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Lao PDR Energy Outlook 2020

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ENERGY AND MINES

Lao PDR Energy Outlook 2020

Economic Research Institute for ASEAN and East Asia (ERIA)

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Foreword

The Lao People's Democratic Republic (Lao PDR) has achieved remarkable high economic growth. Its average gross domestic product (GDP) growth rate was 7.79% during the period 2000–2016, the highest growth rate amongst the Association of Southeast Asian Nations (ASEAN) member states during the same period. In 2016, its real GDP per capita was US$2,352. This strong economic growth in the 6 years from 2000 to 2016 was also accompanied by an increase in energy consumption by all sectors. To facilitate the energy policy planning of the Lao PDR, the Ministry of Energy and Mines with technical and financial support from the Economic Research Institute for ASEAN and East Asia (ERIA) successfully launched the *Lao PDR Energy Statistics 2018*, providing overall energy information about energy demand and supply. The data and statistics have greatly benefited the policy planning in areas of energy efficiency, renewable energy, and best energy mix to maintain energy security. As the Ministry of Energy and Mines and involved agencies continued to collect the updated energy data with the support from ERIA, it has facilitated technical staff from the Ministry of Energy and Mines and ERIA's experts to produce this *Lao PDR Energy Outlook 2020*.

As the Lao PDR continues to rely on electricity exports, hydropower and renewable energy will play a crucial role in the country's energy sustainability. It is also important to note that the Lao PDR's reliance on fossil fuel imports to meet the growing energy demand in the transport and industry sectors will need to be diversified to other possible fuel mixes such as the introduction of electric vehicles as the country has abundant electricity produced from hydropower and coal-fired power plants.

On behalf of the Ministry of Energy and Mines, I am very grateful for the technical and financial support for this *Lao PDR Energy Outlook 2020* project. We will continue to consult with ERIA to build the energy data to support energy policies and planning in the Lao PDR.

Dr Khammany Inthirath

Minister of Ministry of Energy and Mines, Lao PDR

December 2019

Acknowledgements

I express my sincerest gratitude to the members of the working group of the *Lao PDR Energy Outlook 2020* for their tireless efforts in collecting, updating, and estimating the results of the Lao PDR's energy outlook and preparing this publication. The working group consists of experts from the Department of Energy, Policy and Planning of the Ministry of Energy and Mines and other line ministries, and the Economic Research Institute for ASEAN and East Asia (ERIA). The working group has been actively contributing their time and expertise to this publication after successfully launching the *Lao PDR Energy Statistics 2018*. I hope this energy outlook will help energy planners and policymakers in preparing appropriate energy policies to meet the growing energy demand and prepare policies to attract investment in sustainable power development and energy-related infrastructure. I would also like to express my gratitude to the Lao State Fuel Company, Électricité du Laos, the Ministry of Industry and Commerce, the Lao National Chamber of Commerce and Industry, the Department of Aviation, Lao Airlines, Lao Skyway, the Ministry of Agriculture and Forestry, the Department of Tax, Ministry of Information, Culture and Tourism, and other ministries and agencies for providing data and information and for their cooperation.

I give special thanks to Mr Shigeru Kimura of ERIA and his team for their excellent contributions to this project.

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Executive Summary

The Economic Research Institute for ASEAN and East Asia (ERIA) has been supporting the Ministry of Energy and Mines (MEM), the Lao People's Democratic Republic (Lao PDR) to produce *Lao PDR Energy Statistics* since 2017 for analysing the historical energy demand supply situation. In addition, for analysing the future energy demand supply situation of the Lao PDR, ERIA started to support MEM in the development of the Lao PDR energy outlook model applying an econometric approach (economic activities influence to energy consumption) in 2018. The development of the Lao PDR's energy outlook model applied the following seven steps:

1. Preparation of macroeconomic data and energy demand supply data
2. Estimation of energy demand formulas using the ordinary least square method (regression analysis)
3. Development of future simulation models using the Long-range Energy Alternatives Planning System (LEAP) (sequential method and producing energy balance tables automatically)
4. Development of macroeconomic model assumptions for future economic growth and energy development plans
5. Finalization of the Business-As-Usual (BAU) scenario result
6. Conducting case studies
7. Evaluation of results of the BAU scenario and the case studies and extraction of policy implications

Consequently, ERIA held three working meetings with staff from the Department of Energy Policy and Planning, the Department of Planning and Corporation, as well as Électricité du Laos, and the Laos State Fuel Company. The first meeting covered steps 1–2, while steps 3–4 were covered at the second meeting using LEAP. The third meeting implemented steps 5–7. This energy outlook modelling of the Lao PDR also had the role of capacity building for staff of MEM. The major outcomes from the energy outlook modelling of the Lao PDR follow.

Total final energy consumption (TFEC) in the BAU scenario increased at an average 4.7% per year over 2015 to 2040 under the gross domestic product (GDP) assumption at 6.2% per annual in the same period. The industry sector grew the fastest (8.3%), followed by the transport sector (6%) and 'others' (1.3%). The low growth in the 'others' sector (consists of residential, commercial, agriculture, fishery and forest sectors) is due to the diversification of energy from traditional biomass to electricity, liquefied petroleum gas, and efficient biomass cooking stoves in the residential sector. In terms of the energy type, electricity will grow the fastest at 8.1%, followed by coal at 7.7%, and oil at 6.1%.

Electricity generation will increase to 70 terawatt hours (TWh) by 2040 from 17 TWh in 2015 at an average growth rate of 5.8% per year. Around 53% of the electricity generated will meet the export target, particularly of Thailand. Hydropower sources will remain dominant in the country's power generation but with a declining share, accounting for around 77% in 2040 compared to 85% in 2015. The remaining share will be those of coal resources (22%) and other renewables (1%).

The total primary energy supply (TPES) will reach 13 million tons of oil equivalent (Mtoe) in 2040, increasing at an average rate of 4.4% per year from 2015. As a major supply for power generation, hydropower sources will increase at an average rate of 8.7% per year over the projection period. Coal will also have an important share in power generation as well as industry. Its growth rate will on average be 4.5% per year. Oil will grow at an average rate of 6.1% per year to meet particularly the fuel demand of road transport.

As a result, carbon dioxide (CO_2) emissions of the BAU scenario in 2040 will be four times the 2015 level due to increases in coal consumption by industry and in power generation.

After the opening of the Hongsa coal-fired power plant, which uses domestic coal such as lignite, the import dependency of the Lao PDR has improved, but on the other hand, its CO_2 emissions have also increased. According to the BAU results, coal-fired power generation will increase by up to 22% of total power generation in 2040. Currently all electricity generated by the Hongsa power plant is exported to Thailand, so that if the Lao PDR stops the electricity export to Thailand, this CO_2 issue will be eliminated. But electricity to be generated by coal in 2040 will include some domestic use, so that CO_2 from coal-fired power generation in the future will be issued. The energy outlook results suggest a controversial issue of coal-fired power generation in the Lao PDR.

To avoid this issue, Energy Efficiency (EE) and Renewable Energy (RE) policies will be very important for the Lao PDR. According to the case studies, if the Lao PDR could achieve high EE targets, TFEC including electricity consumption will decrease 20% and CO_2 emissions will also reduce 15% compared to BAU. The promotion of EE will reduce coal demand in the industry sector and power generation through the reduction of electricity demand across the sectors as well as oil demand in the industry and transport sectors. If the Lao PDR could achieve high RE targets, CO_2 emissions will decrease 45% from the BAU scenario. This reduction will come from a decrease in coal-fired power generation as well as coal consumption (three times more due to thermal efficiency). The combination of EE and RE promotion policies will contribute to the mitigation of CO_2 emissions in the future.

The Lao PDR depends on the import of petroleum products from neighbouring countries such as Thailand. The main use of petroleum products are transport fuels such as gasoline, diesel oil, and jet fuel but the majority is gasoline and diesel oil. According to the energy outlook, the Lao PDR will still depend on petroleum products and its share to the TFEC will be more than 40% in 2040. One option for the Lao PDR to reduce the import of petroleum products such as gasoline and diesel oil will be the use of electric vehicles (EVs). If EVs use electricity from hydropower in the Lao PDR, the country will be able to reduce the import of gasoline and diesel oil as well as saving the outflow of the Lao PDR's national wealth. In addition, the

Lao PDR will also greatly reduce CO_2 emissions from a decrease in transport fuel consumption. But it is challenging for the Lao PDR because the investment needed in infrastructure to support EVs such as electricity charge stations will be huge. In addition, EVs need lots of additional electricity, so that the Lao PDR itself will have to construct hydropower plants for its own use. It will also need huge sums of money. In this regard, appropriate financial mechanisms provided by international financial institutions such as the World Bank, the Asia Development Bank, the Clean Development Mechanism, and the Joint Carbon Mechanism will be investigated.

Chapter 1

Introduction

Han Phoumin

1.1 Background

The Lao People's Democratic Republic (Lao PDR) is in the middle of the Southeast Asian peninsula. It is bounded by five countries: China in the north, Viet Nam in the east, Cambodia in the south, and Thailand and Myanmar in the west. The Lao PDR has a total area of 236,800 square kilometres, about 70% of which is covered by mountains. In 2017, the country had a population of 6.787 million people, with an average population density of 28.66 persons per square kilometres (Lao Statistics Bureau, 2017). The country's geographical administration comprises 18 provinces, with Vientiane as the capital.

Since the country shifted to an open-door economic policy in 1986, the Lao PDR has experienced rapid growth and poverty reduction through its openness to trade, investment, and integration to the regional and world economies. The gross domestic product (GDP) in 2015 increased 7.56% from the previous year, increasing to KN39,647 billion at 2010 constant prices (Lao Statistics Bureau, 2017). This is equivalent to US$140,814 million, bringing the per capita income to US$1,628. The economy has been gradually changing from agricultural-oriented activities to a wider range of activities such as services and industry. While electricity generation is expected to increase due to large investments in the mineral and hydropower sectors, the construction business is benefiting from foreign direct investment in hydropower and transport projects, such as the railway line from Vientiane to the border with China, which is under construction and almost completed.

The population and sustained economic growth are the main contributing factors to the increasing energy demand in the Lao PDR. Also, the fast connectivity in terms of the electricity grid extension to remote areas brings additional demand in tandem with increasing per capita income.

1.2 Energy Supply–Demand Situation

The Lao PDR is relatively well endowed with renewable energy resources, especially hydropower and biomass. Since 1990 hydropower resources are being intensively developed to provide electricity for the requirements of the country and neighbouring countries. Every year the Lao PDR receives a significant amount of hard currencies from those power exports, widely considered as a driving force to boost socioeconomic development and the energy security of the country.

The total primary energy supply (TPES) of the Lao PDR increased from 1,618 thousand tons of oil equivalent (ktoe) in 2000 to 4,765 ktoe in 2015 at an average annual growth rate of 7.5%. Coal had the highest increase over the 2000−2015 period at an average of 42.2% per year. This is because the Hongsa coal-fired power plant started full production in 2015, resulting in a significant increase in coal supply that year. The Hongsa power plant was constructed only for export purposes to Thailand. The second-highest growth during 2000−2015 was hydropower at 9.8% per year. Hydropower is the major energy source for electricity production in the Lao PDR. Petroleum supply also increased rapidly at an average of 8.5% per year. Since the power sector does not use oil products, most of the increased demand came from the transport sector. The Lao PDR exports most of its electricity products to Thailand. However, it also imports from neighbouring countries to meet demand during the dry season and at the border areas not connected to the grid. The Lao PDR's TPES, which reflects the net trade of electricity (import minus export), shows a negative value, making the Lao PDR a net electricity exporting country. Its electricity supply grew from 225 ktoe in 2000 to 817 ktoe in 2015, reflecting an almost fourfold increase in electricity export over the 15-year period. In 2000, biomass had the largest share in the TPES at 78%, followed by petroleum (15%), hydropower (5%), and coal (0.5%). Coal grew rapidly, increasing its share in the TPES to 33% by 2015 due to the opening of the Hongsa coal-fired power plant in 2015.

Biomass continues to be an important energy source, and is mostly consumed in the rural areas. In places where modern energy is inaccessible, the Lao PDR people use biomass as a main source for cooking, heating, and other activities because it is abundant, obtainable everywhere, and mostly free. In 2015, 1.30 million tons of oil equivalent (Mtoe) of biomass, representing 13.7% of the TPES, was used. The slower growth of biomass supply indicates that there was a substitution from biomass for cooking in the residential sector to liquefied petroleum gas. The share of the other supplies increased, but not as drastically as that of coal. Hydropower's share increased to around 9% by 2015, while the share of petroleum products reached 20%. The Lao PDR started generating electricity from solar energy in 2014, but the amount remained small.

The consumption of oil products was the second largest after biomass. The Lao PDR does not have oil refineries; thus, the demand for oil products has been met by imports from Thailand and Viet Nam. In 2015, the Lao PDR imported 0.99 Mtoe of oil products to supply the demand from the transport and other sectors. In the same year, 6.49 Mtoe of coal was consumed, mainly by the power generation sector, i.e. the Hongsa power plant, which is the first and largest coal-fired power plant that started operation in 2015. Therefore, from 2015 onwards, coal demand is expected to increase sharply.

Due to its geographic advantage and its many rivers, the Lao PDR is a rich country in terms of hydropower resources. According to the Mekong River Commission's *State of the Basin Report 2018* (MRC, 2019), the potential of the country's hydropower resources is 26,000 MW. However, until 2015, only 3,894 megawatts (MW) or 15% of the total potential had been realized. In 2015, it produced around 16,501 gigawatts per hour (GWh) of electricity (Department of Energy Policy and Planning, 2015). Out of this, 65.7% (equivalent to 10,842 GWh) had been exported to Thailand, Viet Nam, and Cambodia; the remainder was consumed domestically. Power exports are projected to increase sharply because of the government's agreements with neighbouring countries that, by 2020, the Lao PDR should export 7,000 MW to Thailand and 5,000 MW to Viet Nam. In addition, in 2018 three hydropower projects are being constructed for the export of power. All export projects are being developed by foreign private investors through the build−operate−transfer scheme.

The power sector plays a major role in the energy sector, as well as in the country's economy, as it generates substantial revenues for the country. The revenues may not be significant in the short to medium term, but for the long term, they will be high or will increase many fold because the ownership of the private power plants will be transferred to the government. The electrification ratio in the Lao PDR is 88.94% in 2015 (Department of Energy Policy and Planning, 2015). The government plans to raise the country's electrification ratio to 95% in

2020. This plan is amongst the government's priorities to eradicate poverty in the country. Considering the increase of electricity demand in the Lao PDR and power production for export, optimisation of the power sector will pay attention to future electricity supply.

1.3 Energy Policies

Since the establishment of the Ministry of Energy and Mines in 2006, energy infrastructure is being developed and expanded. Also, energy policies are being developed and gaining public attention and support. The policies have gradually evolved from just the power sector policy to broader energy policies and the development of a sustainable and environment-friendly energy sector. The improvement of energy policies could be credited to the strong support from the Association of Southeast Asian Nations (ASEAN) and other international organisations, especially the Economic Research Institute for ASEAN and East Asia (ERIA) for their continued cooperation and support on energy policies of Cambodia, the Lao PDR, and Myanmar to catch up with other ASEAN countries.

The Lao PDR is a landlocked country in the middle of the Mekong subregion. It is surrounded by the three big economies of China, Thailand, and Viet Nam and the two medium economies of Myanmar and Cambodia. Thus, the Lao PDR can promote itself as a land-linked country to take advantage of its geography. Based on the energy policies exchanged in the platform of ASEAN energy cooperation, evidence shows that those countries have high energy demand and support the energy trade and power integration in this region because it can raise regional energy security and sustainable development. The Lao PDR has been trading electricity with Thailand for many decades; and now it expands this policy to other neighbouring countries to support regional energy cooperation. Particularly, the Lao PDR will increase power exports to 15,000 MW by 2030 – 10,000 MW to Thailand and 5,000 MW to Viet Nam, Cambodia, and Myanmar.

Apart from international cooperation, the Lao PDR also aims to:

- Increase access to electricity by grid extensions and off-grid rural electrification in which the target is to achieve the electrification rate of more than 95% by 2020.
- Maintain an affordable tariff to promote economic and social development.
- Promote energy efficiency and conservation.

- Make modern energy more affordable and accessible for every Lao PDR citizen, even in remote areas.
- Increase the share of renewable energy in total energy supply by 30% in 2030, including 10% biofuels in the oil supply for the transport sector.

The Lao PDR's energy outlook suggests appropriate energy policies and action plans to contribute to the achievement of the aims mentioned above.

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Mekong River Commission (MRC) (2019), *State of the Basin Report 2018.* Vientiane: Mekong River Commission.

Chapter 2

Methodology

Cecilya Laksmiwati Malik

2.1 Model Framework

Energy modelling involves the forecast of final energy consumption and the corresponding primary energy requirements or supply. Final energy consumption forecasts cover the industry and transport sector, as well as 'the Others' sector, which comprises agriculture, residential, commercial, and other sectors.

The Lao PDR energy outlook model was developed using the Long-range Energy Alternatives Planning System (LEAP)[1] software, which is an accounting system used to develop projections of energy balance tables based on final energy consumption and energy input and/or output in the transformation sector. Final energy consumption was forecast using energy demand equations by the energy sector and future macroeconomic assumptions.

The energy demand equations are econometrically estimated using historical data, while future values are projected using the estimated energy demand equations under given explanatory variables. An econometric approach means that future demand will be heavily influenced by historical relations between socioeconomic activities and energy demand. However, the supply of energy and new technologies is treated exogenously.

Microfit,[2] a macroeconomic software was used in estimating the demand functions. Microfit offers an extensive choice of data analysis options. It is a versatile aid in evaluating and designing advanced univariate and multivariate time series models. It is an interactive, menu-driven programme with a host of facilities for estimating and testing equations, forecasting, data processing, file management, and graphic display.

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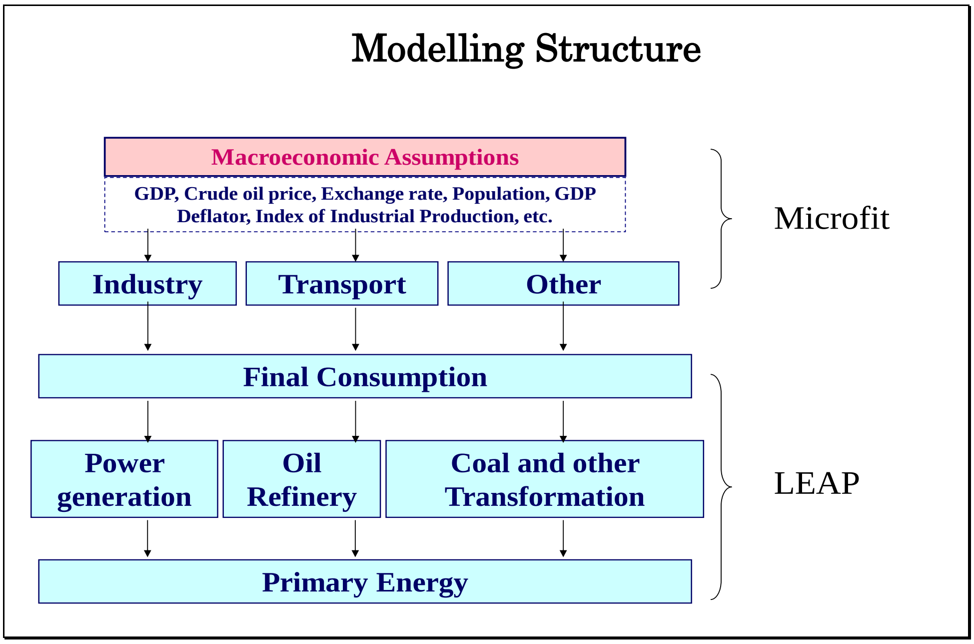
[1] LEAP or the Long-range Energy Alternatives Planning System is an energy policy analysis and climate change mitigation assessment software developed at the Stockholm Environment Institute. For more information see: http://www.energycommunity.org/default.asp?action=47

[2] For more information on Microfit, see http://www.econ.cam.ac.uk/people-files/emeritus/mhp1/Microfit/Microfit.html

Figure 2.1 showed the model structure from final energy demand projection and forecast of transformation inputs and/or outputs to arrive at the primary energy requirements including the computer software used in the modelling work.

Figure 2.1 Structure of the Lao PDR Energy Outlook Model

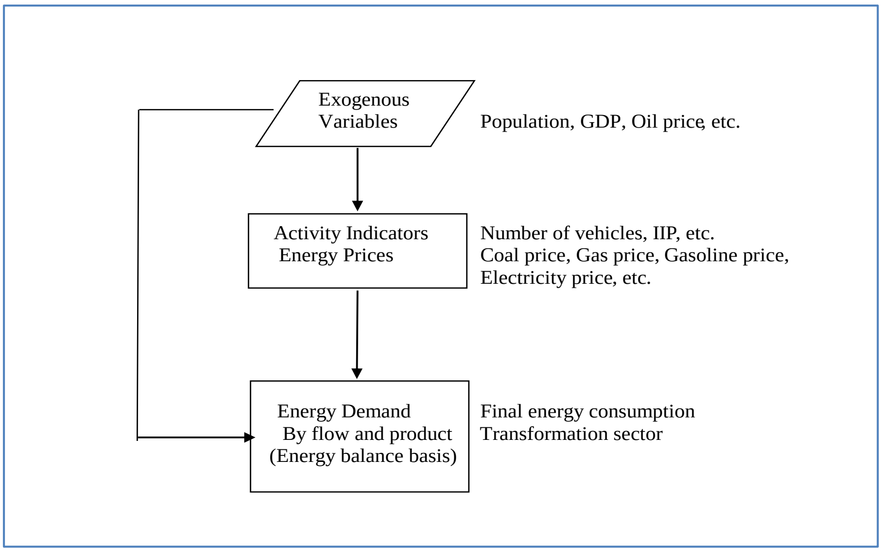


GDP = gross domestic product, LEAP = Long-range Energy Alternatives Planning System.
Source: Lao PDR modelling work.

2.2 Estimating Demand Equation

The future energy demand for various energy sources are forecast using assumed future values of the macroeconomic and activity indicators. The future values of these indicators were also derived using historical data when data are enough for such analysis. The overall concept of estimating the final energy demand equation is shown in Figure 2.2.

Figure 2.2 Process Flowchart of the Lao PDR Energy Outlook Model



GDP = gross domestic product, IIP = Index industrial production.
Source: Lao PDR modelling work.

In this process flowchart, energy demand is modelled as a function of activity such as income, industrial production, number of vehicles, number of households, number of appliances, and floor area of buildings. In the residential sector for example, the demand for electricity could be a function of number of households, disposable income, and penetration rate of electrical appliances. In the commercial sector, energy consumption could be driven by building floor area, private consumption, and other factors that encourage commercial activities.

Such relationships among variables were derived using linear regression. The basic formulation is:

$$\textit{Energy Demand (De)} = f(Y, Pe/PGDP, De_{-1})$$

where,

Y: Income (GDP, etc.)

Pe: Energy price (Oil price, etc.)

PGDP: GDP` deflator (Overall price, CPI, etc.)

Pe/PGDP: Relative variable

De: Energy Demand (Coal, oil, gas, and electricity)

De_{-1}: Lag variable (show habit)

As mentioned earlier, the regression analysis for the Lao PDR energy outlook was derived using Microfit. The derived econometric equations were used in the LEAP model to estimate future energy demand based on growth assumptions of the activity (independent) variables such as the gross domestic product (GDP).

In cases where regression analysis is not applicable due to insufficient data or there is a failure to derive a statistically meaningful equation, appropriate growth assumptions were used to forecast future demand.

2.3 Forecasting Primary Energy Requirements

Having forecast the future final energy demand, the corresponding primary energy requirements need to be projected. Some of these primary energy requirements are the inputs to transformation to produce secondary fuels. Energy transformation involves electricity generation, oil refining, gas processing, charcoal making, and any other process that converts fuels from primary energy to secondary products.

For the Lao PDR, only the primary requirements for electricity generation were considered in the transformation sector. There is a plan to construct an oil refinery in the future. Since no firm capacity was provided, the oil refinery was not included in this first energy outlook.

Electricity in the Lao PDR is mainly produced from hydropower plants. The Lao PDR also has coal, solar, and biomass power plants. The electricity generation process in the model calculated the fuel requirement to produce electricity. The calculation of the primary energy requirements for electricity generation involves the following steps:

- *Forecasting the total electricity generation requirements*

  The total electricity generation requirement is greater than the final electricity demand to cover the electricity consumption in the power stations and the expected losses in the transmission and distribution systems. The additional requirement for the Lao PDR was above 10% of the total final demand.

- *Forecasting electricity generation capacity requirements*

  This involves two processes. The first process is forecasting the total capacity requirement, which is the capacity needed to meet the peak demand. The total capacity requirement is the peak demand plus the assumed reserve margin which is a percentage of the peak demand. The reserve margin is the preferred amount of available capacity above the peak demand to ensure that there is no disruption in the supply.

The second process is determining the power plants that should be added when the total capacity of the existing power plants cannot meet the peak demand. This is not the case for the Lao PDR due to its vast hydropower potential. The Lao PDR has been developing a sizeable amount of its hydropower resources for export to Thailand. Its coal resources have also been developed mainly for export to Thailand. Biomass and solar capacities will be further developed in the future with some possibility of also developing wind power plants.

- *Forecasting generation by each type of power plant*

  Generation by individual type of power plants in the Lao PDR's energy model used the dispatch rule that will meet both the annual demand for electricity as well as the instantaneous demand for power in time slices of the year. Each power plant will be run (if necessary) up to the limit of its maximum capacity factor in each dispatch period.

2.4 Estimating Fuel Inputs

Finally, the information of electricity generation together with conversion efficiency variables or the thermal efficiencies are used to calculate the input fuels required by power plants. This can be derived from the simple formula below:

$$Fuel\_Input_i = \frac{Electricity\_Generation_i}{Efficiency_i}$$

2.5 Case Studies and Scenarios

The Lao PDR outlook examined the Business-As-Usual (BAU) scenario reflecting the Lao PDR's current goals and action plans:

BAU. This scenario uses the historical correlations of final energy consumption and economic activity from 2000 to 2016. The GDP growth rate is appropriate. The GDP growth rate is used to estimate other drivers of energy demand like the GDP of the industrial sector, GDP per capita, number of vehicles, etc. In view of the use of the regression analysis, the trend of future consumption will be similar to the historical trends. The energy supply would be based on the current targets of the government as well.

In addition, the outlook examined the impact of the following cases:

1. Changes in the GDP. In this regard, the study examined the impact of increasing the GDP growth rates by 1% higher than that of the BAU scenario GDP growth rate. Next the study examined the impact if the GDP growth rate decreased 1% more than the BAU scenario for assessing energy demand sensitivity to the GDP.
2. High oil prices. Under this case, the crude oil price was assumed to reach $200 by 2030 and $250 by 2040, compared to $150 and $200 under the BAU scenario for assessing energy demand sensitivity to the energy price.
3. Additional energy efficiency (EE) promotion. This case examined the impact of implementing energy efficiency and conservation programmes that will reduce final energy consumption in the BAU scenario by 10% in 2040 (EE10) and by 20% in 2040 (EE20).
4. Renewable energy (RE) development. This case examined the impacts of implementing an RE development policy that will increase the share of RE (solar and wind) in the power generation mix to 10% by 2040 (RE10) and to 20% by 2040 (RE20).

Chapter 3

Data

Cecilya Laksmiwati Malik

The energy demand projections of the Lao People's Democratic Republic (Lao PDR) up to 2040 were implemented applying the econometrics approach wherever possible. The energy demand projections up to 2040 applied historical correlations of final energy consumption and economic activity from 2000 to 2015. The historical data consisted of energy data, socioeconomic data, and energy price.

3.1 Energy Data

The historical energy demand data were taken from the Lao PDR Energy Balance Tables 2000–2015 (MEM, 2018). The Department of Energy Policy and Planning (DEPP), the Department of Planning and Cooperation, under the Ministry of Energy and Mines (MEM) compiled the national energy data. The primary energy sources of the Lao PDR consist of coal, oil, hydropower, and biomass. Oil products were imported to meet domestic requirements.

Table 3.1 shows the historical energy data of the Lao PDR from 2000 to 2015 and Table 3.2 shows the 2015 Energy Balance Table of the Lao PDR, which was used as the base year for this *Lao PDR Energy Outlook*.

In the case of the transport sector, the final energy consumption was broken down to domestic aviation and road transport. In road transport, the final consumption included the consumption of other petroleum products, which were actually the lubricants used in the vehicles.

Table 3.1 Lao PDR Energy Data, 2000–2015 (ktoe)

Sector	Fuel	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Intl Aviation Bunkers	Jet Fuel	-40.50	-40.64	-40.77	-40.90	-41.03	-41.17	-41.30	-41.44	-41.57	-41.71	-41.85	-41.98	-42.12	-42.26	-42.39	-40.97
Total Final Energy Consumption	Anthracite	9.17	11.91	18.85	22.99	27.88	30.30	37.20	45.00	62.87	67.17	127.03	135.00	130.31	120.00	121.67	81.31
	Lignite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.39	20.87	28.28	57.43	77.90	225.27	242.52	310.46
	Motor Gasoline	77.39	77.37	82.42	84.88	90.80	95.74	103.72	117.47	122.82	137.34	144.62	152.29	160.37	166.11	162.08	172.02
	Jet Fuel	3.28	3.29	3.30	3.31	0.00	3.33	3.34	3.35	3.36	3.37	3.39	3.40	3.41	3.42	3.43	3.31
	Gas/Diesel Oil	184.20	210.96	212.62	219.65	225.78	232.76	322.30	328.01	392.75	462.69	462.69	473.07	516.64	552.45	591.63	729.25
	Fuel Oil	3.48	3.54	3.95	4.04	4.05	4.18	4.21	4.50	4.81	5.49	5.51	7.86	7.38	7.74	8.74	9.64
	LPG	1.78	1.78	1.85	1.85	1.87	1.89	2.05	2.06	2.16	2.25	2.32	2.87	2.97	3.13	3.53	3.78
	OOP	0.22	0.23	0.30	0.33	0.37	0.42	0.52	0.63	0.63	0.93	1.30	1.48	1.68	1.91	2.17	2.47
	Biomass	1103.48	1129.96	1157.08	1184.85	1213.29	1242.41	1272.22	1374.50	1474.68	1424.60	1385.93	1347.26	1292.44	1282.44	1292.71	1304.03
	Charcoal	70.69	72.32	73.98	75.68	77.42	79.20	81.02	89.96	106.18	126.30	128.22	130.14	132.00	133.50	137.50	141.50
	Electricity	55.03	61.09	65.94	76.00	77.64	86.95	120.92	138.96	164.75	194.16	209.90	219.79	264.45	290.76	326.09	364.52
	Total	1508.72	1572.43	1620.28	1673.59	1719.10	1777.18	1947.51	2104.44	2342.41	2445.18	2499.20	2530.58	2589.55	2786.73	2892.08	3122.30
Industry Sector	Anthracite	9.17	11.91	18.85	22.99	27.88	30.30	37.20	45.00	62.87	67.17	127.03	135.00	130.31	120.00	121.67	81.31
	Lignite	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.39	20.87	28.28	57.43	77.90	225.27	242.52	310.46
	Gas/Diesel Oil	10.79	7.56	7.89	4.15	4.52	3.33	79.11	63.93	79.00	93.12	87.95	95.08	78.13	93.80	29.60	36.55
	Fuel Oil	3.48	3.54	3.95	4.04	4.05	4.18	4.21	4.50	4.81	5.49	5.51	7.86	7.38	7.74	8.74	9.64
	Biomass	47.16	48.29	49.45	50.63	51.85	53.09	54.37	58.74	63.02	60.88	59.23	57.58	39.84	59.44	57.01	55.73
	Charcoal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Electricity	11.59	11.60	14.10	17.49	18.80	20.34	47.25	53.85	60.48	65.38	60.80	63.67	75.91	96.17	134.47	150.10
	Total	82.21	82.90	94.24	99.31	107.10	111.25	222.14	226.02	277.56	312.91	368.81	416.63	409.46	602.42	594.01	643.79
Transport Sector	Motor Gasoline	77.39	77.37	82.42	84.88	90.80	95.74	103.72	117.47	122.82	137.34	144.62	152.29	160.37	166.11	162.08	172.02
	Jet Fuel	3.28	3.29	3.30	3.31	0.00	3.33	3.34	3.35	3.36	3.37	3.39	3.40	3.41	3.42	3.43	3.31
	Gas/Diesel Oil	173.11	203.12	204.45	215.23	220.99	229.15	242.91	263.80	313.47	369.30	374.47	377.70	438.24	458.37	561.76	692.43
	OOP	0.22	0.23	0.30	0.33	0.37	0.42	0.52	0.63	0.63	0.93	1.30	1.48	1.68	1.91	2.17	2.47
	Total	254.00	284.00	290.46	303.75	312.16	328.65	350.49	385.25	440.29	510.94	523.77	534.87	603.70	629.81	729.44	870.23
Other Sector	Gas/Diesel Oil	0.29	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
	LPG	1.78	1.78	1.85	1.85	1.87	1.89	2.05	2.06	2.16	2.25	2.32	2.87	2.97	3.13	3.53	3.78
	Others	1127.01	1153.99	1181.61	1209.90	1238.86	1268.51	1298.88	1405.72	1517.84	1490.02	1454.92	1419.82	1384.60	1356.50	1373.20	1389.80
	Biomass	1056.32	1081.67	1107.63	1134.22	1161.44	1189.31	1217.86	1315.76	1411.66	1363.72	1326.70	1289.68	1252.60	1223.00	1235.70	1248.30
	Charcoal	70.69	72.32	73.98	75.68	77.42	79.20	81.02	89.96	106.18	126.30	128.22	130.14	132.00	133.50	137.50	141.50
	Electricity	43.43	49.49	51.84	58.51	58.83	66.61	73.67	85.10	104.27	128.78	149.10	156.12	188.54	194.60	191.61	214.42
	Total	1172.52	1205.53	1235.57	1270.53	1299.85	1337.29	1374.88	1493.16	1624.56	1621.33	1606.62	1579.09	1576.39	1554.50	1568.62	1608.28

Note: ktoe = kilotons of oil equivalent, Intl= international, LPG = liquefied petroleum gas, OOP = other petroleum product.
Source: Ministry of Energy and Mines (MEM), (2018), *Lao PDR Energy Statistics 2018*.

Table 3.2 Lao PDR Energy Balance Table, 2015 (ktoe)

		1.	4.							6.	8.	9.	10.	12.
				4.1	4.3	4.5	4.6	4.7	4.10					
		Coal	Petroleum Products	Motor Gasoline	Jet Fuel	Gas/Diesel Oil	Fuel Oil	LPG	Other Petroleum Products	Hydro	Geothermal, Solar etc.	Others	Electricity	Total
1.	Indigenous Production	1.801								1.232	0	1.619		4.652
2.	Imports		971	180	44	729	10	4	2				176	1.147
3.	Exports												-993	-993
4.	International Marine Bunkers													
13.1	International Aviation Bunkers		-41		-41									-41
5.	Stock Changes													
6.	Total Primary Energy Supply	1.801	930	180	3	729	10	4	2	1.232	0	1.619	-817	4.765
8.	Total Transformation Sector	-1.410								-1.232	0	-173	1.453	-1.362
8,1	Main Activity Producer	-1.410								-1.232	0	-2	1.453	-1.190
8,8	Charcoal Processing											-172		-172
9.	Loss & Own Use												-272	-272
10.	Discrepancy	0	-9	-8	0		0	-1			0	0	0	-9
11.	Total Final Energy Consumptions	392	920	172	3	729	10	4	2			1.446	365	3.122
12.	Industry Sector	392	46			37	10					56	150	644
13.	Transport Sector		870	172	3	692			2					870
13,2	Domestic Air Transport		3		3									3
13,3	Road		867	172		692			2					867
14.	Other Sector		4			0		4				1.390	214	1.608
14,1	Residential & Commercial		4					4				1.390	212	1.605
14.1.1	Commerce and Public Services		2					2				274	74	351
14.1.2	Residential		1					1				1.116	137	1.254
14,2	Agriculture		0			0							3	3
15.	of which Non-Energy Use		2						2					2
16	Electricity Output in GWh	2.567								14.326	0	4		16.896

Note: GWh = gigawatt hour, ktoe = kilotons of oil equivalent, LPG = liquefied petroleum gas.

Source: Ministry of Energy and Mines (MEM), (2018), *Lao PDR Energy Statistics 2018*.

In estimating the aviation fuel demand function, the aviation fuel consumption is defined as the domestic demand and international aviation bunkers (aviation fuel for international flights). The international aviation bunkers in the Energy Balance Table was reported as part of the total primary energy supply (TPES) and the absolute value was used in the summation.

The 'Others' sector consumption of the Lao PDR is the commercial/services sector, residential, and agriculture sectors. The demand function was estimated for the fuels consumed in each of the subsectors of Others.

3.2 Macroeconomic Data

The economic indicators used in energy modelling were taken from the World Development Indicators database of the World Bank (World Bank, 2018). These data were gross domestic product (GDP), major sectors gross value-added (GVA), GDP deflator, consumer price index (CPI), official exchange rate, total population, urban and rural population, and population in the largest city (Table 3.3).

There were other economic indicators used in the estimation of the final energy demand equation, but these data were obtained from national statistics as described in the national data section.

3.3 International Crude Oil Price

The international crude oil price in the Lao PDR outlook model used the imported price of Japan cost, insurance, and freight (CIF) as representing the world crude oil price. The data were based on ERIA's activities on Energy Outlook and Saving Potential provided by the Institute of Energy and Economics, Japan (IEEJ). Figure 3.1 shows the CIF crude oil price from 2000 to 2015.

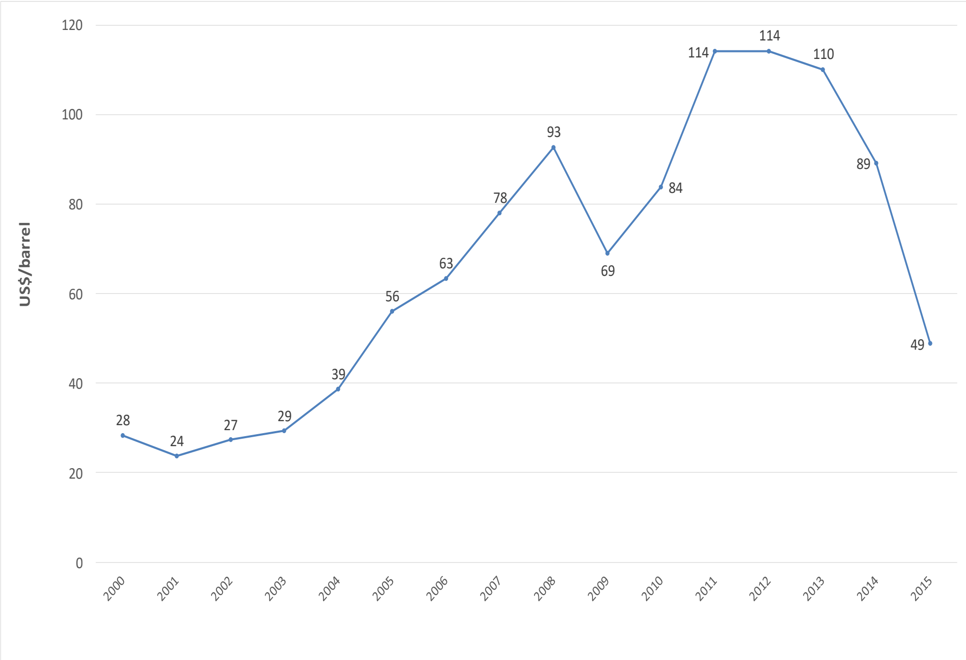
Table 3.3 World Development Indicators, 2000–2015

Series Name	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Agriculture, value added (constant 2010 US$)	1.49E+09	1.55E+09	1.61E+09	1.65E+09	1.70E+09	1.73E+09	1.80E+09	1.93E+09	2.00E+09	2.06E+09	2.11E+09	2.13E+09	2.18E+09	2.25E+09	2.34E+09	2.42E+09
Agriculture, value added (constant LCU)	1.03E+13	1.07E+13	1.11E+13	1.14E+13	1.18E+13	1.20E+13	1.25E+13	1.34E+13	1.39E+13	1.43E+13	1.47E+13	1.47E+13	1.51E+13	1.56E+13	1.62E+13	1.68E+13
Consumer price index (2010 = 100)	48.14	51.90	57.42	66.32	73.26	78.50	83.84	87.64	94.32	94.36	100.00	107.58	112.16	119.30	124.23	125.81
GDP (constant 2010 US$)	3.58E+09	3.79E+09	4.01E+09	4.26E+09	4.53E+09	4.85E+09	5.27E+09	5.67E+09	6.11E+09	6.57E+09	7.13E+09	7.70E+09	8.32E+09	8.99E+09	9.67E+09	1.04E+10
GDP (constant LCU)	3.51E+13	3.72E+13	3.94E+13	4.18E+13	4.44E+13	4.76E+13	5.17E+13	5.56E+13	5.99E+13	6.44E+13	6.99E+13	7.55E+13	8.16E+13	8.82E+13	9.49E+13	1.02E+14
GDP deflator (base year varies by country)	38.81	42.25	44.92	50.96	56.41	61.28	67.91	72.96	79.42	77.10	84.19	87.81	100.00	106.47	112.57	115.21
Industry, value added (constant 2010 US$)	6.38E+08	7.02E+08	7.73E+08	9.15E+08	9.84E+08	1.11E+09	1.30E+09	1.41E+09	1.59E+09	1.82E+09	2.17E+09	2.53E+09	2.86E+09	3.08E+09	3.30E+09	3.54E+09
Industry, value added (constant LCU)	5.90E+12	6.50E+12	7.16E+12	8.47E+12	9.11E+12	1.03E+13	1.21E+13	1.30E+13	1.47E+13	1.68E+13	2.01E+13	2.34E+13	2.65E+13	2.85E+13	3.06E+13	3.27E+13
Manufacturing, value added (constant 2010 US$)	1.93E+08	2.16E+08	2.44E+08	2.58E+08	2.97E+08	3.27E+08	3.72E+08	4.23E+08	4.61E+08	4.88E+08	5.06E+08	5.59E+08	6.14E+08	6.36E+08	6.98E+08	7.29E+08
Manufacturing, value added (constant LCU)	2.30E+12	2.58E+12	2.91E+12	3.08E+12	3.54E+12	3.91E+12	4.44E+12	5.04E+12	5.51E+12	5.83E+12	6.04E+12	6.67E+12	7.33E+12	7.59E+12	8.33E+12	8.70E+12
Official exchange rate (LCU per US$, period average)	7887.64	8954.58	10056.33	10569.04	10585.38	10655.17	10159.94	9603.16	8744.22	8516.05	8258.77	8030.06	8007.76	7860.14	8048.96	8147.91
Population in largest city	4.42E+05	4.67E+05	4.93E+05	5.20E+05	5.50E+05	5.80E+05	6.13E+05	6.47E+05	6.83E+05	7.21E+05	7.61E+05	8.04E+05	8.48E+05	8.96E+05	9.46E+05	9.97E+05
Population, total	5.33E+06	5.41E+06	5.50E+06	5.58E+06	5.66E+06	5.75E+06	5.85E+06	5.95E+06	6.05E+06	6.15E+06	6.25E+06	6.33E+06	6.42E+06	6.49E+06	6.58E+06	6.66E+06
Rural population	4.16E+06	4.17E+06	4.18E+06	4.18E+06	4.18E+06	4.18E+06	4.18E+06	4.18E+06	4.19E+06	4.18E+06	4.18E+06	4.16E+06	4.15E+06	4.13E+06	4.11E+06	4.09E+06
Services, etc., value added (constant 2010 US$)	1.23E+09	1.30E+09	1.38E+09	1.43E+09	1.56E+09	1.72E+09	1.85E+09	1.99E+09	2.16E+09	2.31E+09	2.44E+09	2.62E+09	2.82E+09	3.10E+09	3.35E+09	3.62E+09
Services, etc., value added (constant LCU)	1.43E+13	1.51E+13	1.60E+13	1.66E+13	1.81E+13	1.99E+13	2.14E+13	2.31E+13	2.51E+13	2.68E+13	2.83E+13	3.04E+13	3.28E+13	3.60E+13	3.89E+13	4.20E+13
Urban population	1.17E+06	1.24E+06	1.32E+06	1.40E+06	1.49E+06	1.58E+06	1.67E+06	1.77E+06	1.87E+06	1.97E+06	2.07E+06	2.17E+06	2.27E+06	2.37E+06	2.47E+06	2.57E+06

GDP = gross domestic product, LCU = local currency unit.

Source: World Bank, World Development Indicators. https://data.worldbank.org/country/lao-pdr?view=chart (accessed 16 June 2018).

Figure 3.1 Nominal Crude Oil Price (CIF Japan)



CIF = cost, insurance, and freight.

Source: ERIA (2018), *Energy Outlook and Energy Saving Potential 2018.*

3.4 National Data

In principle, national data should be used in estimating energy demand formulas. The World Bank's World Development Indicators data for the Lao PDR exclude the local energy price and other activity data that were relevant for estimating energy demand equations.

Local energy price

The Lao PDR local energy price included petroleum products (gasoline, diesel, LPG, etc.), electricity price, coal, and electricity. Import CIF, CPI, and sales price were the basis in determining the domestic energy price. As explained in the previous section on methodology, these local energy prices should be the relative price not the absolute price.

$$Energy\ Demand\ (De) = f(Y,\ Pe/PGDP,\ De_{-1})$$

Where:

Y: Income (GDP, etc.)

Pe: Energy price (Oil price, etc.)

PGDP: GDP` deflator (Overall price, CPI, etc.)

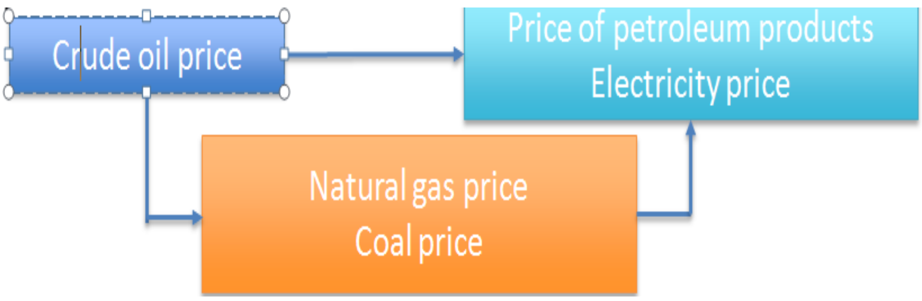
Pe/PGDP: Relative variable

De: Energy demand (Coal, oil, gas, and electricity)

De_{-1}: Lag variable (show habit)

The international energy price can be used to explain the local energy price if the data are not available. Thus, the local energy price will be a function of the international energy price.

Figure 3.2 Estimating Local Energy Price



Source: Prepared by author.

Examples:

Motor gasoline price	:	MGprice = f(Poil/exr/pgdp, MGprice(-1))
Electricity price	:	Eprice = f(NGprice, Eprice(-1))
Natural gas price	:	NGprice = f(Poil/exr/pgdp, NGprice(-1))
Poil	:	Crude oil price (US$/barrel, nominal)
Exr	:	Exchange rate
Pgdp	:	GDP deflator

In the Lao PDR, electricity generation is mostly from hydropower resources. Thus, the local electricity price should not be explained by the international crude oil or coal price. The DEPP was able to obtain the local electricity price by the different consumer tariff groups, which were services, households, industry, and 'Others' sectors (Table 3.4).

Table 3.4 Electricity Price (KN/MWh)

Year	Households	Services	Industry	Other Sectors
2000	109,370	384,900	217,560	85,700
2001	170,390	450,580	332,780	159,350
2002	204,790	635,990	378,490	188,770
2003	252,420	783,140	480,650	221,390
2004	352,350	876,190	587,550	279,220
2005	371,160	882,040	590,140	289,030
2006	425,410	877,510	586,280	283,270
2007	406,950	874,260	567,560	248,010
2008	415,960	860,600	565,200	236,560
2009	469,920	845,160	546,540	251,500
2010	480,240	848,090	544,740	364,070
2011	492,010	844,630	527,850	390,820
2012	561,130	933,110	577,410	411,340
2013	607,940	939,780	647,840	464,780
2014	624,270	1,004,150	674,990	482,000
2015	650,510	1,109,190	687,490	492,940

KN = kip, MWh = megawatt hour.
Source: Department of Energy Policy and Planning.

Local activity data

The local activity data that were commonly used in estimating the energy demand function of the final sectors were:

- Industry sector: Index of Industrial Production (IIP)
- Road sector: Number of vehicles
- Residential sector: Number of households
- Commercial sector: Number of buildings, floor area

These local activity data were usually explained by macro variables such as GDP. Examples:

Index of Industrial Production	:	IIP = f(Industrial GDP, IIP(-1))
Number of cars	:	Ncar = f(GDP, Ncar(-1))
Floor area	:	Floor = f(commercial GDP, floor(-1))
Number of Households	:	NHH = f(Population, NHH(-1))

The local activity data collected by DEPP for estimating the demand function for road transport was the number of vehicles (Table 3.5)

Table 3.5 Vehicle Statistics of the Lao PDR, 2000–2015

	Motorcycle	Tuk-Tuk	Sedan	Pickup	Van	SUV	Truck	Bus	TOTAL
2000	153.781	4.347	8.995	15.074	2.199	3.970	10.559	1.831	200.756
2001	168.379	4.405	9.428	17.581	2.603	4.355	11.841	1.899	220.491
2002	196.963	4.405	9.696	19.042	3.691	4.584	13.085	2.042	253.508
2003	195.353	6.407	8.045	25.490	2.729	5.832	8.424	2.164	254.444
2004	285.740	7.871	10.063	36.421	3.777	6.949	11.346	3.972	366.139
2005	337.719	8.043	11.204	42.994	4.862	7.909	13.441	4.234	430.406
2006	453.158	8.441	12.939	59.519	7.236	8.668	15.296	3.033	568.290
2007	509.421	8.518	14.792	68.360	9.355	10.399	17.994	2.242	641.081
2008	623.310	8.460	15.203	77.616	12.675	9.752	19.070	2.520	768.606
2009	711.800	8.624	17.671	93.080	18.634	10.801	23.031	2.707	886.348
2010	804.087	8.542	21.638	109.362	24.727	12.155	25.452	2.825	1.008.788
2011	899.436	8.537	27.901	127.913	22.156	24.052	28.673	3.190	1.141.858
2012	950.238	8.545	31.673	137.723	32.228	15.336	30.799	3.337	1.209.879
2013	1.112.072	8.601	43.860	162.633	50.124	19.876	38.454	3.861	1.439.481
2014	1.218.379	8.737	51.284	185.086	42.770	22.515	44.293	4.120	1.577.184
2015	1.280.673	8.761	51.540	204.360	46.293	24.665	46.654	4.448	1.667.394

Source: Department of Energy Policy and Planning.

References

Ministry of Energy and Mines (MEM) (2018), *Lao PDR Energy Statistics 2018*. Vientiane: MEM.

World Bank. *World Development Indicators.* https://data.worldbank.org/country/lao-pdr?view=chart (accessed 16 June 2018).

Chapter 4

Estimation of Energy Demand Formulas

Minh Bao Nguyen

Energy is an important commodity for achieving economic development. As economic activities increase, the demand for energy increases. In addition, changes in energy prices make a direct influence on energy consumption and economic growth. Rising energy prices bring an incentive to use energy sources more efficiently and conservatively, resulting in lower energy consumption. On the other hand, the increase of energy prices leads to inflation through the increase of the cost of other goods and then the gross domestic product (GDP) will decrease. Therefore, there is a direct link between energy consumption and socioeconomic variables such as energy price and economic output (or GDP). Logically, an increase in GDP leads to an increase in energy consumption, but on the contrary, an increase in energy prices results in lower energy consumption.

This chapter focuses on the estimation of energy demand formulas based on historical data on energy consumption, socioeconomic data, and activity indicators for forecasting the future energy demand of the Lao People's Democratic Republic (Lao PDR) until 2040.

4.1 Methodology

The demand function was estimated using the econometric approach which is a top-down approach linking the macroeconomic model and energy model.

In the econometric approach, energy demand is modelled as a function of macroeconomic activities such as income (or GDP), relative prices amongst sources of energy, and energy consumption at previous period.

$$E = f(Y, Pe/CPI) \text{ or } E = f(Y, Pe/CPI, E\text{-}1)$$

Where:

E: Energy demand

Y: Income (or GDP)

Pe: Energy price

CPI: Consumer price index

Pe/CPI: Relative energy price over CPI

E-1: Energy consumption at previous period

The relationships amongst the above variables are derived by regression analysis software, a computer programme for carrying out econometric analysis, estimating and testing equations, data processing, file management, graphic display, estimation, hypothesis testing, and forecasting under univariate and multivariate model specifications.

The future energy demand for various energy sources will be forecast by using the estimated formulas mentioned above with the assumed future values of the macroeconomic, energy price, and other activity indicators. However, not all energy consumption of the sectors could be estimated as a demand formula due to the limitation of the data.

To estimate the energy demand formulas for the economic activities in different sectors such as the industry, transport, commercial, and residential sectors, we disaggregate energy consumption by each sector into type of energy such as gas, petroleum products, electricity, and coal consumption and then test the regression results for their relationship with GDP, energy prices, and other related indicators.

Historical energy demand data were taken from the national energy data compiled by the Economic Research Institute for ASEAN and East Asia and the Lao PDR Ministry of Energy and Mines. The economic indicators used in energy modelling such as gross domestic product (GDP) and manufacturing GDP, value-added (MFGGDP) were taken from the World Bank's *World Development Indicators*. Other socioeconomic data such as number of households and electricity prices were obtained from national sources.

In cases where regression analysis is not applicable due to insufficient data or failure to derive a statistically effective equation, other exogenous approaches such as growth as GDP or the share of percentage approach were used.

4.2 Estimation of Energy Demand Formulas

Industry sector

The total energy consumption in the industry sector is not broken down into subsectors. On the basis of fuel type, the total energy consumption each year since 2000 to 2015 is the sum of the different types of fuel, consisting of coal (anthracite and lignite coal), petroleum products (diesel and fuel oil), other (fuelwood and other biomass, etc.), and electricity.

Based on the available data, the estimation of demand formulas has been done for the total energy consumption in the industry sector and by type of fuel if applicable.

1) Total energy demand in industry sector

The total energy demand in the industry sector (INTT) was estimated by using the independent variables such as the real price of crude oil (RPOIL), manufacturing GDP (MFFGDP), and energy consumption of the previous year. A dummy variable was included for the year 2013 to get a sound equation.

The result of the estimated demand equation is:

$$INTT=-93.1478*CONS - 0.0092903*RPOIL+ 0.7749E\text{-}4*MMFGGDP + 0.15530*INTT(-1) + 119.2306*DUM13$$

More detail on the result of the regression analysis is shown in Table A4.1 and Figure A4.1 (see Annex).

2) Fuel oil demand in industry sector

Fuel oil demand in the industry sector (INFO) was estimated using RPOIL, GDP (shown as MGDP) and energy consumption of the previous year as the independent variables. The regression test was also done with INGDP, but the use of GDP is better than INGDP. A dummy variable was also included for the year 2011.

The result of the estimated demand equation is as follows:

$$INFO = 0.85902*CONS - 0.1207E\text{-}3*RPOIL + 0.5747E\text{-}7*MGDP+ 0.38105*INFO(-1)+1.8212*DUM11$$

More detail on the result of the regression analysis is shown in Table A4.2 and Figure A4.2 (see Annex).

3) Lignite coal demand in industry sector

Lignite coal demand in the industry sector (INLG) was estimated using the independent variables including GDP (shown as MGDP) and energy consumption of the previous year. RPOIL is not applicable, because lignite coal is local coal and the demand for using lignite coal is not affected by RPOIL. The regression test was done with INGDP, but the use of GDP is also better than INGDP. A dummy variable was included for 2013 to get a sound equation. The result of the estimated demand equation is as follows:

$$INLG = -76.4174*CONS + 0.1335E\text{-}5*MGDP + 0.94608*INLG(-1) + 110.2891*DUM13$$

Basically, the estimation of the lignite coal demand formula using the above variables is a sound one. However, when this formula was linked with the energy model for energy projection, lignite coal demand was increasing at an annual growth rate of 13.7% in the period 2015–2040, which is higher than the annual growth rate GDP (6.2%) by about 2.2 times. This is irrational and in this case we assume that INLG will increase as GDP but higher with elasticity of 1.1. The formula should be as follows:

$$INLG = GrowthAs(Key\backslash MGDP,1.1)$$

4) Electricity demand in industry sector

Electricity demand in the industry sector (INEL) was estimated using the real price of electricity (RPELC), GDP (shown as MGDP), and energy consumption of the previous year as the independent variables. However, the result showed that the sign of coefficient of RPELC is positive. This is irrational because, electricity demand will increase when the price increases. We have changed this formula in type of log form with a dummy variable used for 2006 and get the result as follows:

$$LINEL = -8.4861*CONS - 0.013641*LRPELC + 0.52512*LMGDP + 0.79083*LINEL(-1) + 0.66174*DUM06$$

The result on electricity projection also is irrational because the result was too high due to a data problem; therefore, we used only INGDP (shown as MINGDP) as the main variable for electricity demand as follows:

$$INEL= GrowthAs(Key\backslash MINGDP,1.35)$$

5) Other fuels

- **Biomass demand in industry sector**

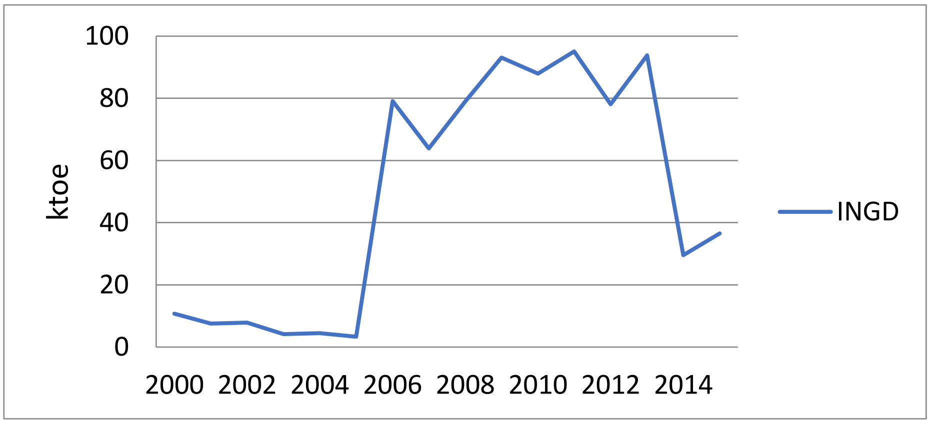
  Biomass demand in the industry sector (INBS) is not affected by RPOIL and is not fit for regression analysis because of a data problem. Based on the historical data trend and use INGDP used as main variable, the biomass demand could be estimated as follows:

$$INBS=GrowthAs(Key\backslash MINGDP,0.5)$$

- **Diesel oil demand in industry sector**

  In the case of diesel oil demand in the industry sector (INGD), the data for 2000–2015 showed irregularities (Figure 4.1), so that the formula for diesel oil could not be estimated.

Figure 4.1 Diesel Oil Consumption in Industry Sector, 2000–2015



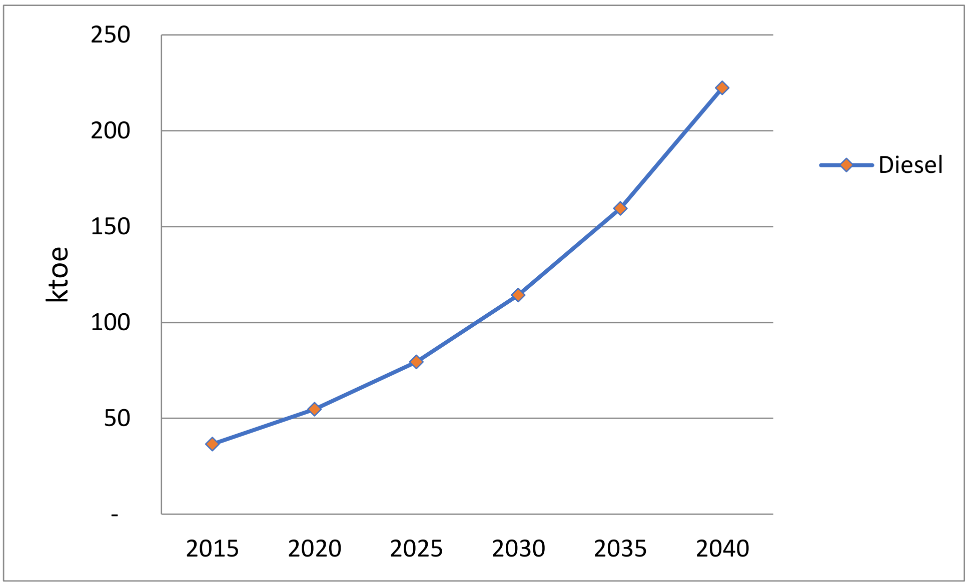
ktoe = thousand tons of oil equivalent, INGD = diesel oil consumption in the industry sector.
Source: Author's analysis.

We assumed that GDP is the only main driver for diesel oil demand as follows:

$$INGD = GrowthAs(Key \backslash MGDP, 1.2)$$

Figure 4.2 below shows the diesel oil demand in the industry sector from 2015 to 2040.

Figure 4.2 Diesel Oil Demand in Industry Sector, 2015–2040



ktoe= thousand tons of oil equivalent.
Source: Author's analysis.

- **Anthracite coal demand in industry sector**

  Anthracite coal demand in the industry sector (INAN) is equal to total energy demand minus the remaining fuels in the industry sector as formula below:

$$INAN=INTT–INFO–INLG–INEL–INBS–INGD$$

Transport sector

The total energy demand of the transport sector is broken-down by subsectors, including air and road transport. There are no data for rail transport and for transport on inland waterways.

The majority of the fuels consumed by the transport sector are petroleum products including motor gasoline, gas/diesel oil, lubricants (or non-energy petroleum products), and jet fuel.

Motor gasoline, gas/diesel oil, and lubricants are used by the road subsector, while jet fuel is used for aviation transport.

1) Road transport

Fuels used in road transport consist of gasoline, diesel oil, and lubricants. We have used the regression analysis to test for each fuel in road transport; however, due to the limitation of statistical data, the regression analysis results were not better than the other method of the share of percentage approach. Therefore, the share of percentage approach was used to estimate the fuel demand formulas in road transport.

a) Total energy demand for road transport

Because of the limitation of data to estimate the demand formula for each of the petroleum products, the function is only estimated for total energy demand in road transport (RDTTT), and then each fuel demand formula will be estimated based on the share of each fuel in the total energy demand.

RDTTT was estimated as a function of GDP, RPOIL, and the previous year consumption. The demand equation for RDTTTis as follows:

$$RDTTT = 37.9381*CONS + 0.7211E\text{-}5*MGDP - 0.011166*RPOIL + 0.14203*RDTTT(-1)$$

The result of the regression analysis is shown in Table A4.3 and Figure A4.3 (see Annex).

b) Fuel types used in road transport

Based on the statistical data, we can estimate the share of each fuel type in the total fuels used in road transport. Assuming that the share of each fuel type is still maintained in the coming years, we can estimate the fuel demand in road transport as follows:

$$RDGD = DSRDSH(-1)*RDTTT$$

$$RDMG=GSRDSH(-1)*RDTTT$$

$$NEPP = LBRDSH(-1)*RDTTT$$

Where:

RDGD = Diesel demand in the road transport

DSRDSH= Diesel share of road transport

RDMG = Gasoline demand in the road transport

GSRDSH= Gasoline share of road transport

NEPP = Non-energy petroleum products

LBRDSH= Lubricant share of road transport

2) Aviation transport

Aviation transport includes international and domestic aviation. The total energy demand for aviation transport (AVTT) was estimated using the GDP and energy consumption of the previous year, because it was impossible to use RPOIL. However, the result of the energy demand projection for aviation transport is irrational with an annual average growth rate of 1.1% in the period 2015–2040 (very low compared to the GDP growth rate of 6.2%). In this case, the exogenous approach was used, with the formula estimated as follows:

$$AVTT = GrowthAs(Key\backslash MGDP, 0.5)$$

Because the data on domestic aviation transport are almost unchanged during the period of 2000–2015, the jet fuel demand for domestic aviation transport (TSJF) was estimated based on the relationship with international aviation. The estimated result of demand formula for TSJF is:

$$TSJF = - 0.063395*CONS + 0.076231*AVTT$$

The result of the regression analysis is shown in Table A4.4 and Figure A4.4 (see Annex).

Residential sector

Energy used in the residential sector consists of electricity, liquefied petroleum gas (LPG), and other fuel (biomass). Because of data problems, biomass is not fit for regression analysis, thus biomass is estimated based on the total energy consumption in the residential sector minus the other remaining fuels.

1) Total energy demand in residential sector

The total energy demand in the residential sector (RETT) was estimated using the residential real price of electricity (RERPELC), population (POP), and the energy consumption of the previous year as the independent variables. A dummy variable was included for the years 2006 and 2008. The result of the estimated demand equation is as follows:

$$RETT= 101.3128*CONS -9.8821*RERPELC + 0.2835E\text{-}4*POP + 0.81543*RETT(-1) + 70.1772*DUM0608$$

The result of the regression analysis is shown in Table A4.5 and Figure A4.5 (see Annex).

2) Electricity demand in residential sector

Electricity demand in the residential sector (REEL) was estimated using the independent variables including the residential real price of electricity (RERPELC), GDP per capita (GDPC), and electricity consumption of the previous year. The result of the estimated demand equation is as follows:

$$REEL = -18.3522*CONS - 1.6288*RERPELC + 5.6521*GDPC + 0.62271*REEL(-1)$$

The result of the regression analysis is shown in Table A4.6 and Figure A4.6 (see Annex).

3) LPG demand in residential sector

LPG consumption per capita in the residential sector (LRELPP) was estimated using Log Form with the independent variables including RPOIL, GDPC, and a dummy variable used for the year 2002.

The result of the estimated demand equation is as follows:

$$LRELPP = -15.8834*CONS - 0.17513*LRPOIL + 0.74058*LGDPC + 0.065054*DUM02$$

Thus, LPG demand in the residential sector will be:

$$RELP = (Exp(LRELPP)) * POP.$$

However, the result of the calculation in the energy model showed that the LPG demand by 2040 is low, with an annual average growth rate of 5% in the period 2015–2040, which is lower than the growth rate of the GDP in the same period.

Urban population (or the urbanisation rate) and income are two main drivers impacting LPG demand. Normally, when the urbanisation rate and income increase, the LPG demand will increase accordingly (with a higher growth rate at the initial period of using LPG compared to the next periods).

Therefore, another exogenous approach is applied with summing that LPG demand will increase with an annual average growth rate higher than GDP around 1.2 times.

As with the above analysis, LPG demand formula is estimated as follows:

$$RELP= GrowthAs(Key\backslash MGDP, 1.2)$$

4) Biomass demand in residential sector

Biomass demand (or other fuels) in the residential sector (REOTH) could be estimated as follows:

$$REOT= RETT-REEL-RELP$$

Commercial sector

Energy used in the commercial sector consists of electricity, LPG, and other fuels (biomass). Similar to the residential sector, biomass is also equal to the total energy consumption in the commercial sector minus the other remaining fuels.

1) Total energy demand in commercial sector

The total energy demand in the commercial sector (CSTT) was estimated using the independent variables consisting of the commercial real price of electricity (CSRPELC), commercial GDP (MCSGDP), and energy consumption of the previous year. The years for estimation started from 2005 to 2015 to get a better equation. A dummy variable was included for the years 2009 and 2014. The result of the estimated demand equation is as follows:

$$CSTT = 336.5932*CONS - 12.7326*CSRPELC + 0.9150E\text{-}6*MCSGDP + 0.28293*CSTT(-1) + 19.4497*DUM09 - 19.9742*DUM14$$

The result of the regression analysis is shown in Table A4.7 and Figure A4.7 (See Annex).

2) Electricity demand in commercial sector

Electricity demand in the commercial sector (CSEL) was estimated using the independent variables such as the commercial real price of electricity (CSRPELC) and commercial GDP (MCSGDP). The years for estimation also started from 2005 to 2015 to get a better equation. A dummy variable was used for the years 2012 and 2014. The result of the estimated demand equation is as follows:

$$CSEL = 104.8994*CONS - 8.2225*CSRPELC + 0.1266E\text{-}5*MCSGDP + 15.6876*DUM12 - 14.7276*DUM14$$

The result of the regression analysis is shown in Table A4.8 and Figure A4.8 (See Annex).

3) LPG demand in commercial sector

LPG demand in the commercial sector (CSLP) was estimated using RPOIL, MCSGDP, and energy consumption of the previous year. A dummy variable was also included for the years 2006 and 2011. The result of the estimated demand equation is as follows:

$$CSLP = 0.0035573*CONS - 0.8711E\text{-}5*RPOIL + 0.9167E\text{-}8*MCSGDP + 0.91328*CSLP(-1) + 0.12769*DUM06 + 0.27396*DUM11$$

The result of the regression analysis is shown in Table A4.9 and Figure A4.9 (See Annex).

4) Biomass demand in commercial sector

Similar to the residential sector, biomass demand (or other fuels) in the commercial sector (REOTH) could be estimated as follows:

$$CSOT = CSTT - CSEL - CSLP$$

Other key variables

Aside from the main variables such as GDP, RPOIL, etc. other related key variables worked as the main drivers for energy demand projection are very important, including GDP deflator, sectoral GDP, and price of electricity. However, these future variables are still lacking due to the limitation of data. Thus, in this study, these functions are also estimated based on the relationships amongst other related available variables by regression analysis.

1) GDP deflator

The crude oil price is clearly tied to economic activity and inflation. In the case of the crude oil price increasing, the consumer price index (CPI) also increases. Therefore, GDP deflator (PGDP) was estimated as a function of the price of crude oil (POILJ) and PGDP of the previous year as follows:

$$PGDP = 3.9492*CONS + 0.063211*POILJ + 0.95527*PGDP(-1)$$

The result of the regression analysis is shown in Table A4.10 and Figure A4.10 (see Annex).

2) Industrial GDP

Industrial GDP (MINGDP) is the main component and contribution to GDP growth. Thus, MINGDP was estimated as a function of GDP and MINGDP of the previous year with the equation as follows:

$$MINGDP = -4101490*CONS + 0.19218*MGDP + 0.59237*MINGDP(-1)$$

The result of the regression analysis is shown in Table A4.11 and Figure A4.11 (see Annex).

3) Manufacturing GDP

Manufacturing GDP (MMFGGDP) was also estimated as a function of GDP (MGDP) and MMFGGDP of the previous year. The estimated equation is shown as follows:

$$MMFGGDP = 148716.0*CONS + 0.012981*MGDP + 0.89060*MMFGGDP(-1)$$

The result of the regression analysis is shown in Table A4.12 and Figure A4.12 (see Annex).

4) Commercial GDP

Similar to MINGDP, commercial GDP (MCSGDP) was estimated as a function of GDP and MCSGDP of the previous year. The estimated equation is as follows:

$$MCSGDP = -235667.1*CONS + 0.15436*MGDP + 0.68017*MCSGDP(-1)$$

The result of the regression analysis is shown in Table A4.13 and Figure A4.13 (see Annex).

5) Industrial price of electricity

Similar to the oil price, the electricity price is strongly relative to economic activities. The electricity price is affected by general inflation such as PGDP and CPI. Therefore, the industrial price of electricity (PELC) was estimated as a function of PGDP and PELC of the previous year. A dummy variable was also included for the years 2007 and 2011. The equation is estimated as follows:

$$PELC =161.9270*CONS + 0.55127*PGDP + 0.69916*PELC(-1)- 48.7882*DUM0711$$

The result of the regression analysis is shown in Table A4.14 and Figure A4.14 (see Annex).

6) Residential price of electricity

Similarly, the residential price of electricity (REPELC) was also estimated as a function of PGDP and REPELC of the previous year. The equation is estimated as follows:

$$REPELC = 17.4258*CONS + 2.6132*PGDP + 0.53734*REPELC(-1)$$

The result of the regression analysis is shown in Table A4.15 and Figure A4.15 (see Annex).

7) Commercial price of electricity

The commercial price of electricity (CSPELC) was also estimated as a function of PGDP. Dummy variables were also included for the years of 2002, 2006, 2007, and 2009. The equation is estimated as follows:

$$CSPELC = 75.5422*CONS + 8.5988*PGDP + 251.3462*DUM0206 + 126.7228*DUM0709$$

The result of the regression analysis is shown in Table A4.16 and Figure A4.16 (see Annex).

Annex

Results of Microfit Regression Analysis

1. Industry Sector

- **Total energy demand**

$$INTT = -93.1478*CONS - 0.0092903*RPOIL + 0.7749E\text{-}4*MMFGGDP + 0.15530*INTT(-1) + 119.2306*DUM13$$

Table A4.1 Ordinary Least Squares Estimation for INTT

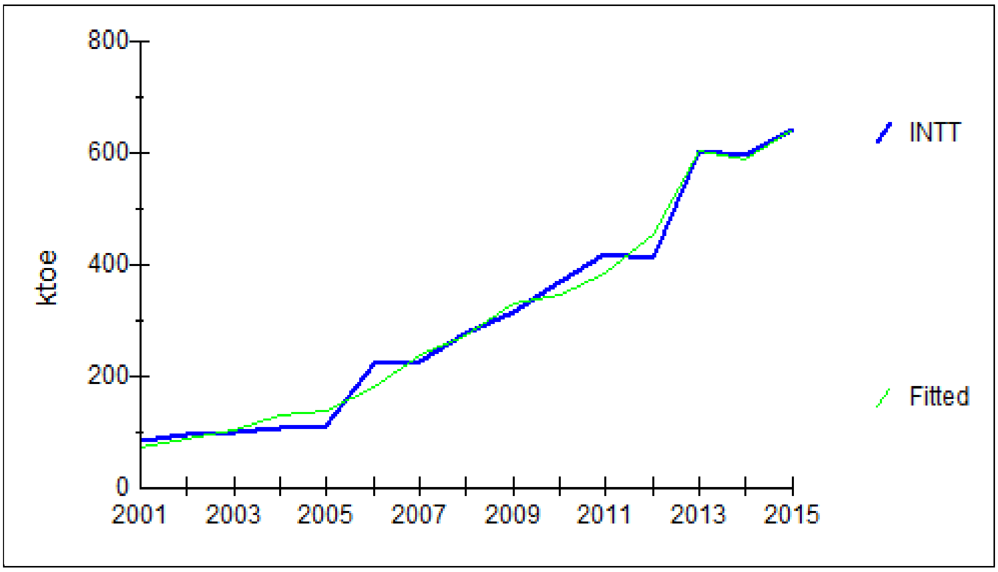
Dependent variable is INTT
15 observations used for estimation from 2001 to 2015

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONS	-93.1478	42.5758	-2.1878[.054]
RPOIL	-.0092903	.0053491	-1.7368[.113]
MMFGGDP	.7749E-4	.2472E-4	3.1348[.011]
INTT(-1)	.15530	.27457	.56562[.584]
DUM13	119.2306	31.7539	3.7548[.004]

R-Squared	.98695	R-Bar-Squared	.98173
S.E. of Regression	26.5668	F-stat. F(4, 10)	189.0852[.000]
Mean of Dependent Variable	304.5698	S.D. of Dependent Variable	196.5561
Residual Sum of Squares	7058.0	Equation Log-likelihood	-67.4380
Akaike Info. Criterion	-72.4380	Schwarz Bayesian Criterion	-74.2082
DW-statistic	2.5609	Durbin's h-statistic	*NONE*

INTT = total energy demand in the industry sector, CONS = constant, RPOIL = real price of crude oil, MMFGGDP = manufacturing GDP, INTT(-1) = total energy demand in the industry sector of the previous year, DUM13 = dummy variable at the year of 2013.
Source: Microfit analysis result.

Figure A4.1 Plot of Actual and Fitted Values for INTT



INTT =total energy demand in the industry sector, ktoe= thousand tons of oil equivalent.
Source: Microfit analysis result.

- **Fuel oil demand**

$$INFO = 0.85902*CONS - 0.1207E\text{-}3*RPOIL + 0.5747E\text{-}7*MGDP+ 0.38105*INFO(-1)+ 1.8212*DUM11$$

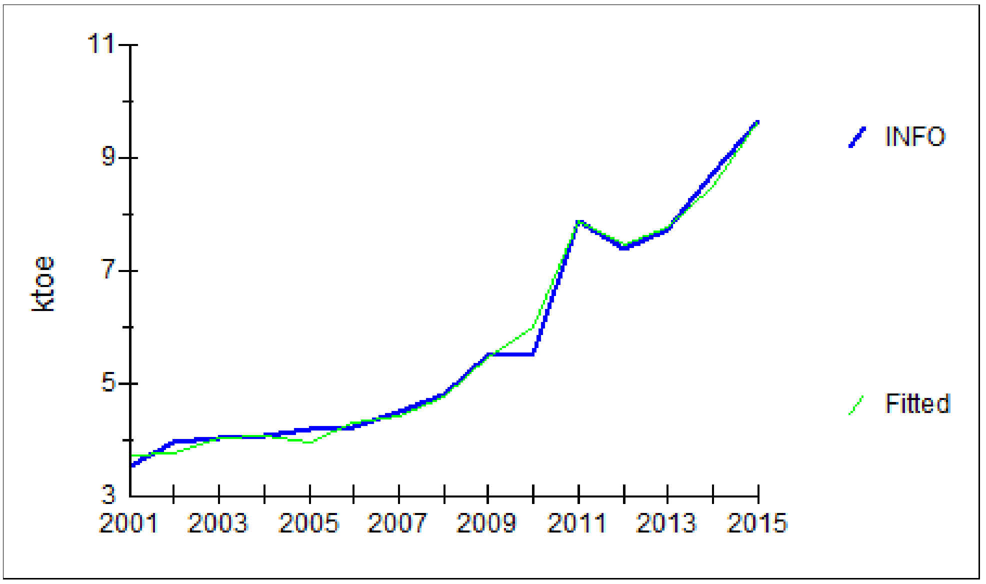
Table A4.2 Ordinary Least Squares Estimation for INFO

```
*******************************************************************************
 Dependent variable is INFO
 15 observations used for estimation from 2001 to 2015
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                        .85902               .31371          2.7382[.021]
 RPOIL                   -.1207E-3             .2964E-4         -4.0741[.002]
 MGDP                      .5747E-7             .1125E-7          5.1070[.000]
 INFO(-1)                    .38105               .13480          2.8268[.018]
 DUM11                       1.8212               .24101          7.5568[.000]
*******************************************************************************
 R-Squared                     .99275   R-Bar-Squared                    .98985
 S.E. of Regression            .20240   F-stat.    F(  4,  10)  342.2573[.000]
 Mean of Dependent Variable    5.7097   S.D. of Dependent Variable       2.0087
 Residual Sum of Squares       .40964   Equation Log-likelihood          5.7198
 Akaike Info. Criterion        .71982   Schwarz Bayesian Criterion      -1.0503
 DW-statistic                  2.2568   Durbin's h-statistic      -.58314[.560]

*******************************************************************************
```

INFO = fuel oil demand in the industry sector, CONS = constant, RPOIL = real price of crude oil, MGDP = gross domestic product, INFO(-1) = fuel oil demand in the industry sector of the previous year, DUM11= dummy variable for the year of 2011.
Source: Microfit analysis result.

Figure A4.2 Plot of Actual and Fitted Values for INFO



INFO = fuel oil demand in the industry sector, ktoe = thousand tons of oil equivalent.
Source: Microfit analysis result.

2. Transport Sector

- **Total energy demand in road transport**

$$RDTTT = 37.9381*CONS + 0.7211E\text{-}5*MGDP - 0.011166*RPOIL + 0.14203*RDTTT(-1)$$

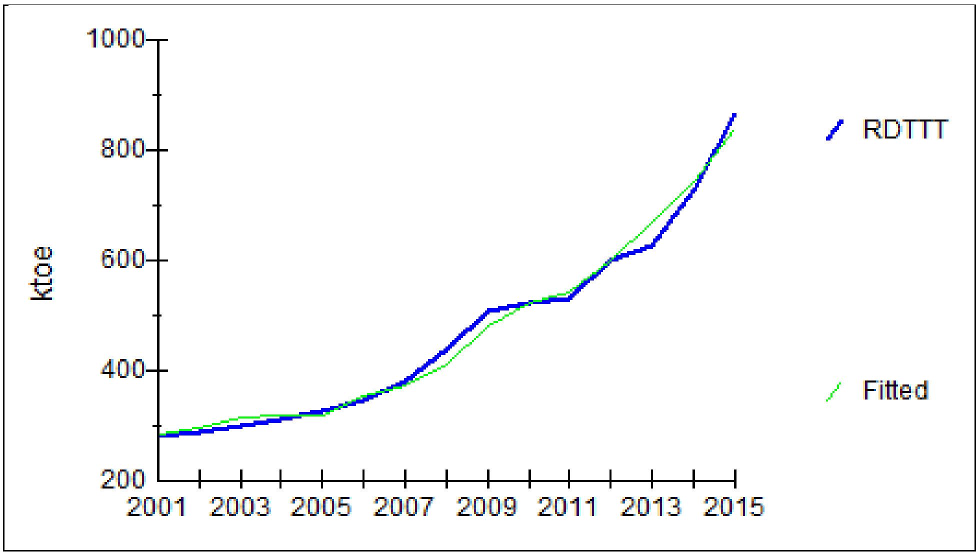
Table A4.3 Ordinary Least Squares Estimation for RDTTT

```
*******************************************************************************
 Dependent variable is RDTTT
 15 observations used for estimation from 2001 to 2015
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                       37.9381              30.8044            1.2316[.244]
 MGDP                       .7211E-5             .2452E-5           2.9405[.013]
 RPOIL                      -.011166             .0032606          -3.4245[.006]
 RDTTT(-1)                  .14203               .35211             .40338[.694]
*******************************************************************************
 R-Squared                     .98892   R-Bar-Squared                   .98590
 S.E. of Regression           21.0531   F-stat.    F(  3,  11)  327.2701[.000]
 Mean of Dependent Variable  470.0620   S.D. of Dependent Variable    177.2902
 Residual Sum of Squares       4875.6   Equation Log-likelihood       -64.6636
 Akaike Info. Criterion      -68.6636   Schwarz Bayesian Criterion    -70.0797
 DW-statistic                  1.3290   Durbin's h-statistic            *NONE*

*******************************************************************************
```

RDTT = total energy demand in road transport, CONS = constant, MGDP = gross domestic product, RPOIL = real price of crude oil, RDTT(-1) = total energy demand in road transport in the previous year.
Source: Microfit analysis result.

Figure A4.3 Plot of Actual and Fitted Values for RDTTT



ktoe = thousand tons of oil equivalent, RDTT = total energy demand in road transport.
Source: Microfit analysis result.

- **Jet fuel demand for domestic aviation transport**

$$TSJF = -\ 0.063395*CONS + 0.076231*AVTT$$

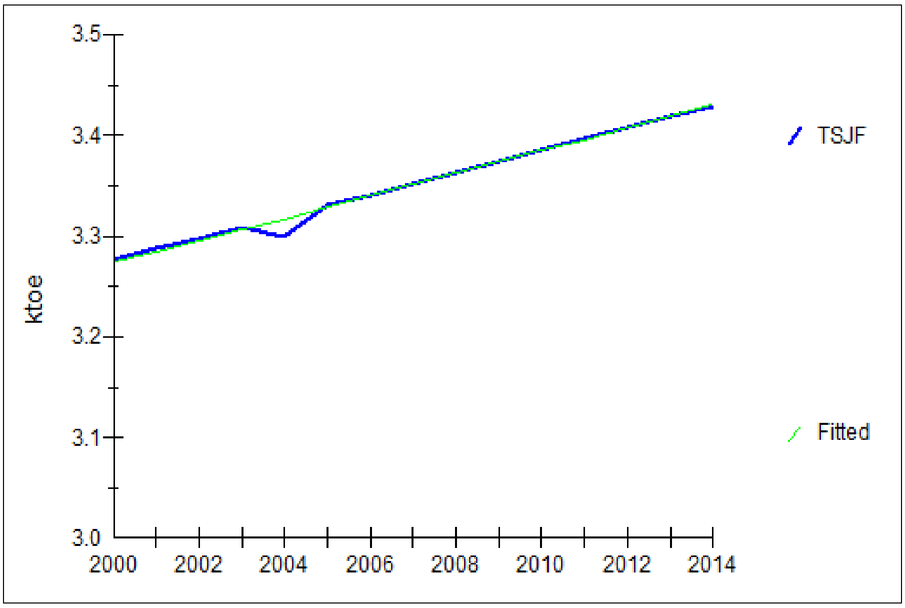
Table A4.4 Ordinary Least Squares Estimation forTSJF

```
*******************************************************************************
 Dependent variable is TSJF
 15 observations used for estimation from 2000 to 2014
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     -.063395            .087224            -.72681[.480]
 AVTT                      .076231            .0019470           39.1521[.000]
*******************************************************************************
 R-Squared                      .99159   R-Bar-Squared                   .99094
 S.E. of Regression           .0047659   F-stat.    F(  1,  13)    1532.9[.000]
 Mean of Dependent Variable     3.3513   S.D. of Dependent Variable     .050081
 Residual Sum of Squares      .2953E-3   Equation Log-likelihood        59.9831
 Akaike Info. Criterion        57.9831   Schwarz Bayesian Criterion     57.2750
 DW-statistic                   2.2219

******************************************************************************
```

TSJF = domestic aviation transport, CONS = constant, AVTT=total energy demand for aviation transport.
Source: Microfit analysis result.

Figure A4.4 Plot of Actual and Fitted Values for TSJF



ktoe = thousand tons of oil equivalent, TSJF=domestic aviation transport.
Source: Microfit analysis result.

3. Residential Sector

- **Total energy demand**

$$RETT = 101.3128*CONS - 9.8821*RERPELC + 0.2835E\text{-}4*POP + 0.81543*RETT(-1) + 70.1772*DUM0608$$

Table A4.5 Ordinary Least Squares Estimation for RETT

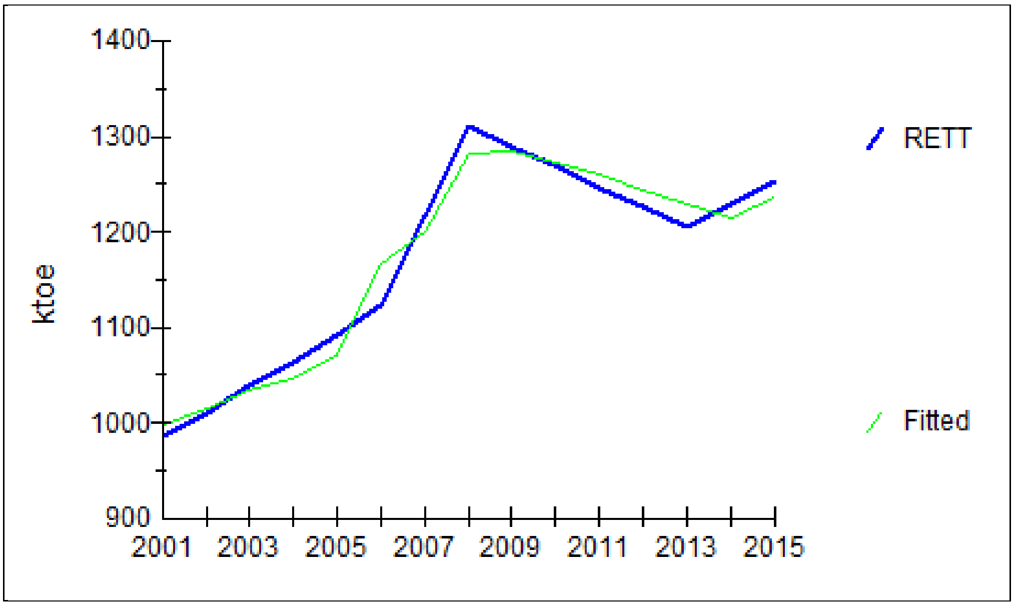
Dependent variable is RETT
15 observations used for estimation from 2001 to 2015

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONS	101.3128	106.3270	.95284[.363]
RERPELC	-9.8821	11.7774	-.83907[.421]
POP	.2835E-4	.3140E-4	.90299[.388]
RETT(-1)	.81543	.11105	7.3430[.000]
DUM0608	70.1772	15.6485	4.4846[.001]

R-Squared	.96642	R-Bar-Squared	.95299
S.E. of Regression	23.4325	F-stat. F(4, 10)	71.9510[.000]
Mean of Dependent Variable	1170.4	S.D. of Dependent Variable	108.0736
Residual Sum of Squares	5490.8	Equation Log-likelihood	-65.5549
Akaike Info. Criterion	-70.5549	Schwarz Bayesian Criterion	-72.3251
DW-statistic	1.9281	Durbin's h-statistic	.15419[.877]

RETT = total energy demand in the residential sector, CONS = constant, RERPELC = the residential real price of electricity, POP = population, RETT(-1) = total energy demand in the residential sector in the previous year, DUM0608= dummy variable for the years of 2006–2008.
Source: Microfit analysis result.

Figure A4.5 Plot of Actual and Fitted Values for RETT



ktoe = thousand tons of oil equivalent, RETT = total energy demand in the residential sector.
Source: Microfit analysis result.

- **Electricity demand**

$$REEL = -18.3522*CONS - 1.6288*RERPELC + 5.6521*GDPC + 0.62271*REEL(-1)$$

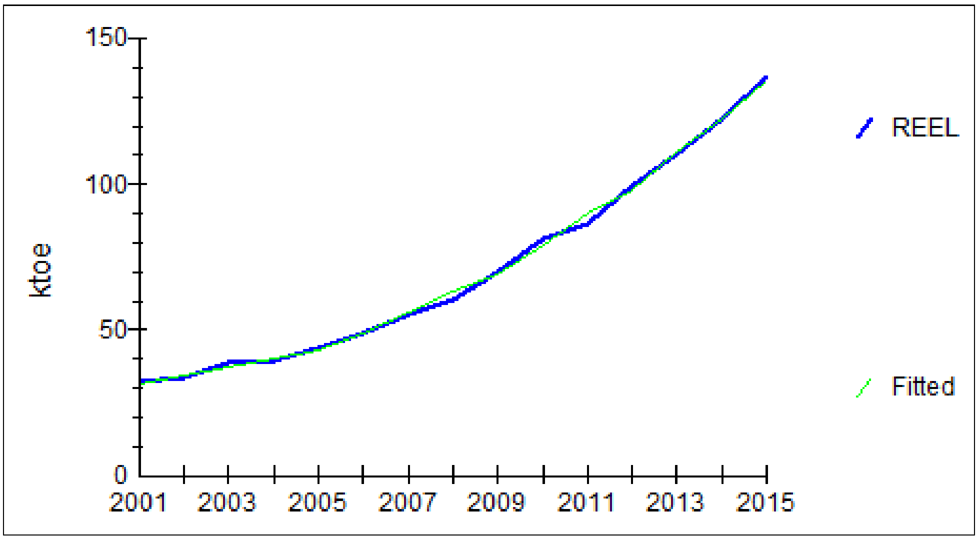
Table A4.6 Ordinary Least Squares Estimation for REEL

```
*******************************************************************************
 Dependent variable is REEL
 15 observations used for estimation from 2001 to 2015
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     -18.3522            9.2434              -1.9854[.073]
 RERPELC                   -1.6288            1.0132              -1.6076[.136]
 GDPC                       5.6521            2.2208               2.5451[.027]
 REEL(-1)                   .62271            .19808               3.1437[.009]
*******************************************************************************
 R-Squared                     .99732   R-Bar-Squared                   .99659
 S.E. of Regression            1.9884   F-stat.    F(  3,  11)    1363.5[.000]
 Mean of Dependent Variable   70.6347   S.D. of Dependent Variable     34.0341
 Residual Sum of Squares      43.4919   Equation Log-likelihood       -29.2680
 Akaike Info. Criterion      -33.2680   Schwarz Bayesian Criterion    -34.6841
 DW-statistic                  2.8493   Durbin's h-statistic      -2.5640[.010]

*******************************************************************************
```

REEL = electricity demand in the residential sector, CONS = constant, RERPELC = the residential real price of electricity, GDPC = GDP per capita, REEL (-1) = electricity demand in the residential sector in the previous year.
Source: Microfit analysis result.

Figure A4.6 Plot of Actual and Fitted Values for REEL



ktoe = thousand tons of oil equivalent, REEL = electricity demand in the residential sector.
Source: Microfit analysis result.

4. Commercial Sector

- **Total energy demand**

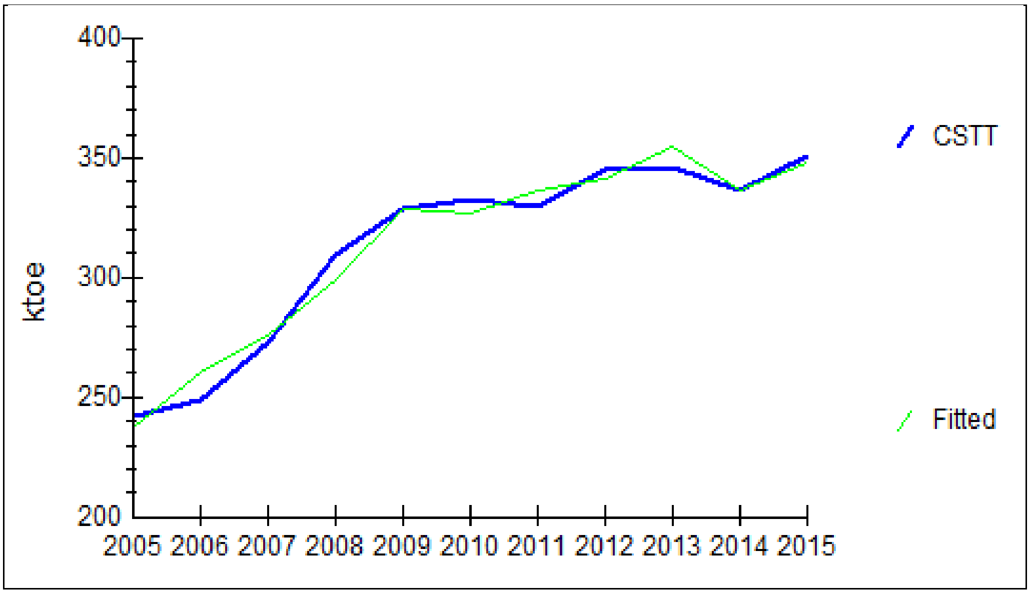
$$CSTT = 336.5932*CONS - 12.7326*CSRPELC + 0.9150E\text{-}6*MCSGDP + 0.28293*CSTT(-1) + 19.4497*DUM09 - 19.9742*DUM14$$

Table A4.7 Ordinary Least Squares Estimation for CSTT

```
*******************************************************************************
 Dependent variable is CSTT
 11 observations used for estimation from 2005 to 2015
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     336.5932           120.8273              2.7857[.039]
 CSRPELC                  -12.7326             5.3545             -2.3779[.063]
 MCSGDP                   .9150E-6           .9425E-6              .97091[.376]
 CSTT(-1)                   .28293             .24849              1.1386[.306]
 DUM09                     19.4497            10.8702              1.7893[.134]
 DUM14                    -19.9742            10.7942             -1.8505[.123]
*******************************************************************************
 R-Squared                    .97296   R-Bar-Squared                    .94591
 S.E. of Regression           9.2407   F-stat.    F(  5,   5)   35.9787[.001]
 Mean of Dependent Variable 313.1328   S.D. of Dependent Variable      39.7342
 Residual Sum of Squares    426.9513   Equation Log-likelihood        -35.7316
 Akaike Info. Criterion     -41.7316   Schwarz Bayesian Criterion     -42.9253
 DW-statistic                 2.5790   Durbin's h-statistic       -1.6953[.090]
*******************************************************************************
```

CSTT = total energy demand in the commercial sector, CONS = constant, CSRPELC = the commercial real price of electricity, MCSGDP = commercial GDP, CSTT(-1) = total energy demand in the commercial sector in the previous year, DUM09 = dummy variable at the year of 2009, DUM14 = dummy variable for the year of 2014.
Source: Microfit analysis result.

Figure A4.7 Plot of Actual and Fitted Values for CSTT



CSTT = total energy demand in the commercial sector, ktoe= thousand tons of oil equivalent.
Source: Microfit analysis result.

- **Electricity demand**

$$CSEL = 104.8994*CONS - 8.2225*CSRPELC + 0.1266E\text{-}5*MCSGDP + 15.6876*DUM12 - 14.7276*DUM14$$

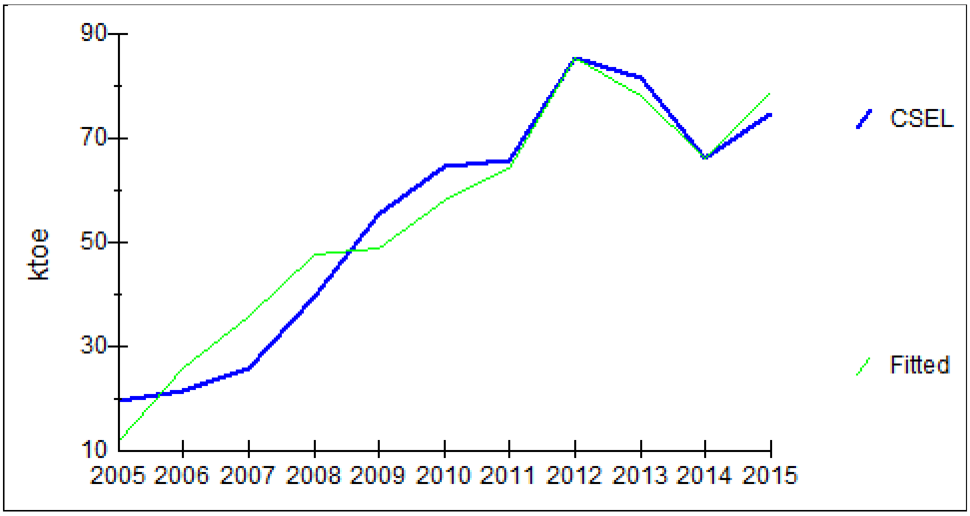
Table A4.8 Ordinary Least Squares Estimation for CSEL

```
*******************************************************************************
 Dependent variable is CSEL
 11 observations used for estimation from 2005 to 2015
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     104.8994            47.5697             2.2052[.070]
 CSRPELC                   -8.2225             2.7448            -2.9957[.024]
 MCSGDP                   .1266E-5           .6865E-6             1.8443[.115]
 DUM12                     15.6876             8.6229             1.8193[.119]
 DUM14                    -14.7276             9.1915            -1.6023[.160]
*******************************************************************************
 R-Squared                      .93743   R-Bar-Squared                   .89571
 S.E. of Regression             7.7740   F-stat.    F(  4,   6)   22.4720[.001]
 Mean of Dependent Variable    54.5322   S.D. of Dependent Variable     24.0728
 Residual Sum of Squares      362.6109   Equation Log-likelihood       -34.8332
 Akaike Info. Criterion       -39.8332   Schwarz Bayesian Criterion    -40.8280
 DW-statistic                   1.3019

*******************************************************************************
```

CSEL = electricity demand in the commercial sector, CONS=constant ,CSRPELC = the commercial real price of electricity, MCSGDP = commercial GDP, DUM12 = dummy variable at the year of 2012, DUM14 = dummy variable at the year of 2014.
Source: Microfit analysis result.

Figure A4.8 Plot of Actual and Fitted Values for CSEL



CSEL = electricity demand in the commercial sector, ktoe= thousand tons of oil equivalent.

Source: Microfit analysis result.

- **LPG demand**

$$CSLP = 0.0035573*CONS - 0.8711E\text{-}5*RPOIL + 0.9167E\text{-}8*MCSGDP + 0.91328*CSLP(-1) + 0.12769*DUM06 + 0.27396*DUM11$$

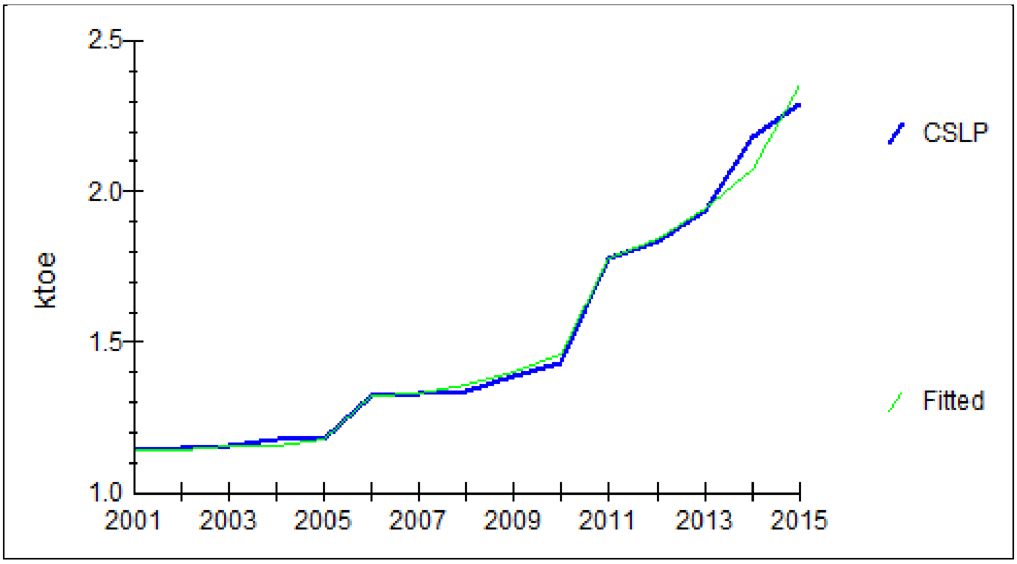
Table A4.9 Ordinary Least Squares Estimation for CSLP

```
*******************************************************************************
 Dependent variable is CSLP
 15 observations used for estimation from 2001 to 2015
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                     .0035573            .14778              .024071[.981]
 RPOIL                   -.8711E-5           .8196E-5             -1.0629[.316]
 MCSGDP                   .9167E-8           .7317E-8              1.2528[.242]
 CSLP(-1)                   .91328            .19316               4.7281[.001]
 DUM06                      .12769           .050137               2.5469[.031]
 DUM11                      .27396           .055377               4.9471[.001]
*******************************************************************************
 R-Squared                     .99125   R-Bar-Squared                   .98639
 S.E. of Regression           .045644   F-stat.    F(  5,   9)  203.9077[.000]
 Mean of Dependent Variable    1.5094   S.D. of Dependent Variable      .39123
 Residual Sum of Squares      .018751   Equation Log-likelihood        28.8503
 Akaike Info. Criterion       22.8503   Schwarz Bayesian Criterion     20.7261
 DW-statistic                  2.5403   Durbin's h-statistic      -1.5768[.115]

*******************************************************************************
```

CSLP = LPG demand in the commercial sector, CONS = constant, RPOIL = real price of crude oil, MCSGDP = commercial GDP, CSLP(-1) = LPG demand in the commercial sector in the previous year, DUM06= dummy variable for the year of 2006, DUM11= dummy variable for the year of 2011.
Source: Microfit analysis result.

Figure A4.9 Plot of Actual and Fitted Values for CSLP



CSLP = LPG demand in the commercial sector, ktoe= thousand tons of oil equivalent.
Source: Microfit analysis result.

5. Other Key Variables

- **GDP deflator**

$$PGDP = 3.9492*CONS + 0.063211*POILJ + 0.95527*PGDP(-1)$$

Table A4.10 Ordinary Least Squares Estimation for PGDP

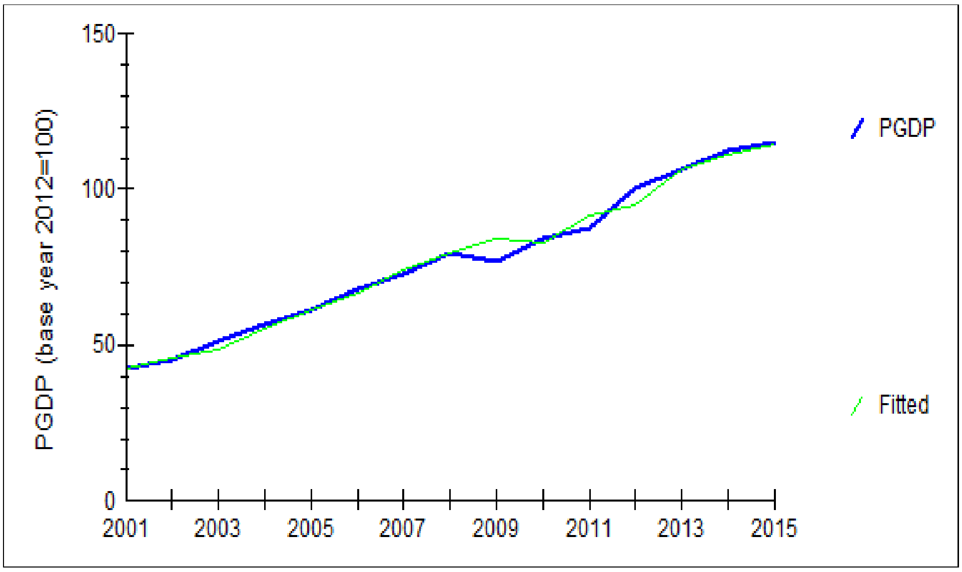
Dependent variable is PGDP
15 observations used for estimation from 2001 to 2015

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONS	3.9492	2.5441	1.5523[.147]
POILJ	.063211	.034247	1.8457[.090]
PGDP(-1)	.95527	.046218	20.6685[.000]

R-Squared	.98703	R-Bar-Squared	.98487
S.E. of Regression	2.9372	F-stat. F(2, 12)	456.5266[.000]
Mean of Dependent Variable	77.2977	S.D. of Dependent Variable	23.8758
Residual Sum of Squares	103.5285	Equation Log-likelihood	-35.7726
Akaike Info. Criterion	-38.7726	Schwarz Bayesian Criterion	-39.8346
DW-statistic	2.5993	Durbin's h-statistic	-1.1796[.238]

PGDP = GDP deflator, CONS = constant, POILJ = the price of crude oil, PGDP(-1) = GDP deflator in the previous year.
Source: Microfit analysis result.

Figure A4.10 Plot of Actual and Fitted Values for PGDP



PGDP = GDP deflator.
Source: Microfit analysis result.

- **Industrial GDP**

$$MINGDP = -4101490*CONS + 0.19218*MGDP + 0.59237*MINGDP(-1)$$

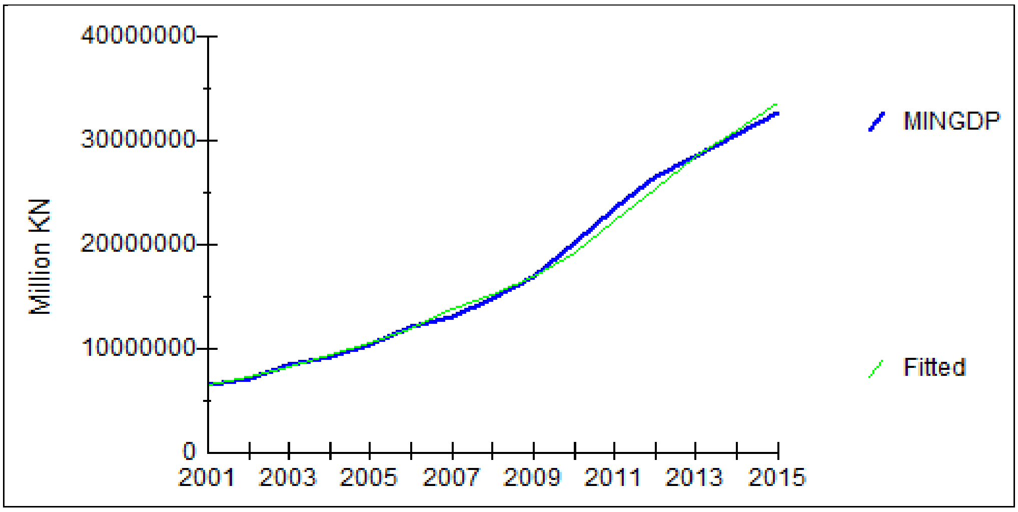
Table A4.11 Ordinary Least Squares Estimation for INGDP

```
*******************************************************************************
 Dependent variable is MINGDP
 15 observations used for estimation from 2001 to 2015
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                      -4101490            2290085            -1.7910[.099]
 MGDP                        .19218            .091138             2.1086[.057]
 MINGDP(-1)                  .59237             .22843             2.5932[.024]
*******************************************************************************
 R-Squared                     .99555   R-Bar-Squared                    .99481
 S.E. of Regression          648481.8   F-stat.    F(  2,  12)     1343.7[.000]
 Mean of Dependent Variable  1.73E+07   S.D. of Dependent Variable      9004807
 Residual Sum of Squares     5.05E+12   Equation Log-likelihood       -220.3463
 Akaike Info. Criterion     -223.3463   Schwarz Bayesian Criterion    -224.4084
 DW-statistic                  .88296   Durbin's h-statistic       4.6403[.000]

*******************************************************************************
```

INGDP = Industrial GDP, CONS = constant, MINGDP(-1) = industrial GDP in the previous year.
Source: Microfit analysis result.

Figure A4.11 Plot of Actual and Fitted Values for INGDP



KN = Lao kip, INGDP = Industrial GDP.
Source: Microfit analysis result.

- **Manufacturing GDP**

$$MMFGGDP = 148716.0*CONS + 0.012981*MGDP + 0.89060*MMFGGDP(-1)$$

Table A4.12 Ordinary Least Squares Estimation for MFGGDP

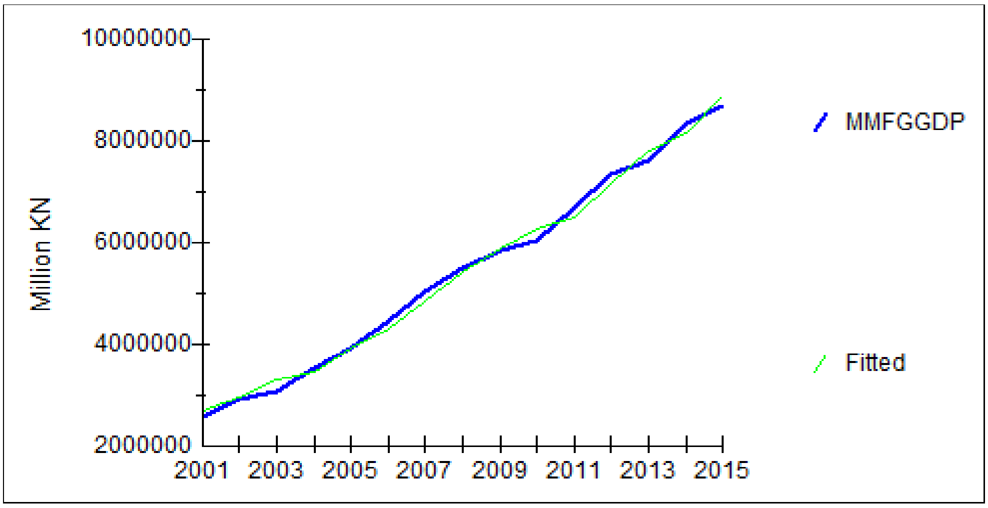
Dependent variable is MMFGGDP
15 observations used for estimation from 2001 to 2015

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONS	148716.0	230113.8	.64627[.530]
MGDP	.012981	.019290	.67294[.514]
MMFGGDP(-1)	.89060	.20832	4.2753[.001]

R-Squared	.99352	R-Bar-Squared	.99244
S.E. of Regression	174642.7	F-stat. F(2, 12)	919.6464[.000]
Mean of Dependent Variable	5433333	S.D. of Dependent Variable	2008278
Residual Sum of Squares	3.66E+11	Equation Log-likelihood	-200.6680
Akaike Info. Criterion	-203.6680	Schwarz Bayesian Criterion	-204.7300
DW-statistic	2.2636	Durbin's h-statistic	-.86410[.388]

MMFGGDP = manufacturing GDP, CONS = constant, MGDP = gross domestic product, MMFGGDP(-1) = manufacturing GDP in the previous year.
Source: Microfit analysis result.

Figure A4.12 Plot of Actual and Fitted Values for MFGGDP



KN = Lao kip, MMFGGDP = manufacturing GDP.
Source: Microfit analysis result

- **Commercial GDP**

$$MCSGDP = -235667.1*CONS + 0.15436*MGDP + 0.68017*MCSGDP(-1)$$

Table A4.13 Ordinary Least Squares Estimation forCSGDP

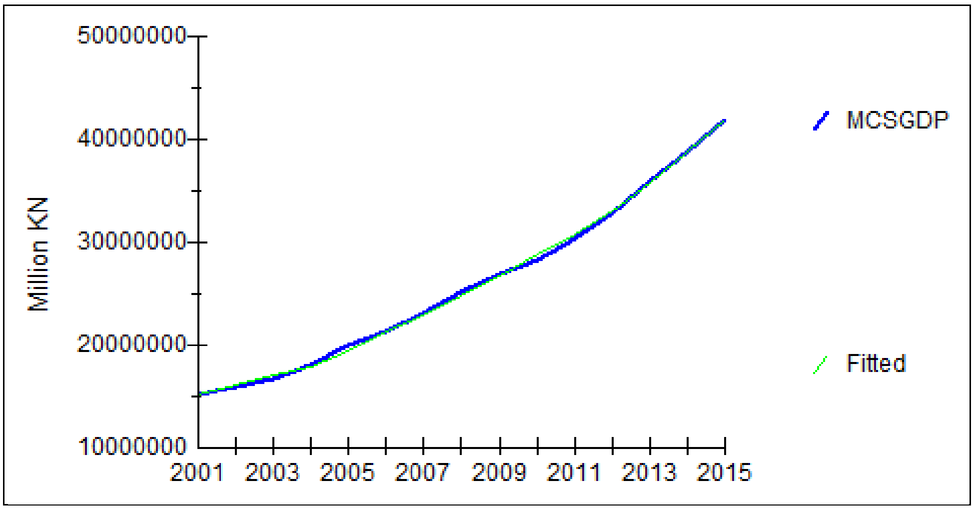
Dependent variable is MCSGDP
15 observations used for estimation from 2001 to 2015

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONS	-235667.1	288128.8	-.81792[.429]
MGDP	.15436	.092351	1.6714[.120]
MCSGDP(-1)	.68017	.24692	2.7546[.017]

R-Squared	.99884	R-Bar-Squared	.99864
S.E. of Regression	316236.6	F-stat. F(2, 12)	5149.2[.000]
Mean of Dependent Variable	2.60E+07	S.D. of Dependent Variable	8581930
Residual Sum of Squares	1.20E+12	Equation Log-likelihood	-209.5742
Akaike Info. Criterion	-212.5742	Schwarz Bayesian Criterion	-213.6363
DW-statistic	1.4154	Durbin's h-statistic	3.8732[.000]

MCSGDP = commercial GDP, CONS = constant, MGDP = gross domestic product, MCSGDP(-1) = commercial GDP in the previous year.
Source: Microfit analysis result.

Figure A4.13 Plot of Actual and Fitted Values for CSGDP



KN = Lao kip, MCSGDP = commercial GDP.
Source: Microfit analysis result.

- **Industrial price of electricity**

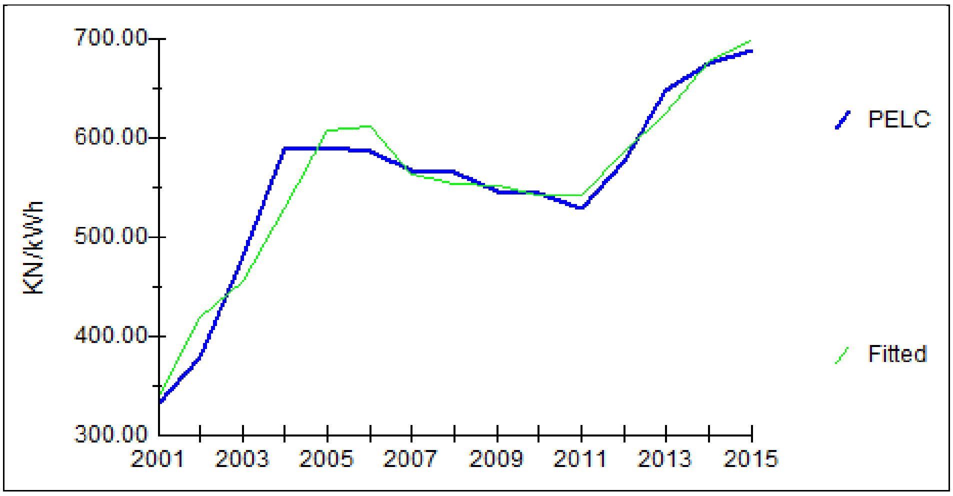
$$PELC = 161.9270*CONS + 0.55127*PGDP + 0.69916*PELC(-1) - 48.7882*DUM0711$$

Table A4.14: Ordinary Least Squares Estimation forPELC

```
*******************************************************************************
 Dependent variable is PELC
 15 observations used for estimation from 2001 to 2015
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                      161.9270              31.1829            5.1928[.000]
 PGDP                        .55127               .48157            1.1447[.277]
 PELC(-1)                    .69916              .096019            7.2815[.000]
 DUM0711                   -48.7882              15.2450           -3.2003[.008]
*******************************************************************************
 R-Squared                     .94045   R-Bar-Squared                     .92421
 S.E. of Regression           26.6848   F-stat.    F(  3,  11)    57.9034[.000]
 Mean of Dependent Variable  553.0340   S.D. of Dependent Variable       96.9273
 Residual Sum of Squares       7832.9   Equation Log-likelihood         -68.2194
 Akaike Info. Criterion      -72.2194   Schwarz Bayesian Criterion      -73.6355
 DW-statistic                  2.0270   Durbin's h-statistic        -.056408[.955]
*******************************************************************************
```

PELC = industrial price of electricity, CONS = constant, PELC(-1) = industrial price of electricity in the previous year, DUM0711 = dummy variable at the years of 2007–2011.
Source: Microfit analysis result.

Figure A4.14 Plot of Actual and Fitted Values for PELC



KN = Lao kip; kWh = kilowatt-hour, PELC = industrial price of electricity.
Source: Microfit analysis result.

- **Residential price of electricity**

$$REPELC = 17.4258*CONS + 2.6132*PGDP + 0.53734*REPELC(-1)$$

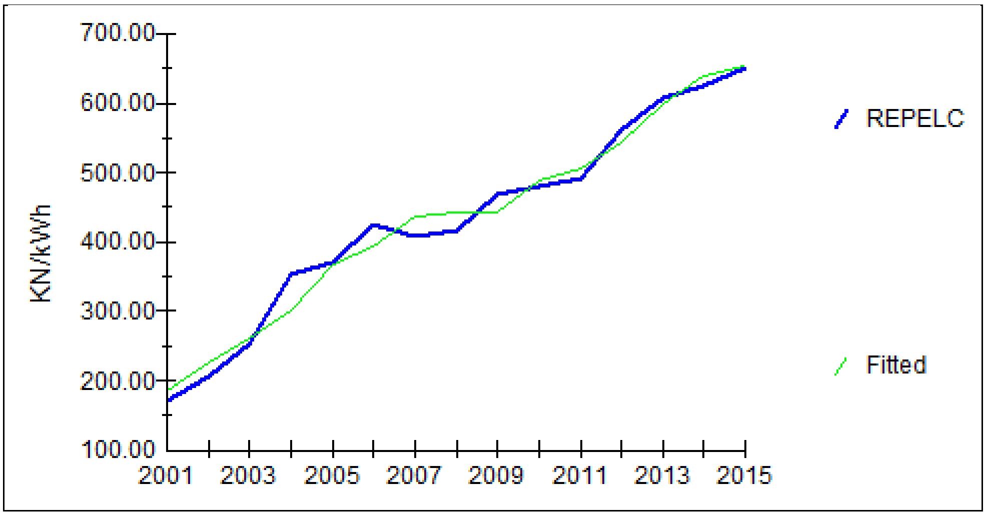
Table A4.15 Ordinary Least Squares Estimation for REPELC

```
*******************************************************************************
 Dependent variable is REPELC
 15 observations used for estimation from 2001 to 2015
*******************************************************************************
 Regressor              Coefficient       Standard Error         T-Ratio[Prob]
 CONS                       17.4258              29.3288            .59415[.563]
 PGDP                        2.6132               1.2494            2.0916[.058]
 REPELC(-1)                  .53734               .19136            2.8080[.016]
*******************************************************************************
 R-Squared                     .97429   R-Bar-Squared                    .97001
 S.E. of Regression           25.4770   F-stat.     F(  2,  12)  227.4023[.000]
 Mean of Dependent Variable  432.3640   S.D. of Dependent Variable     147.1135
 Residual Sum of Squares       7789.0   Equation Log-likelihood        -68.1772
 Akaike Info. Criterion      -71.1772   Schwarz Bayesian Criterion     -72.2392
 DW-statistic                  2.1426   Durbin's h-statistic      -.41138[.681]

*******************************************************************************
```

REPELC = residential price of electricity, CONS = constant, PGDP = GDP deflator, REPELC(-1)= residential price of electricity in the previous year.
Source: Microfit analysis result.

Figure A4.15 Plot of Actual and Fitted Values for REPELC



kWh = kilowatt-hour, KN = Lao kip, REPELC = residential price of electricity.
Source: Microfit analysis result.

- **Commercial price of electricity**

$$CSPELC = 75.5422*CONS + 8.5988*PGDP + 251.3462*DUM0206 + 126.7228*DUM0709$$

Table A4.16 Ordinary Least Squares Estimation for CSPELC

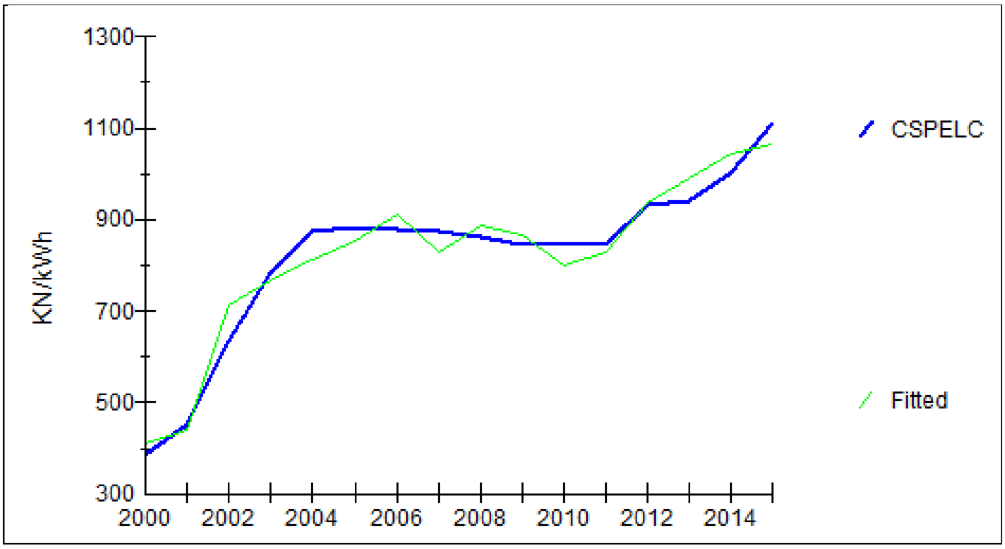
Dependent variable is CSPELC
16 observations used for estimation from 2000 to 2015

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
CONS	75.5422	50.3153	1.5014[.159]
PGDP	8.5988	.55517	15.4886[.000]
DUM0206	251.3462	30.6202	8.2085[.000]
DUM0709	126.7228	31.1180	4.0723[.002]

R-Squared	.95286	R-Bar-Squared	.94107
S.E. of Regression	45.3103	F-stat. F(3, 12)	80.8451[.000]
Mean of Dependent Variable	821.8325	S.D. of Dependent Variable	186.6487
Residual Sum of Squares	24636.2	Equation Log-likelihood	-81.4181
Akaike Info. Criterion	-85.4181	Schwarz Bayesian Criterion	-86.9633
DW-statistic	2.1057		

CSPELC = commercial price of electricity, CONS = constant, PGDP = GDP deflator, DUM0206 = dummy variable for the years of 2002–2006, DUM0709 = dummy variable for the years of 2007–2009.
Source: Microfit analysis result.

Figure A4.16 Plot of Actual and Fitted Values for CSPELC



CSPELC = commercial price of electricity, kWh = kilowatt-hour, KN = Lao kip.
Source: Microfit analysis result.

Chapter 5

Model Assumptions

Minh Bao Nguyen

This chapter focuses on model assumptions for projecting future energy demand and greenhouse gas emissions in the Business-As-Usual (BAU) scenario and other scenarios in the case studies. These assumptions used were based on the future values of macroeconomic, energy price, and other activity indicators such as electricity generation technologies, as well as energy development policies.

5.1 Macroeconomic Assumptions

Population: In 2015, the total population in the Lao People's Democratic Republic (Lao PDR) was 6.49 million. The population is projected to increase at an average annual rate of about 1.5%, reaching about 9.42 million in 2040. It is assumed that there is no difference in population between the BAU scenario and other scenarios in the case studies.

GDP: The Lao PDR's gross domestic product (GDP) grew at an average annual rate of 8.0% during 2005–2010, and was slightly down to 7.8% during 2010–2015. The GDP is assumed to grow at an average annual rate of 7.1% during 2016–2020, followed by 6.4% and 5.7% for the periods of 2020–2030 and 2030–2040, respectively. These projections are used for the development of the BAU scenario and also used as a base for the scenario of changes in the GDP in the case studies.

The assumptions on the growth of the GDP and population are shown in Table 5.1.

Table 5.1 Assumption on Annual Average Growth of GDP and Population

Period	GDP Growth (%)	Population Growth (%)
2015–2020	7.1	1.5
2020–2030	6.4	1.5
2030–2040	5.7	1.5

GDP = gross domestic product.
Source: Author's assumptions based on consultation with relevant ministries.

5.2 Crude Oil Price

Future changes in crude oil prices remain highly uncertain. In this study, the crude oil price, as referred to Japan's average import price (nominal dollars per barrel), is assumed to increase from US$49 a barrel in 2015 to US$80 a barrel in 2020, US$150 a barrel in 2030, and US$200 a barrel in 2040. These assumptions are used for the development of the BAU scenario and also used as a base for the scenario of high oil prices in the case studies.

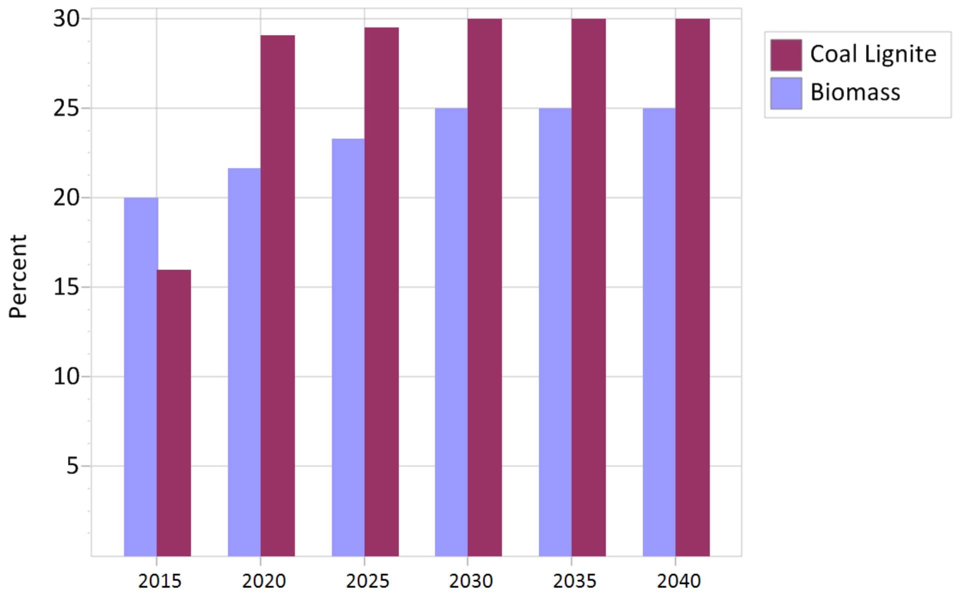
5.3 Electricity Generation Technologies

Electricity generation thermal efficiency

The thermal efficiency of electricity generation reflects the amount of fuel required to generate a unit of electricity. Thermal efficiency was set exogenously based on the historical data in electricity generation and development trends in the future.

The base year 2015 thermal efficiency by fuel type (coal and biomass) was derived from the 2010–2017 energy balance tables. Thermal efficiency is expected to improve considerably over time in the BAU scenario as more advanced generation technologies become available.

Figure 5.1 Thermal Efficiency of Coal and Biomass Power Plants up to 2040



Source: Author's assumptions based on consultation with experts from the Ministry of Energy and Mines.

Electricity generation fuel mix

The fuel mix used in electricity generation is an important input for the energy outlook, because it is a key driver for primary energy demand and greenhouse gas emissions. It was also an exogenous input to the model.

The main sources of electricity generation in the Lao PDR are hydropower plants and one coal-fired power plant. According to the Mekong River Commission study in 1995, the Lao PDR has a large potential hydropower source of 26,000 megawatts (MW) (ERIA, 2019). By 2015, the total installed capacity of hydropower reached 3,737 MW accounting for 16.2% of total potential hydropower. It is assumed that around 15,000 MW and 20,000 MW capacity of hydropower would be installed by 2030 and 2040, respectively. Hydropower plants provide electricity to both domestic customers (through the grid) and foreign markets (Thailand and Viet Nam).

The Lao PDR also has a considerable potential coal source, mostly as lignite in Hongsa in Xayabouly province. By 2015, the total installed capacity of the Hongsa coal-fired thermal plant was 1,878 MW. This capacity assumed would reach to around 3,000 MW and 3,500 MW by 2030 and 2040, respectively.

By 2015, a total power capacity of 5,641 MW had been developed and produced around 17,099 gigawatt hours (GWh) of electricity for both domestic consumption and export. Electricity generation is mainly from hydropower, accounting for nearly 85.1% (equivalent to 14,543 GWh), the remaining shares are the coal-fired thermal power plant (14.9%) and negligible renewable energy (RE).

The share of electricity generated at the coal-fired thermal power plant is projected to increase considerably, from 14.9% in 2015 to 22.5% in 2040, while hydropower will slightly decrease from 85.1% in 2015 to 77.1% in 2040. The remaining share of 0.4% by 2040 is coming from RE sources.

5.4 Other Energy Development Policies

The Lao PDR does not have a comprehensive national energy policy setting out a systematic approach to energy planning, policy formulation, and sector development. However, the government has issued a Law on Electricity, as well as policies, strategies, and plans for large hydropower and RE resources. The present strategic and planning approach is essentially concentrated on the development of the country’s potential hydropower resources to meet domestic as well as export demands. RE use and technology development, on the other hand, are explicitly covered in the national RE development strategies.

The existing laws, regulations, policies, strategies, and development plans are summarised as follows:

Law on Electricity: The Law on Electricity was amended in 2011 and enacted on 20 December 2011 by replacing the earlier Law on Electricity notified on 8 December 2008. The Law on Electricity specifies the principles, rules, and measures on the organisation, operation, management, and inspection of electrical activities for the high effectiveness of electricity generation and business operation.

Renewable Energy Development Strategy: The strategy issued in October 2011 is the main policy framework for the development of RE in the country. The strategy sets a target of increasing the share of RE in total energy consumption to 30% by 2025. The government also aims to increase the share of biofuels to meet 10% of the demand for transport fuels by 2025.

Policy on Sustainable Hydropower Development in the Lao PDR: The policy applies to all hydropower projects larger than 15 MW throughout the project development process (planning, construction, operation, and transfer/closure stages) and incorporates technical, engineering, economic and finance, and environment and social impacts aspects. At present, the policy is under the revision process conducted by the Ministry of Energy and Mines.

Power Development Plan: Article 9 of the Electricity Law states that the electricity enterprise shall prepare the electricity development plan. Électricité du Laos (EDL) prepares the Power Development Plan (PDP) every 3to 5years. EDL formulated the PDP 2010–2020 in August 2010, revising the former PDP 2007–2017. In August 2011, EDL updated PDP 2010–2020 by reflecting the latest electricity demand forecast and prospective project developments in the generation and transmission sector.

Energy Efficiency and Conservation (EEC): The National Socio-Economic Development Plan (2006–2010), published in October 2006, stated a policy to promote environment management and, moreover, clean and highly-energy efficient technologies and industrial development in the industry and construction sectors. The Lao PDR is a developing country with relatively small energy consumption, and accordingly, there is no specific national strategy for energy saving. But the country is considering the development of an energy-saving strategy and policy with the support provided by the Asian Development Bank. An energy-saving act has not been developed, but there is a plan to develop one within several years.

The Law on Electricity (enacted in 2011) stipulates that the responsible ministries and agencies establish, approve, and test the quality of domestically produced or imported electrical equipment in order to secure the safety and energy-saving capability of electric machinery and equipment.

Currently, EEC in the Lao PDR is at an early stage. There are several EEC activities in the commercial and residential sectors focusing on energy saving of lighting equipment. A plan to reduce the energy consumption by government institutions by 10% between 2006 and 2007 was implemented. Moreover, the current energy saving target is also set by the government aiming to reduce energy intensity by 10% by 2025.

5.5 Case Studies

The BAU scenario was developed based on the above assumptions, accordingly, energy demand and supply are projected based on the relation between energy consumption and the macroeconomic indicators such as GDP, oil price, population, as well as policies on energy development, assuming that there would be a lack of additional policies to promote EEC and RE development.

The above indicators and energy policies may be variable: that is the reason why we need to evaluate the impacts of these variables on energy demand, supply, and CO2 emissions.

In this study, some case studies are implemented including changes in the GDP, high oil price, additional EE promotion, and RE development with assumptions as follows:

1) Changes in GDP: It is assumed that the GDP annual growth rate could increase or decrease with an additional ±1% (compared to the BAU scenario) as shown in Table 5.2.

Table 5.2 Changes in GDP Annual Growth Rate

Unit: KN trillion

Scenario	2015	2020	2025	2030	2035	2040	AAGR 2015–2040
BAU	101.8	142.5	194.3	263.2	347.2	458.2	6.2%
GDP increasing 1%	101.8	149.3	213.3	302.8	418.7	579.1	7.2%
GDP decreasing 1%	101.8	135.9	176.8	228.5	287.4	361.7	5.2%

AAGR = annual growth rate, BAU = Business-As-Usual, GDP = gross domestic product, KN= kip.
Source: Prepared by author.

2) Higher oil price: It is assumed that the crude oil price could increase from US$150 by 2030 and US$200 by 2040 in the BAU scenario to US$200 by 2030 and US$250 by 2040, respectively.
3) EEC promotion: It is assumed that the total final energy consumption (TFEC) would reduce by 10% (case 1 of EEC10) and 20% (case 2 of EEC20) compared to the BAU scenario through EEC activities in 2040.
4) RE development: It is assumed that the share of power generation outputs from RE sources (solar and wind) could reach 10% (case 1 of RE10) and 20% (case 2 of RE20) of the total power generation (compared to a negligible share under the BAU scenario) by 2040. These additional increases are assumed for replacing the coal-fired power plant.

   The maximum capacity factor of wind and solar power plants are 20% and 15%, respectively, while the coal-fired power plant's maximum factor capacity is 75% (or around 6,600 hours operation per year). It means that 5 MW of solar could be replaced only for around 1 MW of the coal-fired power plant at the same amount of power generation outputs.

References

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

Chapter 6

Assessment of Future Simulation Results

Shigeru Kimura

There were several scenarios or cases studied for the Lao People's Democratic Republic (Lao PDR) Energy Outlook as described in Chapter 5. The base case is defined as the Business-As-Usual (BAU) scenario. The other cases studies are the gross domestic product (GDP) scenarios, oil price scenarios, energy efficiency and conservation (EEC) promotion scenarios, and renewable energy (RE) development scenarios.

This chapter provides the result of the simulation runs for the BAU scenario and the other case studies.

6.1 Business-As-Usual Scenario

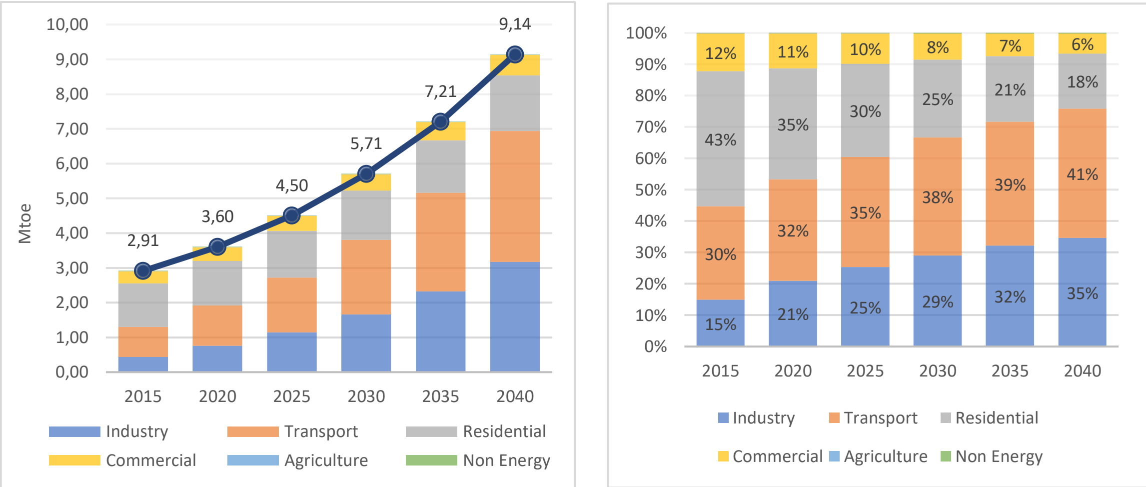
The BAU scenario is developed based on the assumptions that the Lao PDR's demand for energy will continue to increase based on historical trends and future growth in the GDP, population, and oil price in the absence of additional policies for EEC and RE promotion. Table A6.1 and Table A6.2 (see Annex) are the base year (2015) and the projected 2040 Energy Balance of the Lao PDR.

Final energy consumption

The total final energy consumption (TFEC) of the Lao PDR increased at an average rate of 4.5% per year, from 1.5 million tons of oil equivalent (Mtoe) in 2000 to 2.9 Mtoe in 2015. Given the assumed economic and population growth, the growth in the TFEC will continue at a slightly higher rate of 4.7% per year during 2015–2040 under the BAU scenario (Figure 6.1).

This growth is brought by the rapid increase of energy consumption in the industry and transport sectors. Coal consumption in the industry sector contributed to the growth of the sector in the past (2000–2015), while in the future, it will be electricity consumption. The industry's electricity consumption will grow at an average rate of around 10% per year under the BAU scenario, while coal is at 7.7% per year.

Figure 6.1 Total Final Energy Consumption by Sector



Mtoe = million tons of oil equivalent.
Source: Author's calculations.

Final energy consumption in the transport sector in the BAU scenario will grow more slowly than in the past, at an average rate of 6.0% per year. Road transport will dominate, due to the growth at 6.1% per year while air transport will grow at 3.0% per year.

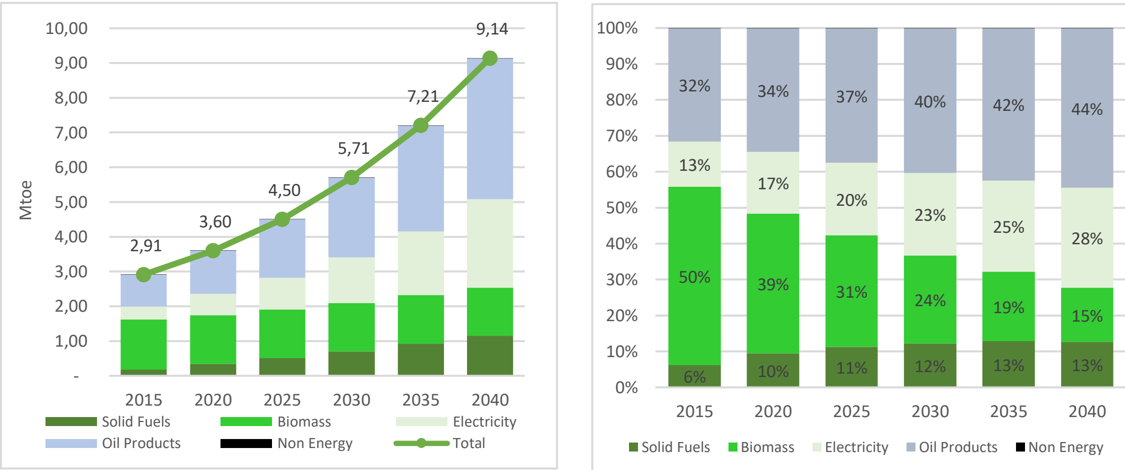
Final energy consumption of the 'Others' sector (mainly consisting of residential and commercial) will grow at an average of 1.3% per year over the outlook period, slower than it was in the past (2.1% per year between 2000–2015). The growth in consumption of the commercial sector will be 2.1% per year, while the residential sector will grow at 1% per year.

The residential sector, although growing the slowest, has had the highest share in the TFEC in the past. This is due to its consumption of biomass for cooking. The share of biomass will decline in the future as household appliances become more efficient and households use more alternatives, such as liquefied petroleum gas (LPG). The residential sector share in the TFEC will decrease from 43% in 2015 to 18% in 2040.

The transport sector had the second largest share in the TFEC (30% in 2015), while the share of the industry sector was 15% and the commercial sector share was 12%. By 2040, the share of the transport sector consumption in the TFEC will increase to 41% and industry to 35%. As a result, the commercial sector's share will decline to 6% by 2040.

In the future, demand for all fuels, except biomass, will continue to increase. For electricity, the demand will increase the fastest at an average rate of 8.1% per year to 2.5 Mtoe in 2040. Coal demand will continue to grow rapidly, but at a slower rate than in the past. The annual growth rate for coal demand would be 7.7% per year over the 2015–2040 period (Figure 6.2).

Figure 6.2 Total Final Energy Consumption by Fuel Type



Mtoe = million tons of oil equivalent.
Source: Author’s calculations.

Oil demand will continue to grow in line with the increase in the number of passenger cars as the income level of the Lao PDR increases. The annual growth rate for oil demand will be 6.1% per year. The share of biomass demand is expected to decrease an average rate of 0.2% per year.

According to the slower growth of biomass demand in the future, the share of this fuel in the TFEC will decline significantly, from 50% in 2015 to 15% in 2040. In its place, oil will become the dominant fuel with its share reaching 44% in 2040.

Electricity demand although growing the fastest, will still have a lower share than oil. The share of electricity in the TFEC increases from 13% in 2015 to 28% in 2040. The remaining share will be that of coal, increasing from 6% in 2015 to 13% in 2040.

Power generation

The Lao PDR’s power generation came mainly from hydro sources prior to 2015. Power generation from hydro sources increased from around 3.5 terawatt hours (TWh) in 2000 to 14.5 TWh in 2015 at an average rate of 9.9% per year. In 2015, the Hongsa coal-fired power plant was in full operation, generating around 3 TWh making the total electricity generation of the Lao PDR 17 TWh.

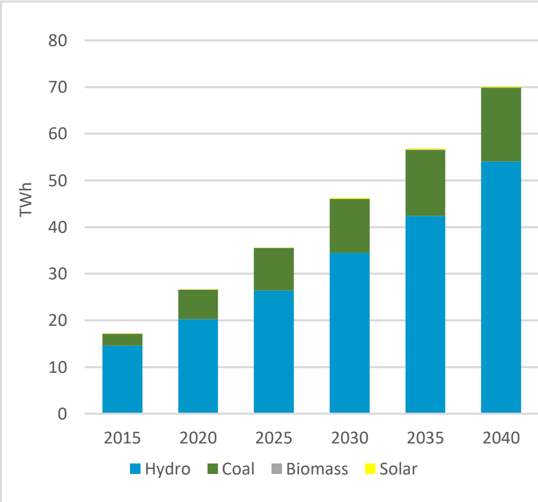
The majority of the electricity produced, especially from the Hongsa power plant was exported to Thailand. Therefore, the future total generation of electricity in the Lao PDR will not only meet the domestic demand but also meet the contracted export target. In addition, the own use and losses (transmission and distribution) of electricity must be included in the future generation of electricity of the Lao PDR.

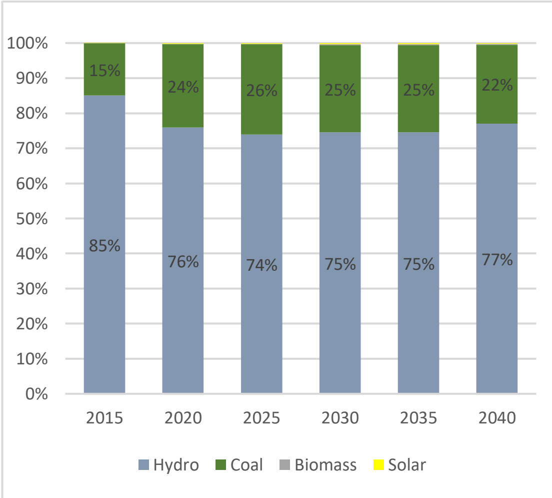
In the BAU scenario, total electricity production of the Lao PDR will reach around 70 TWH in 2040, where 53% of this amount will be for export purposes. The projected average annual growth of electricity production between 2015 to 2040 will be around 5.8% per year, slower than between 2000 to 2015 (Figure 6.3).

By type of fuel, generation from other renewable sources which consist of solar, wind, and biomass will grow the fastest at an average rate of 18.4% per year. The main reason for this very rapid growth is that this energy outlook is influenced by national RE targets. Generation from coal will grow at an average rate 7.6% per year while hydropower generation will grow at 5.4% per year.

The share of hydropower will remain dominant in the total power generation of the country. Its share in total power generation, however, will decline to 77% in 2040 from 85% in 2015. Hydropower in 2040 will be replaced by coal (22%), biomass, and other renewables (solar and wind).

Figure 6.3 Power Generation by Fuel Type





TWh = terawatt hour.
Source: Author's calculations.

Primary energy supply

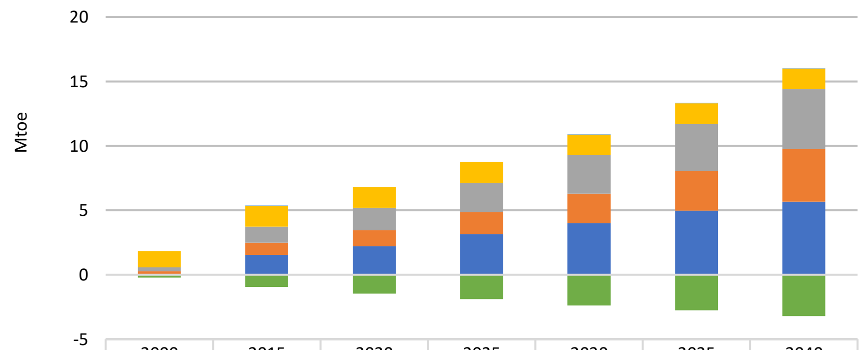
The total primary energy supply (TPES) in the Lao PDR grew faster than the final energy consumption at about 6.9% per year, from around 2 Mtoe in 2000 to 4 Mtoe in 2015. Amongst the major energy sources, the fastest-growing fuel between 2000 and 2015 was coal at 40.8% per year. This is mainly due to the requirement of the Hongsa coal-fired power plant which started production in 2015, resulting in a significant increase in coal supply that year. The Hongsa power plant was constructed only for export purposes to Thailand.

Hydropower, the main supply for power generation in the country grew at an average rate of 9.9% per year over the 2000–2015 period. Oil, the major supply for the transport sector, grew at a slower rate of 8.5% per year and biomass, the major supply for the residential sector, grew at an average rate of 1.7% per year.

The Lao PDR exports most of its electricity to Thailand. However, it also imports electricity, especially during the dry season and to areas not connected to the national grid. Electricity in the TPES reflected the net electricity trade (import minus export), and a negative value indicated that the Lao PDR has been a net electricity exporting country. The electricity export in the TPES increased significantly at an average rate of 10.1% per year. Another renewable supply (solar) has been be used since 2005, but the amount was small, amounting to 0.09 Mtoe in 2015.

In the BAU scenario, the Lao PDR's TPES is projected to increase more slowly than in the past, at an average annual rate of 4.4%, reaching 13 Mtoe in 2040 (Figure 6.4). Coal is projected to continue growing, but at a slower rate of 5.3% per year compared to the past. Hydropower will also increase at a slightly higher rate than coal at 5.4% per year. Oil is projected to increase at an average annual rate of 6.1% over 2015–2040 and it will be highest as compared to coal and hydropower. Biomass, on the other hand, will experience a declining trend as LPG and more efficient biomass stoves will be used in the residential sector.

Figure 6.4 Total Primary Energy Supply



	2000	2015	2020	2025	2030	2035	2040
Electricity	-0,22	-0,95	-1,46	-1,90	-2,38	-2,76	-3,20
Solar, Wind, Ocean	0,00	0,00	0,00	0,01	0,01	0,02	0,01
Biomass	1,26	1,62	1,58	1,59	1,61	1,62	1,60
Hydro	0,30	1,25	1,74	2,27	2,97	3,64	4,65
Oil	0,27	0,93	1,25	1,70	2,31	3,07	4,07
Coal	0,01	1,55	2,22	3,17	4,00	4,98	5,68
Total	1,62	4,40	5,34	6,83	8,52	10,56	12,81

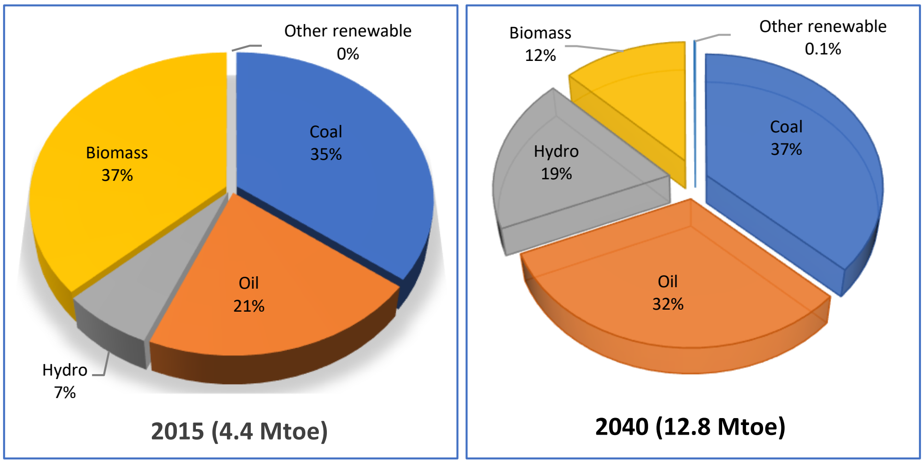
Mtoe = million tons of oil equivalent.
Source: Author's calculations.

The Lao PDR will continue its export target, and the net electricity trade in the total supply will reach 3.2 Mtoe, increasing on average by 5% per year between 2015 to 2040.

In terms of share in the TPES, biomass had the highest share over the 2000 to 2015 period. The share, however, declined from 78% in 2000 to 37% in 2015. The coal share was only 1% in 2000, but its share became the second largest in 2015 (35%) because coal was used not only for industry but also power generation. The oil share in the TPES was second highest in 2000 (17%). In 2015, the share increased to 21%, which was lower than coal. Hydropower share in the TPES increased from 5% in 2000 to 7% in 2015. The electricity trade value in the TPES was mostly from hydropower resources.

In the BAU scenario, the coal share in the TPES will be the highest in 2040 (37%) in line with the expansion of the Hongsa power plant. The oil share will also increase to 32%, and hydro's share in the TPES will increase to 19% by 2040. As a result, the share of biomass in the TPES will decrease to 12% by 2040. The other renewables share remains very small (Figure 6.5).

Figure 6.5 Energy Mix of the Total Primary Energy Supply

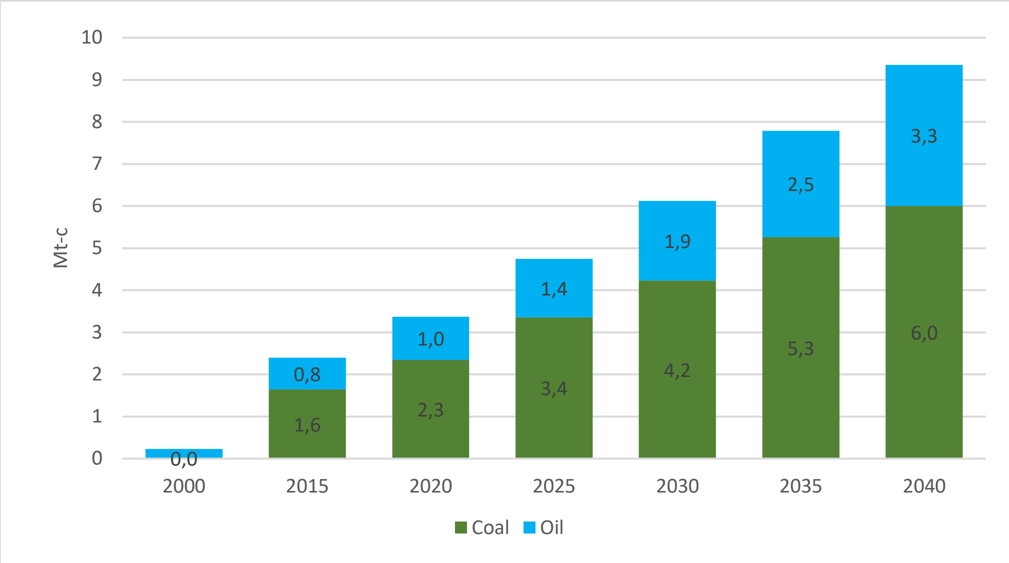


Mtoe = million tons of oil equivalent.
Source: Author's calculations.

CO_2 emissions

The major sources of CO_2 emissions from fuel combustion in the Lao PDR are solid fossil fuel (coal) and liquid fossil fuel (oil). In 2015, the CO_2 emissions from coal combustion was 68%, because the coal share was 35% of the TPES, while oil was only 21%. Therefore, the majority of CO_2 emissions came from burning coal. Total CO_2 emissions were 2.4 million ton-c (in terms of carbon content) or approximately 8.8 million ton-CO_2 in 2015. The CO_2 emissions will reach 9.4 million ton-c (Mt-c) by 2040 in the BAU scenario, increasing at an average rate of 5.6% per year. Coal combustion will still be the major source for CO_2 emissions since its share in the TPES increases to 37% due to increased use of coal in power generation and industry (Figure 6.6).

Figure 6.6 Total CO_2 Emissions



Mt-c = million tons of carbon.
Source: Author's calculations.

Energy indicators

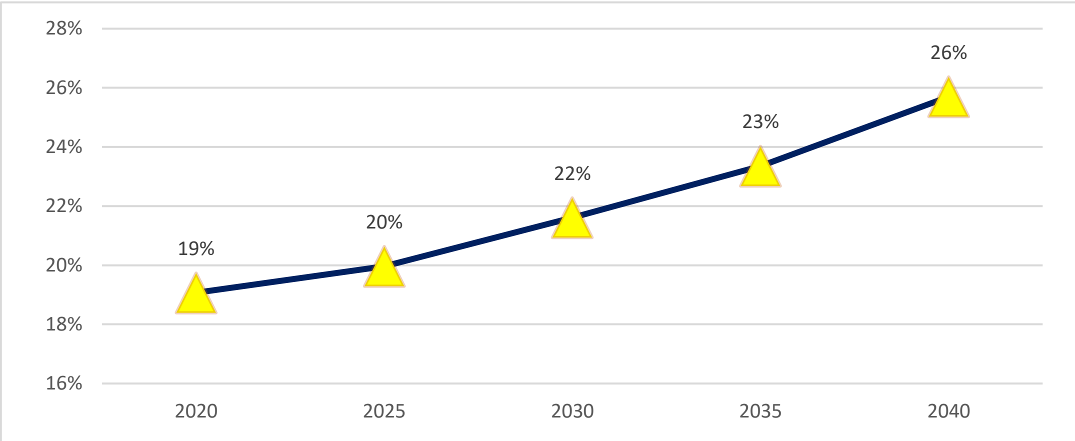
Energy indicators are often used to analyse a country import dependency on energy, energy consumption per capita, energy consumption per GDP, elasticity between TPES and GDP, as well as CO_2 emissions.

Import dependency

In terms of import dependency, the Lao PDR imported all its oil requirements and some electricity to meet consumption during the dry season and in the border areas without electricity access. Measuring import dependency is by dividing the total energy import to the total energy production. The total production of the Lao PDR consisted of coal, hydropower, biomass, solar and wind.

The import dependency ratio was 19% in 2015, an increase from 17% in 2000 due to the increase in oil consumption, particularly in the transport sector. In the BAU scenario, the Lao PDR import dependency is projected to continue increasing and will reach 26% by 2040 (Figure 6.7). If the Lao PDR increases domestic coal consumption for power generation instead of hydropower generation, the import dependency ratio should decline because of different thermal efficiency between coal power plants and hydropower plants. Nevertheless, oil consumption will increase faster than coal, which will result in an increase of the import dependency ratio.

Figure 6.7 Import Dependency



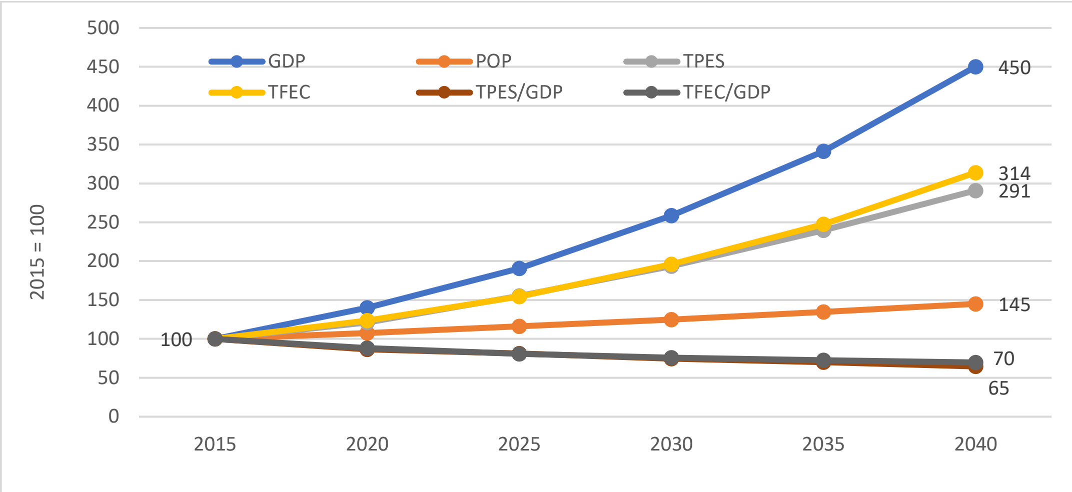
Source: Author's calculations.

Energy and CO_2 emissions intensity

Energy intensity is defined as the total primary energy supply or total final energy consumption (TPES or TFEC) divided by the gross domestic product (GDP). GDP, as explained in the previous chapter will grow at an average rate of 6.2% per year over the projection period, while population growth will be 1.5% per year. Based on these assumptions, GDP in 2040 will be 4.5 times what it was in 2015, while the population will be 1.5 times. TPES and TFEC will triple in the next 25 years, indicating a slower growth than the GDP. Consequently, the TPES and TFEC intensity will decline (Figure 6.8).

The TPES intensity in the BAU scenario will decline at an average rate of 1.7% per year, from 424 to 274 toe/million US$ over the 2015 to 2040 period. TFEC intensity will decline at a slower rate of 1.4% per year, from 281 to 196 toe/million US$. Declining energy intensities indicate that there is an improvement of energy consumption (primary and final) in all sectors. Primary and final energy intensity in the BAU scenario will improve by 30% and 35%, respectively in 2040 compared to 2015. Unfortunately, improvements do not come from the promotion of energy efficiency in the Lao PDR. It comes from energy diversification from biomass to conventional energy such as oil and electricity and biomass will take the role of absorber which mitigates the increase of conventional energy.

Figure 6.8 Energy Indicators (2015 = 100)



GDP = gross domestic product, POP = population, TFEC = total final energy consumption, TPES = total primary energy supply.
Source: Author's calculations.

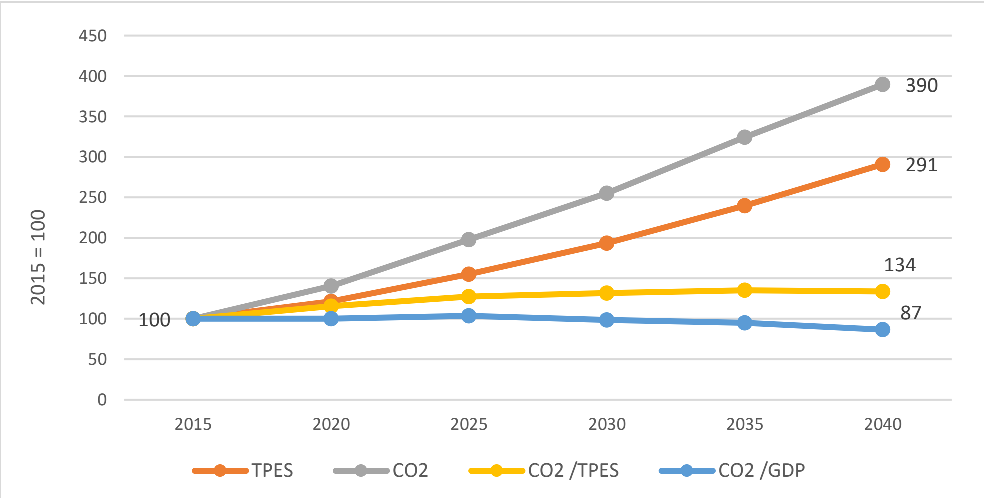
Per capita energy consumption, measured as the ratio of TPES to the total population, was 0.7 toe/person in 2015 higher than it was in 2000 (0.3 toe/person). This increase in energy per capita indicates improvement in energy access of society, which was reflected by the electrification ratio. In the BAU scenario, energy consumption per capita will continue to increase and will reach 1.4 toe per person in 2040.

Energy elasticity, which is the ratio of percentage growth in energy and the GDP will improve from 0.9 over the 2000–2015 period to 0.7 over the projection period regarding the TPES. For the TFEC, the elasticity will shift from 0.6 to 0.7 over the same period.

As with energy intensity, CO_2 intensity measures the ratio of GDP or the TPES to the CO_2 emissions. Both the CO_2/GDP and CO_2/TPES increased in the past as coal and oil consumption increased significantly faster than the GDP growth.

Under the BAU scenario, CO_2 emissions in 2040 will almost be four times from the 2015 level, indicating a slower growth than the GDP. As a result, the CO_2/GDP will decline by 0.9 times in the next 25 years (Figure 6.9). Initially, the CO_2/GDP will increase until 2025 then start to decline to 2040. Overall, the CO_2/GDP will decline at an average rate of 0.6% per year, from 232 ton-c/million US$ in 2015 to 200 ton-c/million US$ in 2040.

Figure 6.9 CO_2 Emissions Intensity (2015 = 100)



GDP = gross domestic product, TPES = total primary energy supply.
Source: Author's calculations.

The CO_2/TPES will increase to 0.73 ton-c/toe by 2040 from 0.55 ton-c/toe in 2015. This change will come from the diversification of the energy share to shift from low carbon energy (biomass and hydro) to fossil fuels (coal and oil) in the Lao PDR.

6.2 Case Studies

The case studies being considered in this outlook are:

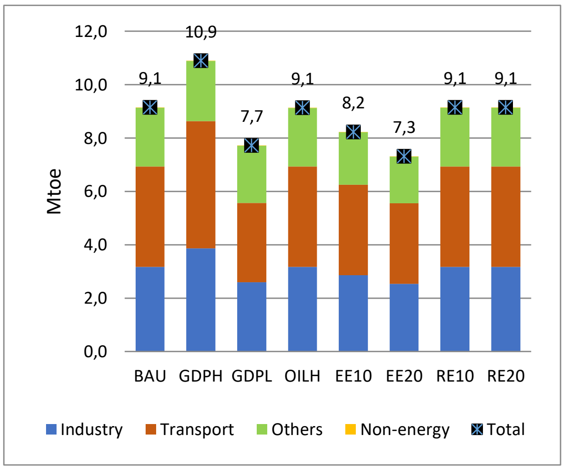
1) **Changes in GDP (GDPH and GDPL)**: It is assumed that the GDP annual growth rate could increase or decrease with additional ±1% as compared to the BAU scenario.
2) **Higher oil price (OILH):** It is assumed that the crude oil price could increase from US$150 by 2030 and US$200 by 2040 in the BAU scenario to US$200 by 2030 and US$250 by 2040, respectively.
3) **EEC promotion:** It is assumed that the TFEC would reduce by 10% (EE10) and 20% (EE20) in 2040 compared to the BAU scenario through the implementation of EEC activities.
4) **RE development:** It is assumed that the share of power generation outputs from RE sources (solar and wind) could reach 10% (RE10) and 20% (RE20) of total power generation (compared to negligible share of the BAU scenario) by 2040. These additional increases are assumed for replacing coal-fired thermal power plants.

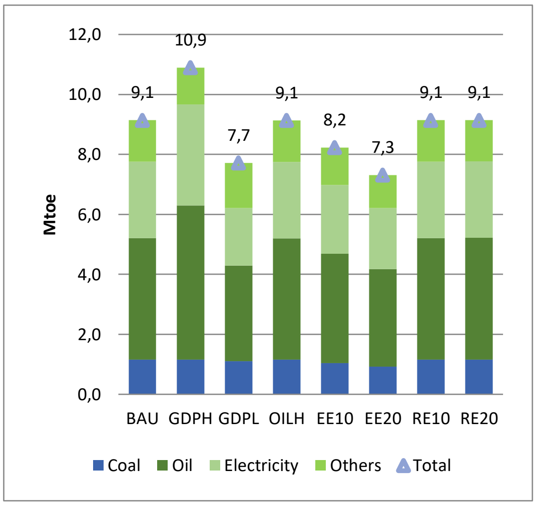
A detailed assumption applied in the case studies has been outlined in Chapter 5. The impacts of the different case studies will be compared to the BAU scenario.

Final energy consumption

The projected TFEC in 2040 by sector and by fuel for the different case studies as compared to the BAU scenario is shown in Figure 6.10. The TFEC for the case studies will be different than the BAU scenario except for the RE development case studies. Under the RE development case studies, the TFEC will be the same as in the BAU scenario because the assumption was on the power generation side, not on the demand side. In the RE case studies, the RE sources (solar and wind) share in the total generation will increase to 10% (RE10) and 20% (RE20) in 2040. Thus, increasing coal-fired thermal power plants will not be as much as in the BAU scenario since some will be replaced by RE sources.

Figure 6.10 Total Final Energy Consumption in 2040 by Cases





BAU = Business-As-Usual, EE = energy efficiency, GDP = gross domestic product, Mtoe = million tons of oil equivalent, RE = renewable energy.
Source: Author's calculations.

Under the GDPH, increasing 1% of the GDP growth rate of the BAU scenario will increase the TFEC by 19% in 2040. Under the GDPL, the TFEC will decrease by 16%. Increasing the oil price by US$50 in 2030 and in 2040, respectively from that of the BAU scenario (OILH) will also decrease the TFEC, but only by 0.1%.

Under the EE20, the TFEC will be 20% lower than that of the BAU scenario while under the EE10, the difference will be 10%. These scenarios are tentatively assumed for assessing the sensitivity of this outlook.

Under the GDPL, reduction in different sectors is not the same. The reduction in the TFEC of the transport sector will be 21%, while for the industry sector 18% and the 'Others' sector 2%. The non-energy sector relates to the transport sector (lubricants), so the reduction will also be similar (21%). The transport and industry sectors are more sensitive to the changes in GDP due to a zero or small share of biomass.

In case of the 'Others' sector, the majority of the consumption is that of the residential sector. Since biomass has the major share in the TFEC of the residential sector, changes in the GDP will not directly impact biomass consumption. In fact, biomass consumption will increase under the GDPL case and decrease under the GDPH case. Under the GDPL, the highest reduction will be in electricity (25%), followed by oil (21%) and coal (5%). The reduction in oil consumption mostly occurs in the road transport sector.

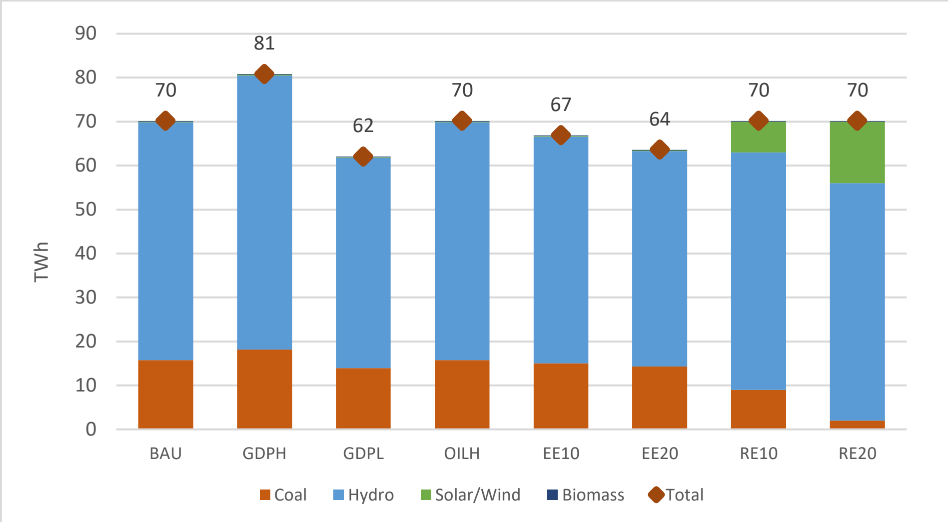
Power generation

As mentioned previously, the electricity demand of the final sector is 25% lower than the BAU scenario under the GDPL. Under the EE20, electricity consumption is only 20% lower than the BAU scenario. Since the electricity export will be the same for all cases, then electricity generation will be the lowest under the GDPL (Figure 6.11).

Under all cases, hydropower is the major source for electricity generation in the Lao PDR (77%). The second largest source for electricity generation will be coal (22%) under all cases except RE cases (RE10 and RE20). The remaining share will be that of biomass and other renewables (solar and wind).

Under RE10 and RE20, the share of solar and wind will be 10% and 20% higher than the BAU scenario. The substitution is assumed only for coal-fired power plants. Thus, the share of coal in total power generation will decrease to 13% under RE10 and 3% under RE20.

Figure 6.11 Comparison of Scenarios to Electricity Generation by 2040



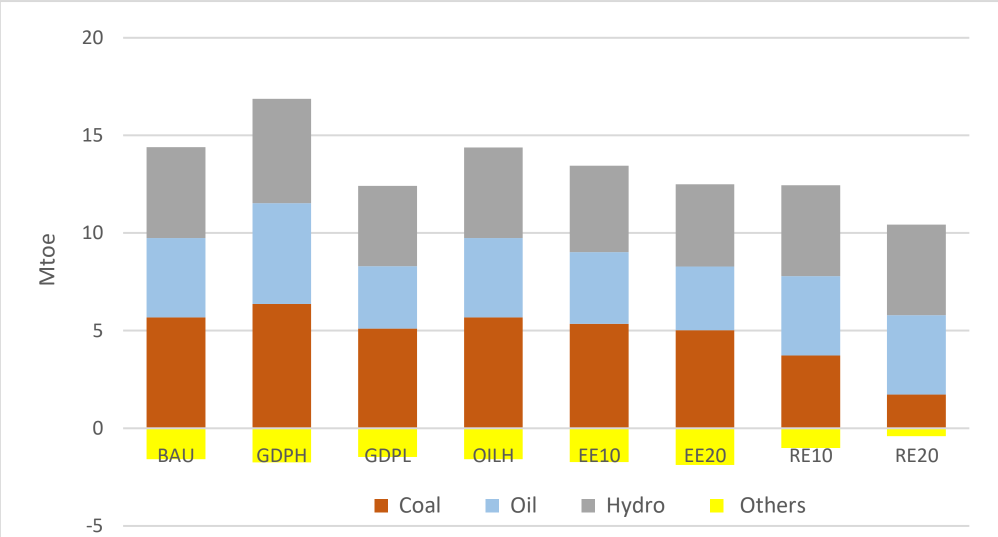
BAU = Business-As-Usual, EE = energy efficiency, GDP = gross domestic product, RE = renewable energy, TWh = terawatt hour.
Source: Author's calculations.

Primary energy supply

The TPES of the Lao PDR in 2040 will be 18% higher than the BAU scenario under the GDPH (Figure 6.12). This increase will mainly come from the use of hydropower and other renewables (solar and wind) to meet the higher electricity demand. Hydropower and other renewable supply under the GDPH will be 15% higher than in the BAU scenario. Coal supply will also be 12% higher than the BAU scenario. Biomass supply, on the other hand, will be 9% lower than the BAU scenario since households tend to use more efficient stoves (such as LPG and electricity) as incomes increase due to the improvement in the economy.

In a reverse situation, where GDP growth declined by 1% (GDPL), biomass supply will increase while the other sources will decrease. Biomass supply will increase by 8% under the GDPL as compared to the BAU scenario. Hydropower and other renewables will decrease by 12%, while coal decreases by 10% resulting in an overall decrease of the TPES by 15%. Under the OILH case, the TPES will also be lower than the BAU scenario, but only by 0.04%.

Figure 6.12 Comparison of Scenarios to TPES by 2040



BAU = Business-As-Usual, EE = energy efficiency, GDP = gross domestic product, Mtoe = million tons of oil equivalent, RE = renewable energy.
Source: Author's calculations.

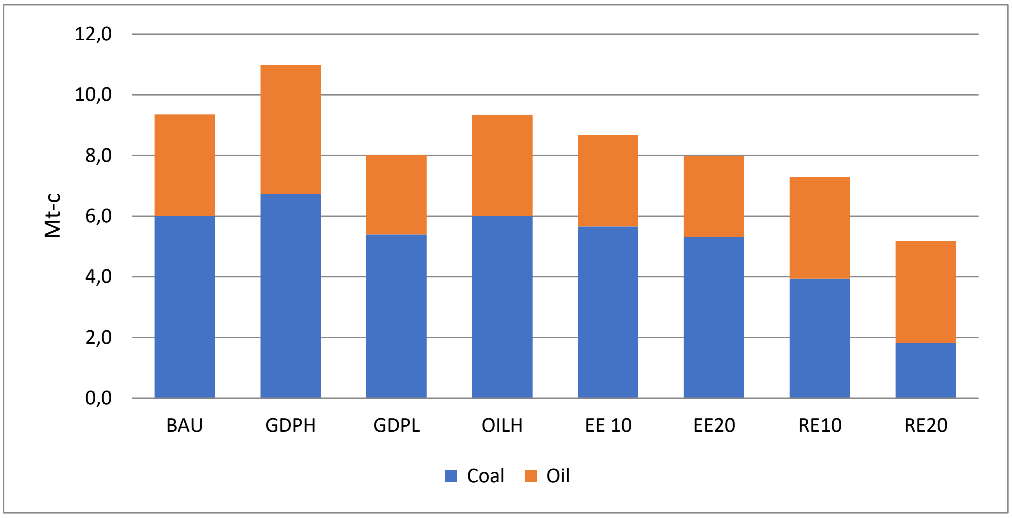
The EE20 and RE20 cases reduce the TPES more than the GDPL. The TPES of EE20 will be 17% lower than BAU while under RE20, the TPES will be the smallest; 22% lower than BAU. This is possible because solar and wind power plants have 100% efficiency, while coal-based power plants efficiency are 30%. So, increasing the share of solar and wind sources in the total electricity production as substitutes to coal-fired power plants (RE20) will reduce coal demand significantly and thus avoid any additional coal import of the Lao PDR.

CO_2 emissions reduction

The CO_2 emissions in the BAU scenario will reach 9.4 Mt-c by 2040, 4.5 times more than it was in 2015. If the GDP growth rate was 1% lower than that of the BAU scenario (GDPL), the TPES will also be lower than the BAU scenario. Consequently, this will result in a lower CO_2 emissions. Total CO_2 emissions under GDPL will be 8.0 Mt-c by 2040, which is 14% lower than the BAU scenario (Figure 6.13). If the GDP growth assumption increased by 1% (GDPH), then the CO_2 emissions will increase to almost 11 Mt-c by 2040; around 17% higher than the BAU scenario. Increasing price of oil (OILH) does reduce the TPES, but very slightly. Therefore, the CO_2 emissions in 2040 will almost be the same as in the BAU scenario.

Other cases (EE10, EE20, RE10, and RE20) will also result in lower TPES compared to the BAU scenario. The EE10 case will reduce CO_2 emissions of 2040 by 7% as compared to BAU, while EE20 can reduce the CO_2 emissions by 15%.

Figure 6.13 Lao PDR CO_2 Emissions by Cases



BAU = Business-As-Usual, EE = energy efficiency, GDP = gross domestic product, Mt-c = million tons-c, RE = renewable energy.
Source: Author's calculations.

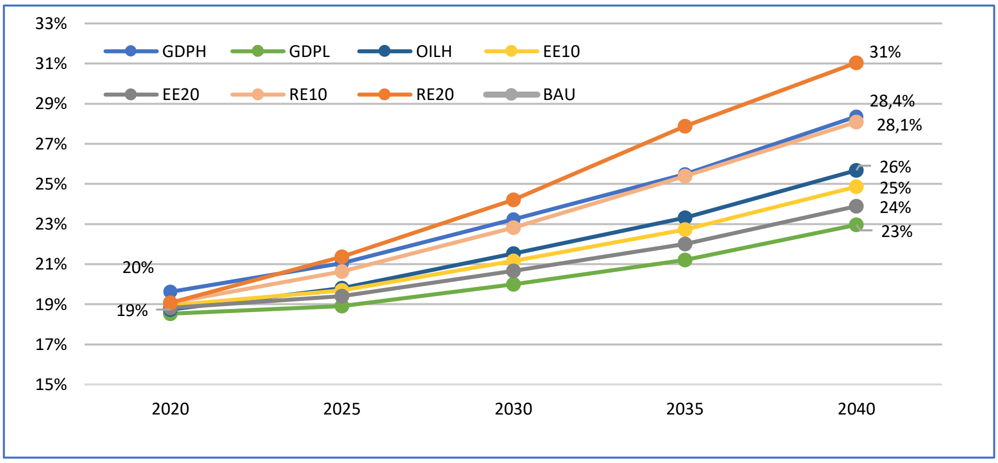
The CO_2 emissions in 2040 will be significantly reduced if the Lao PDR promotes solar and wind power generation instead of coal-fired power plants. If the policy is to increase the share of solar and wind in the total power generation by 10% (RE10), the CO_2 emissions reduction in 2040 will reach 22%. If the share increases to 20%, then the CO_2 emissions reduction will reach 45%; the lowest from all cases.

Energy indicators

Import dependency

In the BAU scenario, the Lao PDR import dependency will reach 26% by 2040. Import dependency will be the highest at 31% under RE20 (Figure 6.14). The RE20 case increases the role of solar and wind in power generation by 20% to substitute electricity produced by coal-fired power plants. Since coal use will decrease in RE20, the domestic production of coal will be lower than in the BAU scenario. In addition, an increase in solar and wind supply will not be as much since renewable plants have 100% efficiency, while coal is only 30%. As a result, the import dependency ratio will be higher than in the BAU scenario. In the RE10 case, the reduction in total energy production will not be as low as in RE20, so that import dependency will only reach 28% in 2040.

Figure 6.14 Lao PDR Import Dependency Ratio



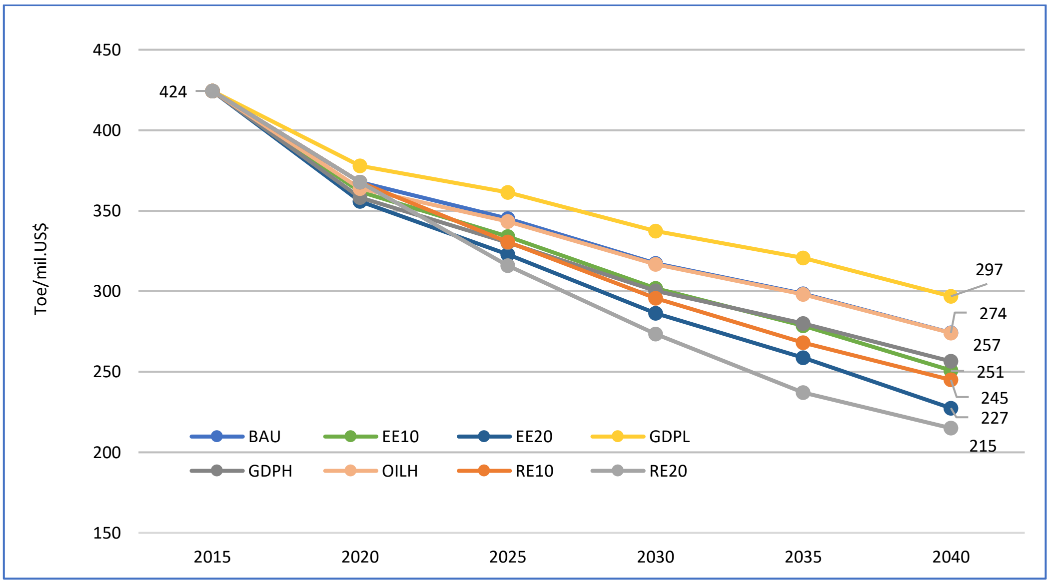
BAU = Business-As-Usual, EE = energy efficiency, GDP = gross domestic product, RE = renewable energy.
Source: Author's calculations.

Energy intensity

In the BAU scenario, primary energy intensity of the Lao PDR will reach 274 toe/million US$ by 2040. If the share of the coal-fired power plant decreases significantly as a result of the increasing renewable solar and wind share to 20% of total power production (RE20), the intensity will be the minimum (215 toe/million US$). This is around 22% lower than BAU (Figure 6.15). If the increment of the solar and wind share is only 10%, the primary energy intensity will decline to 245 toe/million US$; almost 11% improvement from the BAU scenario.

The other cases (EE10, EE20, and OILH) will also improve the energy intensity but not as much as the RE20. The improvement of energy intensity from the BAU scenario will be 9% and 17% for the EE10 and EE20, respectively. In the case of OILH, the energy intensity is almost the same as in the BAU scenario since the difference in TFEC and TPES is small.

Figure 6.15 Primary Energy Intensity

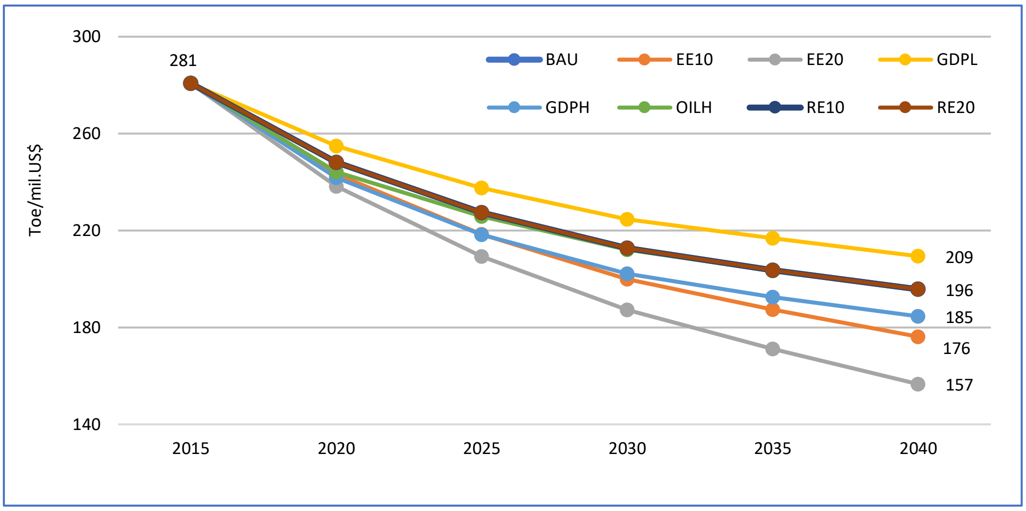


BAU = Business-As-Usual, EE = energy efficiency, GDP = gross domestic product, toe = tons of oil equivalent, RE = renewable energy.
Source: Author's calculations.

If the GDP growth rate is 1% lower than the BAU scenario (GDPL), both the TPES and GDP will be growing more slowly. The result of the primary energy intensity in 2040 will be 257 toe/million US$ in 2040, slightly higher than EE10 (254 toe/million US$). The primary energy intensity will be higher than in the BAU scenario if the GDP is growing faster (GDPH); 297 toe/million US$ toe/million US$.

The final energy intensity of the BAU scenario in 2040 will be 196 toe/million US$; 0.7 times lower than in 2015. Implementing a 20% energy saving target (EE20) will result in a 20% improvement of BAU final energy intensity (Figure 6.16). The final energy intensity under the EE20 will be 157 toe/million US$ in 2040. In the EE10, the final energy intensity will only be 10% lower than the BAU scenario, which is 176 toe/million US$. Higher GDP growth (GDPH) will result in a lower final energy intensity than BAU (185 toe/million US$) and lower GDP growth (GDPL) will result in a higher intensity (209 toe/million US$).

Figure 6.16 Final Energy Intensity



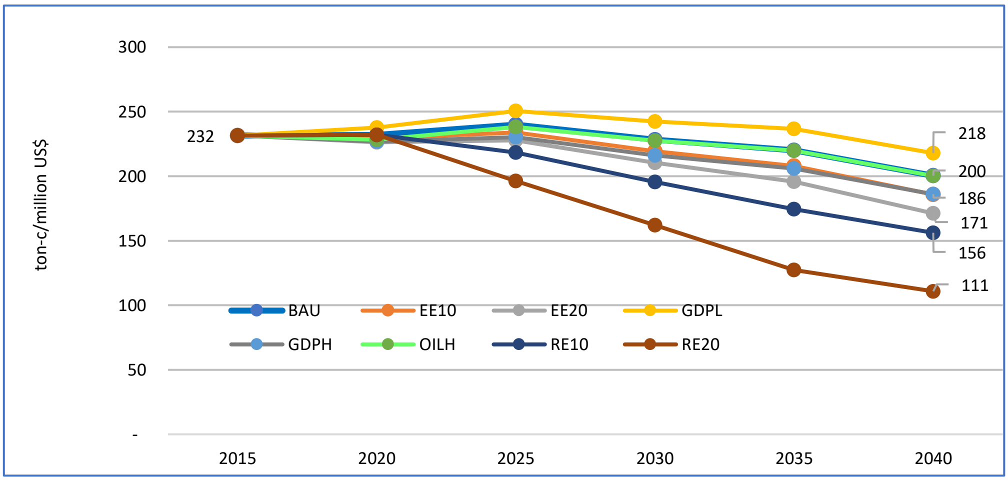
BAU Business-As-Usual, EE = energy efficiency, GDP = gross domestic product, toe = tons of oil equivalent, RE = renewable energy.
Source: Author's calculations.

The final energy intensity remains the same as the BAU scenario for the RE10 and RE20 because these two cases impact only on the TPES. The higher oil price will reduce the TFEC, but as discussed above, only very slightly. So, the final energy intensity will almost be the same as that of the BAU scenario.

CO_2 emissions intensity

The CO_2 emissions intensity in 2040 will be lower than the BAU scenario for all cases with the same GDP assumption of BAU because the total CO_2 emissions will be lower as explained above. In the BAU scenario, CO_2 emissions intensity (CO_2/GDP) will be 200 ton-c/million US$. Promoting RE development by 20% (RE20) will result in the lowest CO_2 emissions intensity of 111 ton-c/million US$, which is 45% lower than the BAU scenario. If RE development is only 10% (RE10), the improvement of CO_2 intensity s compared to the BAU scenario will only be 21% (Figure 6.17).

Figure 6.17 CO_2 Emissions Intensity (CO_2/GDP)



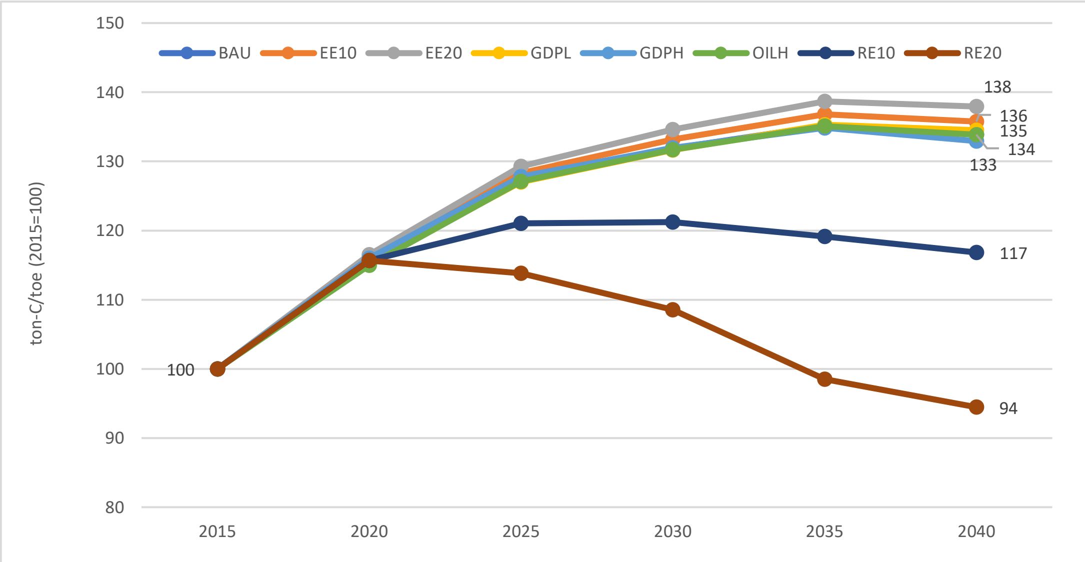
BAU = Business-As-Usual, EE = energy efficiency, GDP = gross domestic product, RE = renewable energy.
Source: Author's calculations.

The EE promotion case only improves the CO_2 intensity by 7% under the EE10 but can be more (15%) under the EE20. Increasing oil prices (OILH) will also improve the CO_2 emissions intensity but by a very small amount (0.1%).

In case of different GDP levels, the CO_2 emissions intensity will be 9% higher than the BAU scenario under GDPL. Under GDPH, the CO_2 emissions intensity will improve 7% more than in the BAU scenario.

The CO_2/TPES of the BAU scenario will be 0.73 ton-c/toe in 2040 and except for the RE development cases (RE10 and RE20), the ratio of other cases will still be around 0.7 ton-c/toe. The RE development cases will decrease the coal share in the TPES significantly, consequently the total share in the TPES will decrease by 2040. In the RE10, the fossil fuel share in the TPES will reduce to 60% from the 70% in BAU and to 40% in the RE20. Consequently, the CO_2 emissions of the country will decrease very sharply in RE development cases and CO_2/TPES intensity will be 13% and 29% lower than BAU under the RE10 and RE20, respectively. Figure 6.18 shows the evolution of the CO_2/TPES intensity of the BAU and the study cases (with index 2015=100).

Figure 6.18 CO_2/TPES Intensity



BAU = Business-As-Usual, EE = energy efficiency, GDP = gross domestic product, RE = renewable energy, TPES = total primary energy supply.
Source: Author’s calculations.

Annex

Table A6.1 Energy Balance Table 2015, BAU

	Coal	Hydropower	Solar and Wind	Biomass	Electricity	Oil	Non-energy	Total
Production	1552	1250	0	1619	0	0	0	4422
Imports	0	0	0	0	177	968	2	1147
Exports	0	0	0	0	-1126	-41	0	-1167
From Stock Change	0	0	0	0	0	0	0	0
Total Primary Supply	1552	1250	0	1619	-949	927	2	4402
Refinery	0	0	0	0	0	0	0	0
Electricity Generation	-1371	-1250	0	-2	1470	0	0	-1153
Transmission and Distribution	0	0	0	0	-157	0	0	-157
Total Transformation	-1371	-1250	0	-2	1314	0	0	-1310
Statistical Differences	0	0	0	172	0	9	0	181
Industry	181	0	0	56	150	46	0	433
Transport	0	0	0	0	0	868	0	868
Residential	0	0	0	1116	137	1	0	1254
Commercial	0	0	0	274	74	2	0	351
Agriculture	0	0	0	0	3	0	0	3
Non-energy	0	0	0	0	0	0	2	2
Total Demand	181	0	0	1446	365	918	2	2912

BAU = Business-As-Usual.

Source: Author’s calculations.

Table A6.2 Energy Balance Table 2040, BAU

	Coal	Hydropower	Solar and Wind	Biomass	Electricity	Oil	Non-energy	Total
Production	5676	4649	15	1600	0	0	0	11939
Imports	0	0	0	0	15	4103	11	4129
Exports	0	0	0	0	-3220	-41	0	-3261
From Stock Change	0	0	0	0	0	0	0	0
Total Primary Supply	5676	4649	15	1600	-3204	4062	11	12808
Refinery	0	0	0	0	0	0	0	0
Electricity Generation	-4519	-4649	-15	-52	6032	0	0	-3202
Transmission and Distribution	0	0	0	0	-283	0	0	-283
Total Transformation	-4519	-4649	-15	-52	5749	0	0	-3485
Statistical Differences	0	0	0	172	0	9	0	181
Industry	1157	0	0	134	1615	264	0	3169
Transport	0	0	0	0	0	3767	0	3767
Residential	0	0	0	985	611	9	0	1605
Commercial	0	0	0	257	317	12	0	586
Agriculture	0	0	0	0	3	0	0	3
Non-energy	0	0	0	0	0	0	11	11
Total Demand	1157	0	0	1376	2545	4052	11	9142

BAU = Business-As-Usual.

Source: Author’s calculations.

Chapter 7

Conclusion and Policy Recommendations

Shigeru Kimura

The total final energy consumption (TFEC) of the Lao People's Democratic Republic (Lao PDR) will increase at an average rate of 4.7% per year from 2015 to 2040. Industry sector consumption will grow the fastest (8.3%), followed by the transport sector (6%), and others (1.3%). The low growth in the other sectors will be due to the slowing of biomass consumption as the residential sector shifts to liquefied petroleum gas (LPG) and more efficient biomass stoves. In terms of energy type, electricity will grow the fastest at 8.1%, followed by coal at 7.7%, and oil at 6.1% but the coal share (13%) will be much smaller than electricity and oil (28% and 44%, respectively).

Electricity production will increase to 70 terawatt hours (TWh) by 2040 from 17 TWh in 2015 at an average rate of 5.8% per year. Around 53% of the electricity produced will be to meet the export target, particularly of Thailand. Hydropower sources will remain dominant in the country's power generation but with a declining share, accounting for around 77% in 2040 from 85% in 2015. The remaining share will be that of coal resources (22%) and other renewables (1%).

The total primary energy supply (TPES) will reach 13 million tons of oil equivalent (Mtoe) in 2040, increasing at an average rate of 4.4% per year from 2015. As a major supply for power generation, hydro sources will increase at an average rate of 8.7% per year over the projection period. Coal supply will also have a remarkable share in power generation. Its growth rate will on average be 4.5% per year. Oil will grow at an average rate of 6.1% per year to meet particularly transport demand.

Based on the case studies, the highest reduction in the TFEC compared to the Business-As-Usual (BAU) scenario will be achieved if the Lao PDR implements a 20% energy efficiency and conservation (EEC) target (EE20) by promoting energy efficiency measures in all sectors of the economy. Slower growth of the gross domestic product (GDP) by 1% from the BAU scenario (GDPL) will also reduce the TFEC by 16%. Increasing the price of oil from the BAU scenario (OILH), will result in a not significant reduction of the TFEC. The promotion of EEC will be one of the important energy policies to mitigate energy consumption under stable economic growth.

Implementing the EE20 will also reduce the TPES by 17%, but not as much as in the 20% renewable energy target (RE20). Although the TFEC of RE20 is higher than the EE20, substituting coal in power generation with solar and wind power will result in a slightly lower

TPES than the EE20 due to the different thermal efficiency between coal-fired power plants and solar and wind power systems. The share of coal in the TPES of RE20 will only be 8%, while in the EE20 it will still be around 38%.

The TPES per GDP (energy intensity) will reach 274 toe/million US$ in 2040 under the BAU scenario. A greater improvement of the energy intensity can be expected through the implementation of the EE20 (17% lower than in the BAU scenario). Implementing the RE20 will further improve the intensity, reducing almost 22% from that of the BAU scenario.

Carbon dioxide (CO_2) emissions under the BAU scenario in 2040 will be four times from the 2015 level. Implementing the RE development programme can reduce CO_2 emissions significantly; 22% and 45% lower than BAU for the renewable energy target (RE10) and RE20, respectively. Implementing an EE20 policy will reduce CO_2 emissions by 15% more than in the BAU scenario, while a 10% energy efficiency target (EE10) will only result in 7% CO_2 emissions reduction.

Implementing the EE20 and RE20 will be beneficial for the Lao PDR since they significantly save energy consumption, improve energy intensity, and reduce CO_2 emissions. However, in case of the RE20, the import dependency will increase to 31% from 26% in the BAU scenario. Implementing the RE20 will reduce domestic coal production, thus increasing the import dependency to 31%. It is a controversial issue for the Lao PDR to balance CO_2 emissions and energy supply security.

To avoid increasing import dependency under the RE10 or RE20, one idea for the Lao PDR is to shift from internal combustion engines to electric vehicles in the road transport sector, which would use electricity from renewable energy sources including large hydropower generation. It can be expected to reduce consumption and the importation of gasoline and diesel oil.

Concluding the energy outlook of the Lao PDR, the following policies are recommended:

- ✓ Promote energy efficiency is a top priority energy policy for the Lao PDR for contributing to a reduction of energy consumption, CO_2 emissions, and money outflow from the Lao PDR to import petroleum products such as gasoline.
- ✓ Increase of renewable energy including large hydropower plants is a second energy policy for the Lao PDR. Combining electrification in the road transport sector will contribute to a reduction in the consumption of transport fuel, mitigate CO_2 emissions, and saving the money flow out of the country.
- ✓ In this regard, the Lao PDR will have appropriate and implementable energy polices such as:
  - Set up the Lao PDR basic energy plan (which will show energy direction in the long term)
  - Several energy master plans will be set up:
    - ➢ EEC master plan
    - ➢ RE master plan
    - ➢ EV master plan