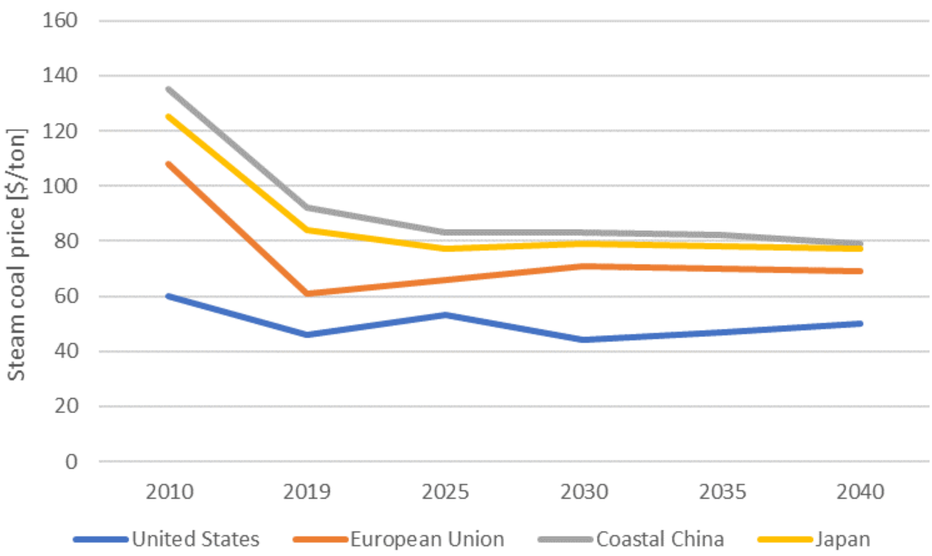
The study has analysed the costs of required generation capacity, and transmission and distribution networks in response to the increase in power demand due to EV penetration. Comparing Case 1 in which only hydropower is added to the draft NPDP EV case and Case 2 in which 300 MW of thermal power and 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.

Chapter 6

Key Findings and Recommendations

1. Key Findings

Chapters 1 and 2

- Economic rationality could not work for penetration of electric vehicles (EV) in the Lao PDR due to less cost competitiveness of EVs, thus policy support is indispensable such as:
  - After 2030, only EVs will be allowed to be imported out of the Lao PDR
  - By 2030, the number of EV charging stations will be more than 10,000 units in the whole Lao PDR as a national target
- In this regard, this study applies three scenarios of EV penetration in the Lao PDR: 10%, 30%, and 50% of EV share per total vehicle stock by 2040. Based on the scenarios, this study forecasts a decrease in gasoline and diesel oil demand by 2040 as well as an increase in electricity demand coming from EVs for analysing impacts to be brought by EV penetration in the Lao PDR:
  - Decrease in oil demand in 2040
  - EV 10%: –284 ktoe
  - EV 30%: –853 ktoe
  - EV 50%: –1,460 ktoe
  - from 2,943 ktoe of petroleum demand in the road transport sector in the business-as-usual (BAU) scenario
  - Increase in electricity demand in 2040
  - EV 10%: +110 ktoe
  - EV 30%: +331 ktoe
  - EV 50%: +551 ktoe
  - from 2,078 ktoe of electricity demand in the total financial energy consumption (TFEC) of BAU
- The penetration of EVs will need EV charging stations and having only a few charging stations will not contribute to EV penetration, leading to the chicken-and-egg dilemma. If the government adopts an EVEV penetration policy, it will face this dilemma.

Chapter 3

- EV penetration in the Lao PDR will bring a large reduction in oil consumption such as gasoline and diesel oil. On the other hand, it will increase electricity demand for EVs. As a result, the TFEC will decrease 12% from the BAU scenario in the case of the EV 50% scenario. Thus, EV penetration will contribute to energy saving in the Lao PDR.
- EV penetration in the Lao PDR will bring a large reduction in CO_2 emissions due to a large decrease in oil consumption, but CO_2 emissions from additional power generation for EVs will depend on the power generation mix:
  - In the case of 100% hydropower generation: Total emissions will be much lower than the BAU scenario (8.2 Mt-C of EV 50% from 9.4 Mt-C of BAU)
  - In the case of 100% coal-fired power generation: Total emissions will be bigger than in the BAU scenario (10.3 Mt-C of EV 50%)
  - In the case of 50% hydropower and 50% coal-fired power generation: Total emissions will be slightly lower than in the BAU scenario (9.2Mt-C of EV 50%)
- EV penetration will contribute to improve energy supply security of the Lao PDR because the volume of imported transport fuel will decrease. On the other hand, domestic energy such as hydropower and coal will increase.

Chapter 4

- EV penetration in the Lao PDR will bring several negative impacts to oil companies in the Lao PDR due to the decrease in oil demand:
  - Revenue of the oil companies will decrease compared to BAU
  - In the case of the EV 50% scenario, gasoline and diesel oil demand will saturate around current level (2018) up to 2040, thus an expansion of the transport fuel market in the Lao PDR will not be expected.
  - In other words, existing oil companies will be able to survive because the current market volume will be maintained. But they will face severe competition due to limited oil market volume.
- Looking at the macroeconomic situation, imports of transport fuel will decrease, so that outflow of national welfare will be saved. In the case of the EV 50% scenario**,** the gross domestic product will be forecast to increase to around 2.4% in 2040 compared to BAU.

Chapter 5

- EV penetration in the Lao PDR will bring several positive impacts to the electricity sector due to an increase in electricity demand:
  - Investment to additional power plants by Electricité du Laos and independent power producers
  - Capacity of hydropower, coal, solar PV, and wind will be expanded.
  - Around $2,000 million will be needed for the construction of additional power plants in the case of EV50.
  - Investment to transmission and distribution lines
  - Around $1,300 million will be needed for strengthening the transmission and distribution networks due to an increase in electricity demand in the case of EV50.
  - As a result, a total of $3,300 million will be needed to support the increase in electricity demand in the case of EV50.
- EV penetration will also expect the need for additional employees to engage in the electricity sector which are power plants, and transmission and distribution networks:
  - 2,600–3,600 employees per year

2. Recommendations

- The penetration of EVs needs government support through setting up appropriate EV policies with the support of the international community.
- EV charging stations will be essential if the Lao PDR increases the number of EVs.
- The penetration of EVs is appropriate for the Lao PDR due to the following expectations:
  - Energy saving
  - CO_2 reduction, with attention to the power generation mix
  - Improvement of energy supply security
  - Moderate negative impact to oil companies but severe competition in the oil market in the Lao PDR
  - Increase of gross domestic product due to oil import saving
  - Huge investment in the power sector ($3.300 million)
- Application of foreign investment is a wise policy for the Lao PDR because of the need for huge investment for EV penetration but applies to power plants like independent power producers. For transmission and distribution networks, EDL and the Ministry of Energy and Mines should invest separately in order to maintain national security off of power supply.

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