Journal of Sustainable Energy & Environment

12 (2021) 59-63

Greener electricity generation from Lao PDR in the future

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Abstract: This study aims to forecast electricity generation and assess average generation cost and CO_2 emission. The baseline electricity generation data is collected from the Ministry of Energy and Mines, Lao PDR. The LCOE for hydropower, solar power, and biopower is selected from IRENA, and LCOE for a coal-fired plant is taken from EIA. Likewise, the annual electricity growth rate, 8.7% for hydropower, 4.5% for coal energy, and 10% for solar and bioenergy, is taken from Lao PDR Energy Outlook 2020. It is found that the electricity generation from 2019-2030 will increase from 46.6 TWh to 105.68 TWh. The average electricity generation cost will decrease from 52.98 USD/MWh to 51.34 USD/MWh during 2019-2030. The average CO_2 emissions per MWh are decreasing from 99.04 kgCO_2/MWh to 71.35 kgCO_2/MWh from 2019 to 2030. By comparison, the average electricity generation cost, which is 51.34 USD/MWh in 2030, will be 3% lower than the electricity generation cost in 2019 of 52.98 USD/MWh.

Keywords: LCOE, renewable energy, electricity generation, CO_2 emission, Lao PDR.

1. Introduction

Today, the global energy system switching towards renewable energy is considered an inevitable and sustainable option to reduce GHG emissions from the energy sector [1]. The success of energy transition depends on the management of energy trilemma or three energy dimensions: energy security, energy equity, and environmental sustainability of energy system [2]. Likewise, the 2030 agenda for sustainable development by United Nations sets a goal to ensure universal access to affordable, reliable, and modern energy services 2030 [3]. Renewable energy, interchangeably clean energy or electricity, accounts for 19% of the world's final energy consumption, which accounts for 113,009 TWh around the world in 2017 [4-5]. According to International Energy Agency (IEA), the global renewable electricity capacity in 2020 is 2,907 GW (hydropower including pump storage: 1,337 GW, 46%; solar power: 723 GW, 24.87%; wind: 686 GW, 23.6%, bioenergy: 146 GW, 5%) and global renewable electricity generation in 2020 is 7,542 TWh [6]. Similarly, the world's gross electricity production, including renewables and non-renewables, has increased from 6,298 TWh to 26,730 TWh from 1974 to 2018, with an average annual growth of 3.3% [7].

Lao People's Democratic Republic (Lao PDR) shares its borders with China, Myanmar, Cambodia, Vietnam, and Thailand. It is also a member of the Association of Southeast Asian Nations (ASEAN), the most important international organization of this region, and aims to become 'battery of ASEAN' [8]. ASEAN countries have an agreement in 1997 to develop an ASEAN power grid which would play an important role in improving energy [9]. The energy policies of the country also guide the power sector development. In Lao PDR, the major policies related to the power sector include (1) the 8th Five-Year National Socio-Economic Plan (2016-2020), (2) Power Development Plan 2020-2030, (3) Energy Policy 2015 and (4) Renewable Energy Development Strategy 2011. The 8th Five Year National Socio-Economic Plan takes account of the strategy to graduate from least developed country (LDC) status by 2020 and the strategy for the transition period of LDC graduation by 2025 [10]. The power development plan aims to diversify the electricity generation sources and expand the transmission and distribution system to supply the domestic and regional electricity demand [11]. In 2018, Lao PDR formulated a national policy on green growth where the energy sector is one of the prioritized sectors. The National Green Growth Strategy of the Lao PDR, 2018, has set provisions for developing biofuels, promoting clean energy (hydropower, solar power, and wind power), and promoting alternative energy [12]. The Renewable Energy Development Strategy 2011 targets to increase the share of small-scale renewable energy to 30% of total energy consumption by 2030 [13]. However, small-scale renewable energy sources in Lao PDR include small hydropower (installed capacity <15 MW), solar power, and biopower. Lao PDR also aims to increase the government revenue from independent power plants (IPP) export investment [14]. In cross-border power trade, Lao PDR has a power export agreement of 9 GW to Thailand, 5 GW to Vietnam, 1.5 GW to Cambodia, and 0.5 GW to Myanmar [15].

Lao PDR has a hydropower potential of 26.5 GW, of which 18 GW is technical potential [16]. According to the Ministry of Energy and Mines, Laos PDR, there are currently 78 installed power plants with a total capacity of 9,575.93 MW [17]. Among them, there are 50 large hydropower plants with a capacity of 7,542.05 MW and 1 coal fired plant with a capacity of 1,878 MW. From the renewable energy sources, there are 17 small hydropower plants with a capacity of 67.09 MW, 6 solar power plants with a capacity of 46 MW, 4 biopower plants with a capacity of 42.79 MW. The electricity consumption also increases from 2.4 GWh to 4.97 GWh at the compound annual growth rate of 9.5% from 2010-2017. It is forecasted that the electricity export from Laos to neighboring countries, especially Thailand, increased from 16 TWh to 50 TWh within 2016-2030. The electricity reserve margin is around 52.6% during the rainy season [15]. However, Lao PDR has also imported 2,050 GWh of electricity from Thailand in 2015 to balance the power deficit in the dry season. Apart from this, it is accounted that around 15% of total electricity production (i.e., 2,565 GWh) is lost in the transmission line of the electricity system [17]. In the context of electricity pricing in Lao PDR, the

electricity price for domestic consumption is 88 USD/MWh, the export price to Thailand is 37 USD/MWh, and the import price from Thailand is 103 USD/MWh in 2016 [15].

Electricity generation cost is a strong determiner of the entire power system [18]. The generation cost of electricity from a hydropower plant can be divided into capital cost and operation and maintenance costs. Capital cost includes i) the cost for structures components (i.e., powerhouse, dam, water intake, gates, screen, and trash rack cleaner), ii) for the mechanical and electrical engineering components (i.e., check valves, turbines, generator, transformer, energy output) and iii) the other expenses (i.e., acquisition of land, planning, authorization), Operation and maintenance costs include expenses for staff, maintenance, administration, provisions for plant renewals, disposal of screenings, and insurance [19]. The generated power of a hydraulic generation unit depends on the specific weight of water, the river inflow, the height of the waterfall, and the efficiency of the turbine and the generator [20]. However, the generation availability and reliability of small hydropower plants are associated with the river inflow variation together with the generation unit availability [21]. Likewise, the Forced Outage Rate, which is the ratio of failure hours to total service hours of the generator, also affects the electricity production cost [22]. Similarly, for solar photovoltaic systems, i) the capital cost includes include photovoltaic module and inverter costs, costs for frames, design, and mounting, and ii) operation and maintenance cost includes repairs, module cleaning, meter rent, insurance [19]. In the context of biopower and coal-fired plant**,** i) the capital cost majorly includes the boiler, steam turbine, generator, fuel cost; ii) operation and maintenance cost, and iii) external cost (i.e., CO_2 abatement cost).

Hence, this study aims i) to calculate the average electricity generation cost per year in Laos PDR till 2030, and ii) to estimate the CO_2 emission per MWh till 2030.

2. Methods and Materials

2.1 Equations

The equations for calculation of average electricity generation cost of electricity and carbon dioxide emission are as follows:

$$\textit{Average electricity generation cost (\$/MWh)} = [(LCOE_{hydro} \times MWh_{hydro}) + (LCOE_{coal} \times MWh_{coal}) + (LCOE_{bio} \times MWh_{bio}) + (LCOE_{solar} \times MWh_{solar})] \div (\textit{Total electricity generation } MWh_{year}) \quad (1)$$

The CO_2 emission is computed by using the Tier 1 approach of 2006 IPCC Guidelines based on the equation 2 [23].

$$CO_2 \textit{ emissions } (\mathrm{KgCO_2e/MWh}) = ((MWh_{coal} \times \textit{Emission Factor}_{coal}) + (MWh_{bio} \times \textit{Emission Factor}_{bio}) \div (\textit{electricity generation per year}) \quad (2)$$

2.2 Baseline Data

The baseline data from 2014-2019 for forecasting of electricity generation is collected from the Ministry of Energy and Mines, Lao PDR, which are given in Table 1 [17].

Table 1. Electricity statistics of Lao PDR during 2014-2019.

Year	Production (GWh)	Export (GWh)	Import (GWh)	Consumption (GWh)	Losses (GWh)
2014	15,275	11,936	1,559	3,792	1,106
2015	16,302	11,549	2,050	4,239	2,565
2016	25,316	20,064	862.35	4,660	3,544
2017	31,323	24,344	499	4,696	5,380
2018	34,664	26,708	300	5,416	2,240
2019	46,600	33,981	300.5	6,595	5,723.5

Source: Ministry of Energy and Mines Lao PDR, 2018 [17**]**.

2.3 Levelized Cost of Electricity (LCOE)

Electricity generation cost over plant lifetime is also expressed in Levelized Cost of Electricity (LCOE). This is commonly used for economic analysis of power generation systems of different energy technologies [24]. According to Ouyang and Lin (2014), the LCOE of wind (onshore) power ranges from 0.071 $/kWh to 0.094 $kWh at 5% discount rate; the LCOE of solar PV ranges from 123 USD/MWh to 201 USD/MWh at 5% discount rate; and the LCOE of biomass electricity ranges from 88 USD/MWh to 98 USD/MWh at 5% discount rate [25]. Another study by Shea and Ramgolam (2019) [26] in Mauritius, a small island developing state, it is found that the LCOE of onshore wind is 167 USD/MWh; the LCOE of offshore wind is 184 USD/MWh; the LCOE of solar PV is 160 $/MWh, and the LCOE of bioenergy is 102 $/MWh. A study in India found that the LCOE of solar power generation with an initial investment of 5.00 USD/kWh/year, with equated payment loan for 30 years at an interest rate of 4% is found 340.30 USD/MWh and the loan payback period is expanded to the working life of power system, the realistic LCOE is 134.26 USD/MWh [27]. Besides this, the learning rate analysis also explains the cost analysis of electricity generation. On the other words, a learning rate analysis explains the percentage reduction in cost for doubling installed capacity. A learning rate analysis of renewable energy generation in India shows that the wind power generation cost is lowered by 17.7% for doubling of installed wind generation capacity. In contrast, there is no significant learning rate in small hydropower [28]. Another study by Rubin et al. [29] it is found that the learning rate of coal energy is 8.3%; the learning rate of wind power is 12%, the learning rate of solar PV is 23%, the learning rate of biopower is 11%, and the learning rate of hydroelectricity is 1.4%. The study indicates that the electricity generation cost of solar power, wind power, and biopower decreases with increasing installed capacity, except for hydroelectricity

It is revealed that the global investment in renewable energy is also increasing up to USD 270 billion in 2014 [30]. However, the economic analysis of energy policies, programs, and technologies is crucial for sustainable energy systems development. There is the vulnerability of market failure due to underinvestment in R&D programs of RE technologies, unpriced environmental impacts, the monopoly in the energy sector, higher initial investment cost [28]. This study will help in the cost analysis of the electricity generation technologies in Lao PDR.

Here the LCOE which are computed by the US National renewable energy laboratory (NREL), US Energy Information Administration (EIA), and International Renewable Energy Agency (IRENA) are compared.

NREL considers the installed capacity for coal energy about 600-675MW, biomass 75-80MW, wind offshore 50-100 MW, solar thermal 100-200MW from 2008-2010. According to NREL, the LCOE of coal energy is 52 USD/MWh, and solar PV is 155 USD/MWh and 80 USD/MWh for biomass [31]. Likewise, according to EIA, the LCOE for coal energy is 68 USD/MWh; for solar PV is 32.80 USD/MWh and for hydropower is 39 USD/MWh [32]. Lastly, IRENA has computed LCOE of electricity technologies by using 17,000 projects all over the world including 620 GW in china or about 35% of the world, India is 136 GW or 8% of the world, and 181 GW of United States which is 10% of the world [33]. The global LCOE of renewable energy in 2019 is given in Table 2.

Hence, for hydropower, solar power, and biomass power, the LCOE from IRENA is used and, for coal energy, the LCOE of EIA is used to estimate the energy statistics of Lao PDR.

Table 2. LCOE of various technologies from different sources.

LCOE	Unit	Coal	Biomass	Hydro	Solar Photovoltaic	Solar CSP	Wind Onshore	Wind Offshore
IRENA	USD/MWh	-	66	47	68	182	53	115
NREL	USD/MWh	52	80	-	155	146	51	77
EIA	USD/MWh	68	-	39	32.80	-	34	115

Source: NREL [31], EIA [32], IRENA [33].

2.4 CO_2 emission factor

Lao PDR has 1 coal-fired plant and 4 biopower plants, these power plants emit CO_2. The CO_2 emission is computed by using equation 2 and emission factor from 2006 IPCC Guidelines [23] as given below in Table 3.

Table 3. CO_2 emission factor.

Energy	Emission Factor (kg CO_2 /TJ)			EF (tCO_2/MWh)
	Default	Low	Upper	
Biomass	54600	46200	66000	0.1956
Natural Gas	56100	54300	58300	0.2019
Lignite	101000	90900	115000	0.3636

2.5. Selection of annual electricity growth rate

According to World Bank data, the average annual GDP growth of Lao PDR from 2000-2019 is 7%. In this study, an average annual growth rate of electricity for hydropower is taken 8.7% per year, for coal energy is 4.5% per year, for solar energy is 10% per year and for biomass energy is 10% per year [34].

3. Results and discussion

3.1. Results

Table 4 shows the forecasted electricity generation by technology, total generation, average generation cost, and CO_2 emission per MWh. It is forecasted that the total electricity generation in 2030 is 105,676.59 GWh, of which hydropower shares 79.94%, coal shares 19.32%, solar power shares 0.18%, and biopower shares 0.56% of the total generation.

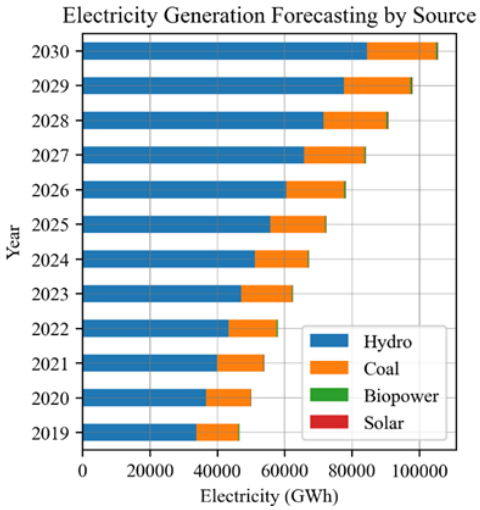

Figure 1. Electricity generation by source during 2019-2030 of Lao PDR.

Figure 1 shows the projected electricity generation by source from 2019 to 2030. Hydropower is the primary energy source for electricity generation, while solar and biopower share a negligible amount of energy sources. Similarly, Figure 2 shows the trend of total electricity generation. It is estimated that electricity generation is increased by 5,320 MWh per year. It is revealed that the cost per MWh of electricity generation in Lao PDR will decrease at a rate of 0.15 USD/MWh per year in Figure 3. The average cost ranges from 51.35 USD/MWh to 52.98 USD/MWh. Figure 4 shows the average CO_2 emissions per MWh of Lao PDR. It is predicted that emissions will decrease at a rate of 2.52 $kgCO_2$ per MWh per year, from 99.04 $kgCO_2$ per MWh in 2019 to 71.35 $kgCO_2$ per MWh in 2030.

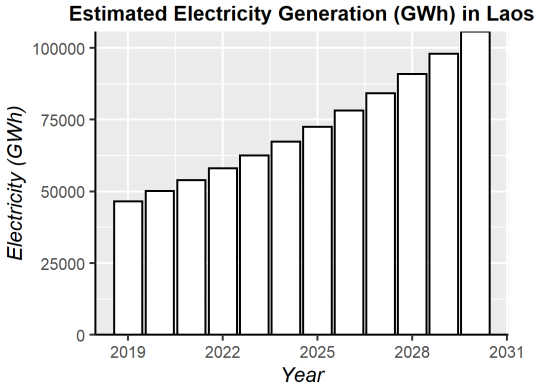

Figure 2. Projected total electricity generation in Lao PDR.

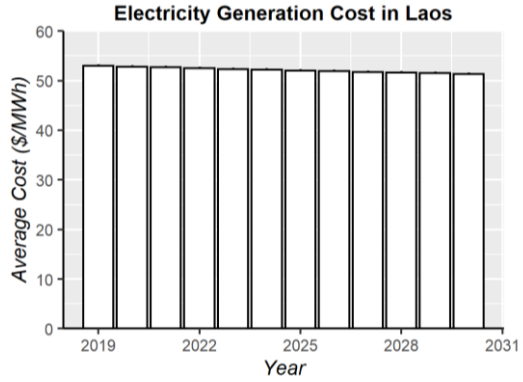

Figure 3. Projected average electricity generation cost of Lao PDR.

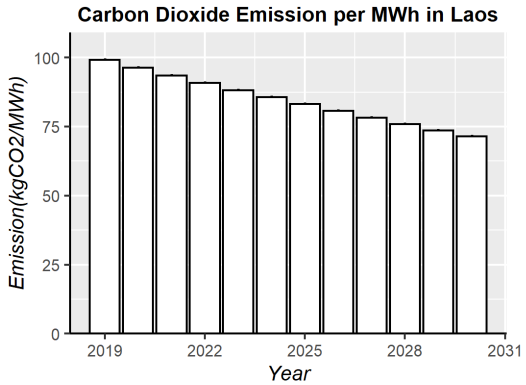

Figure 4. Projected CO_2 emission per MWh in Lao PDR.

Table 4. The projected electricity generation, average generation cost, and average CO_2 emissions during 2019-2030 in Lao PDR.

Year	Hydro (GWh)	Coal (GWh)	Solar (GWh)	Biomass (GWh)	Generation (GWh)	Total cost ($ billion)	Average Cost ($/MWh)	$KgCO_2$/MWh
2019	33,744.93	12,582.00	67.00	207.03	46,600.95	2.469	52.98	99.04
2020	36,680.74	13,148.19	73.70	227.73	50,130.35	2.647	52.81	96.25
2021	39,871.96	13,739.86	81.07	250.50	53,943.39	2.840	52.65	93.52
2022	43,340.82	14,358.15	89.18	275.55	58,063.70	3.048	52.49	90.84
2023	47,111.47	15,004.27	98.10	303.11	62,516.94	3.272	52.34	88.21
2024	51,210.17	15,679.46	107.90	333.42	67,330.95	3.514	52.18	85.64
2025	55,665.45	16,385.04	118.70	366.76	72,535.94	3.774	52.03	83.12
2026	60,508.35	17,122.36	130.56	403.43	78,164.71	4.056	51.89	80.66
2027	65,772.57	17,892.87	143.62	443.78	84,252.84	4.360	51.75	78.25
2028	71,494.79	18,698.05	157.98	488.15	90,838.97	4.688	51.61	75.89
2029	77,714.83	19,539.46	173.78	536.97	97,965.05	5.042	51.47	73.59
2030	84,476.02	20,418.74	191.16	590.67	105,676.59	5.425	51.34	71.35

3.2 Discussion

This study estimates that the electricity generation in Lao PDR will increase from 46.6 TWh in 2019 to 105.68 TWh in 2030. The average electricity generation will be increased by 5 % per year. In comparison, the Ministry of Energy and Mines, Lao PDR, has also stated in Lao PDR Energy Outlook 2019 that electricity generation will increase from 17 TWh in 2015 to 70 TWh by 2040 at an average 5.8% per year. The prediction is based on the business-as-usual scenario, computed using LEAP model with an average 1.5% population growth rate from 2015, 6.4% GDP growth rate from 2020-2030, and 4.7% growth rate of total final energy consumption [34]. In addition, Asian Development Bank (ADB) has also estimated that the electricity generation would increase from 23 TWh in 2016 to 87 TWh in 2030 [15]. The projected electricity generation, forecasted by ADB, includes electricity export 50 TWh with a compound annual growth rate of 9% and domestic market 37 TWh with an annual compound growth rate of 13%. It is also recorded that 46 power plants with an installed capacity of 4,079 MW are under construction [15].

The domestic energy demand of Lao PDR increases from 4.4 Mtoe to 12.8 Mtoe during 2015-2040, while consumption will increase from 2.91 Mtoe to 9.14 Mtoe in the same period [34]. The Laos government's goal has planned addition renewable energy such as small hydro of 400MW, wind onshore of 73 MW, biomass power plants of 36 MW, and solar photovoltaics of 33 MW [35]. The plan includes the development of floating solar energy farms of more than 1,000 MW in the reservoir of large hydropower plants [15]**.** Moreover, the Laos government has established a national green energy policy, which focuses on the energy sustainability of ASEAN. Thus, clean energy is the principal goal for promoting a pollution-free country by 2050. The government has encouraged domestic and foreign private investment in renewable development and importing electricity vehicles to achieve the goals. For solar photovoltaic, to reduce using kerosene in rural areas, private companies offer solar photovoltaic units to households for a long payback period [12].

In the context of emission, it is found that the average CO_2 emission per MWh in the power sector will decrease from 99.04 $kgCO_2$/MWh in 2019 to 71.35 $kgCO_2$/MWh in 2030. The average CO_2 emission rate is calculated from the emission rates of fuels used for electricity generation, where CO_2 emission from the biomass power plant is 195.6 kgCO2/MWh, coal- lignite is 363.6 $kgCO_2$/MWh. The average CO_2 trend is decreasing while electricity generation from coal-lignite fired is increasing due to the proportion of power generated from coal will reduce from 27% to 19.3% of total generation during 2019-2030.

In the context of the cost of electricity, it is found that the average electricity generation cost was 52.98 USD/MWh in 2019 and will continuously decrease to 51.34 USD/MWh in 2030. Generally, the weighted average generation cost trend is decreasing, especially solar photovoltaic systems that drastically reduce from 378 USD/MWh to 68 USD/MWh or 83%, for biomass decrease 76 USD/MWh to 66 USD/MWh during 2010 to 2019 [33]. According to IRENA, 2019, the generation cost of hydropower has increased during 2010-2019, that is 37 USD/MWh to 47 USD/MWh [33]. The generation cost of hydropower depends on their planned capacity. Besides this, the generation cost of solar power is also lessening due to the advancement in solar technology. Overall, the electricity generation cost will be cheaper over time. Oppositely**,** coal energy's weighted average generation cost increases, but at a much lower rate, from 50 USD/MWh to 51.6USD/MWh during 2009-2030 [31].

4. Conclusion

This study found that the electricity generation from 2019-2030 will increase from 46.6 TWh to 105.68 TWh. It is also revealed that the average generation cost for all energy technologies are decreasing. In the aggregate of all energy generation technologies, the average cost of electricity generation will decrease from 52.98 $/MWh in 2019 to 51.34 $/MWh in 2030. However, this cost analysis is based on global level LCOE, which might differ over time. Another major environmental issue is carbon emission from energy development. Although the total CO_2 emission increases with the increasing electricity production, the average CO_2 emission per MWh will decrease from 99.04 $kgCO_2$/MWh to 71.35 $kgCO_2$/MWh from 2019 to 2030 due to the inclusion of more renewable energy. The result indicates the future greener electricity production in Lao PDR.

Thus, the electricity generation cost of Lao PDR will be cheaper in the future, which might drive cheaper electricity tariffs. Future endeavors should be given on the more detailed economic analysis of electricity generation by each technology based on a real cost basis. The research and development of renewable energy, especially solar photovoltaic, benefit the environment and rural electrification. The CO_2 emission from energy development should analyze from life cycle perspectives. Furthermore, for greener, cleaner, and cheaper electricity production, solar power, wind power, and biopower should be promoted.

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