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Price duration curve and cost of renewable energy for electricity generation for power development plan of Thailand (PDP 2018)

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Abstract

Electricity supply security has become one of the main concerns in the national energy supply plan. Diversification of fuels used for electricity generation is therefore a major tool for energy acquisition. The fuels used for electricity generation are natural gas, coal, hydropower, oil, imported from neighboring countries, and renewable energy.
There have been four major groups of generators in Thailand, who are Electricity Generating Authority of Thailand (EGAT, a state enterprise), Independent Power Producers (IPPs), Small Power Producers (SPPs), and Very Small Power Producers (VSPPs). In addition to those major groups of producers, there have been import and exchange of electricity with neighboring countries, such as Lao PDR and Malaysia.
The latest Power Development Plan of Thailand (PDP 2018), issued in April 2019, provides detailed plan of supply of electricity until 2037. The plan includes electricity supply from fossil fuels and renewable energy, which are subjected to different generation costs. Possible price duration curves for annual supplies in 2037 is derived, and the average generation costs from 2018 till 2037 are estimated. The cost proportion electricity from renewable energy is planned to increase from 7.5% in 2018 to 21.7% in 2037, which indicates a significant substitution of renewable energy for traditional fossil fuels.

Keywords: Power development plan, renewable energy, price duration curve, electricity generation cost

1. Introduction

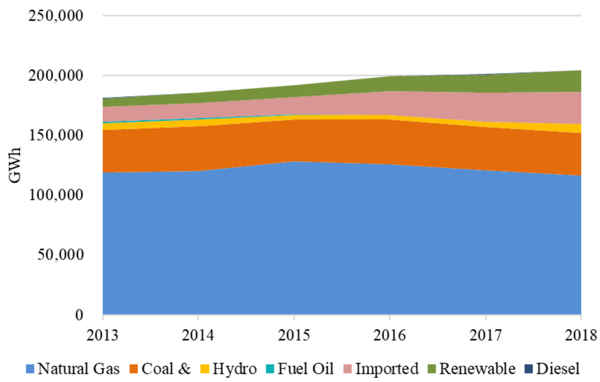

Fig. 1. Electricity generation by fuels during 2013 and 2018.
(Source: Energy Policy and Planning Office, Ministry of Energy, Thailand)

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Electricity supply security has become one of the main concerns in the national energy supply plan. Diversification of fuels used for electricity generation is therefore a major tool for energy acquisition. The fuels used for electricity generation are natural gas, coal, hydropower, oil, imported from neighboring countries, and renewable energy, as shown in Fig. 1.

The Electricity Generating Authority of Thailand (EGAT) is the main power generator among other private producers, while the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA) are the power distributors.

Thai government has also promoted private investment in power business for the last two decades. There have been three major groups of private generators in the country, who are Independent Power Producers (IPPs), Small Power Producers (SPPs), and Very Small Power Producers (VSPPs). The private producers have been established due to their installed capacities and supply conditions.

1) Independent Power Producers (IPPs) are power plants with installed capacity larger than 90 MW, and primarily fueled by natural gas and coal, that provide base load to the system and are bounded with long-term power purchasing agreements with EGAT. IPPs operate their plants under the authority's command and are paid for electricity actually supplied to EGAT and are guaranteed for a minimum power supply or a take-or-pay revenue.
2) Small Power Producers (SPPs) are power plants with typical capacities of 100-200 MW, whose main objective is to supply electricity directly to industrial customers in the vicinity area, and sell the excess of their generated power to the grid with either firmed or non-firmed agreements.
3) Very Small Power Producers (VSPPs) are power plants with installed capacities less than 10 MW, who are contracted with PEA or MEA. They are intended to be very small power plants and make use of local waste materials from agricultural processing plants. Their revenues are based on the feed-in tariff (FiT), which varies with the type of fuel input throughout the project's life.

The electricity supply structure is shown in Fig. 2, which includes EGAT, IPPs, SPPs, and VSPPs as generators, and PEA and MEA as distributors.

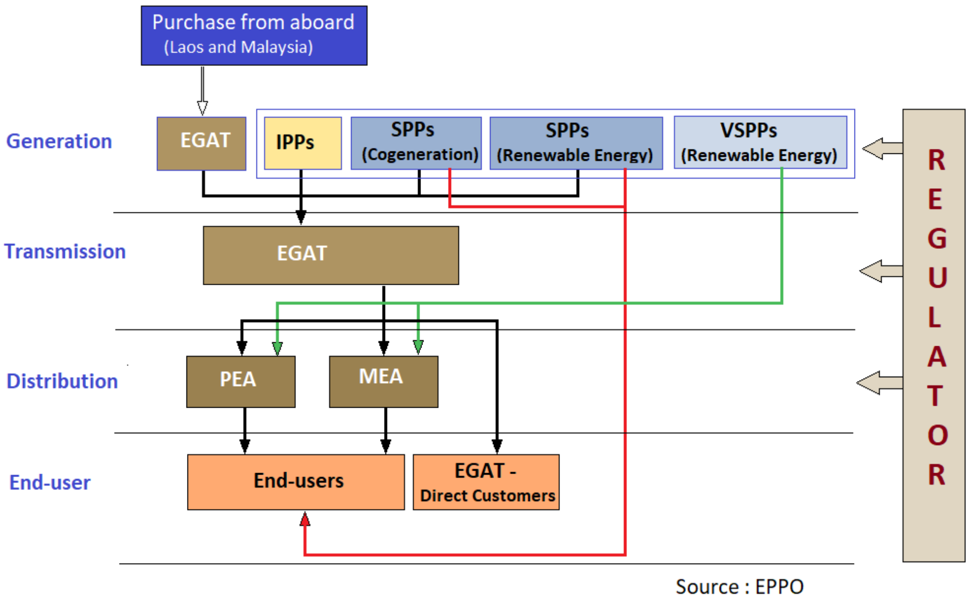


Fig. 2. Electricity supply industry in Thailand
(Source: Energy Policy and Planning Office, Ministry of Energy, Thailand)

In addition to those major groups of producers, there have been import and exchange of electricity with neighboring countries, such as Lao PDR and Malaysia. The installed capacities of the generator groups are provided in Fig. 3.

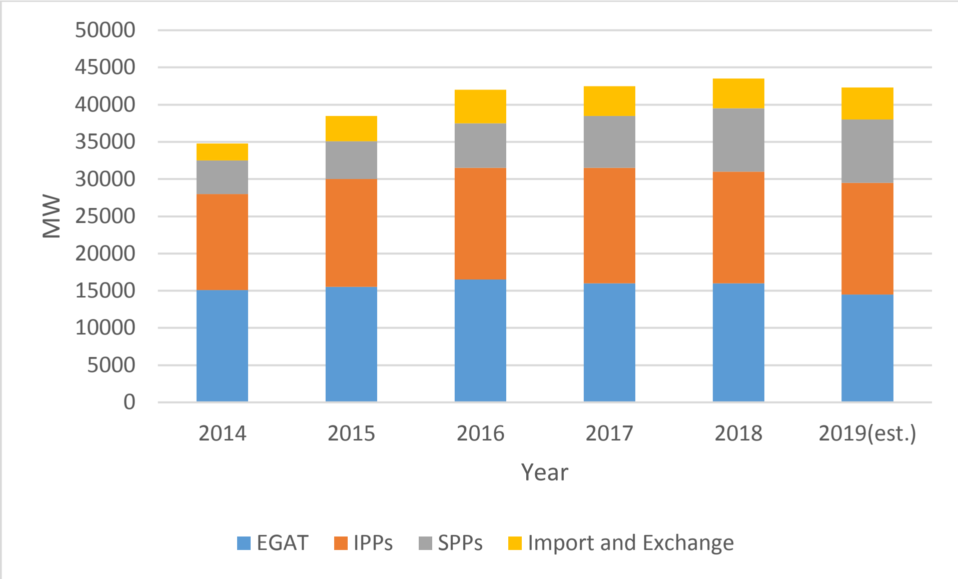


Fig. 3. Electricity installed capacity by groups of producers during 2014 and 2019.
(Source: Energy Policy and Planning Office, Ministry of Energy, Thailand)

It is worth noting that most of the power suppliers, both within the country and from neighboring countries, are obligated to set forth agreements, which require them to deliver the contracted amounts. On the other hand, the grid authority is also required to meet the contractual requirements with power suppliers. Therefore, the grid authority will have to manage by contractual requirements, which may not necessarily base on the lowest cost of generation. The investigation for the average unit cost of electricity planned for generation and delivery in the Power Development Plan of Thailand (PDP 2018) [1] from 2018 to 2037 can be useful for future planning.

2. Data and Methods

There have been studies and evaluations of similar situations regularly. G. Oggioni, F.H. Murphy, and Y. Smeers [2] evaluated the impacts of priority dispatch in the European electricity market by comparing the impacts of the Nodal Pricing and European Market Coupling organizations under two main wind policies. Those were to accommodate all wind energy and "no priority dispatch" policy. Similar effects were found for both policies when wind penetration was not too high. Cataldi Alessandra, Clo Stefano, and Pietro Zoppoli [3] analyzed the merit-order effect of solar and wind energy on the Italian wholesale electricity market over the period 2005-2013, and found that an increase in 1 GWh of the hourly average production from solar and wind sources reduced the wholesale electricity price by 2.3 Euro/MWh and 4.2 Euro/MWh respectively. Due to the increase in the production over time, the price impacts tended to decrease. Paul Deane, et.al. [4] noted that the increase in electricity from renewable energy lowered electricity wholesale prices and caused a shift in the merit orders of conventional thermal plants on the dispatching curve. The merit order effect in European electricity wholesale markets was quantified to be 1.6 Euro/MWh and 4.2 Euro/MWh for 2030 and 2050. Cherrelle Eid, Paul Codani, Yannick Perez, Javier Reneses, and Rudi Hakvoort [5] reviewed trading platforms for existing Distributed Energy Resources (DER) in electricity markets. Jorge Blazquez, Rolando Fuentes-Bracamontes, carlo Andrea Bollino, and Nora Nezamuddin [6] brought to attention the incompatibility between electricity liberalization and renewable policy and pointed out the paradox of the not-dispatchable renewable technologies regardless of their close to zero marginal costs. Amy O'Mahoney and Eleanor Denny [7] estimated the historic cost savings due to electricity from wind in the Irish electricity market by using an hourly time series OLS regression model for 2009, and found that a saving of Euro141 million was resulted to the market dispatch.

R.N. Allan and A.M. Shaalan [8] reviewed he traditional costing techniques and modelling methods that improved the probabilistic techniques of production costing. One of the technique employed Fast Fourier Transforms to deduce capacity outage probability, while the other involved the capacity availability model with the period load duration curve to determine the expected energy served and the expected energy not served due to unit outages. Jintaek Lim, Jinhwan Jang, Jaeseok Choi, Kyeonghee Cho, and Junmin Cha [9] evaluated the economic credits and reliability of renewable generators using probabilistic reliability and production cost simulation method, and confirmed the viability of the method with test results. J. Valenzuela and M. Mazumdar [10] illustrated a procedure for constructing a stochastic system-based model for the price duration curve. Pascal Michaillat and Shmuel Oren [11] computed the Electricity Price Duration Curve (EPDC) under price and quantity competition models and compared the numerical results with modeling flexibility.

The economic dispatch of electricity generally starts with the generator with the lowest marginal cost, and extends to those with the next lowest costs until the demand is met, as shown in Fig. 4.

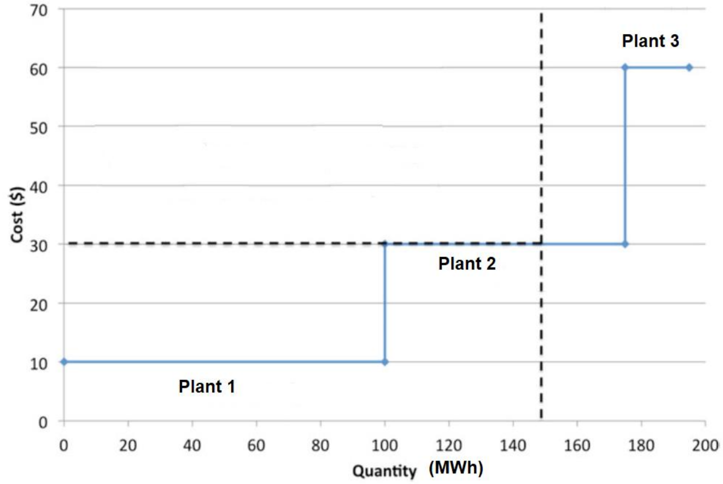


Fig. 4. Economic dispatch of electricity.

There are instances where the dispatch schemes are deviated from the general sequence, from the cheapest to the most expensive, as a result of renewable energy promotion or contractual engagement due to security purpose. Electricity from wind and solar is recently prioritized into the top of the list for dispatching, although the generation cost is not the lowest. This can be explained with the environmental benefit, which less CO2 and other greenhouse gases are emitted throughout its life cycle. IPPs and SPPs are often honored on the dispatch list, because they are obligated under the power purchase agreements (PPA). When an IPP is ready to dispatch, it is eligible for availability payment, even though it is not required to generate. SPPs are also obligated in the similar manner with IPPs. The dispatch of electricity in Thailand has been planned in accordance with the constraints, in addition to the generation cost.

2.1. Generation capacities

According to the Power Development Plan for Thailand (PDP 2018) [1], there will be power plants to be installed and to be retired during 2018 to 2037, by which the excess capacity will be maintained at least or above the required reserve limit. Different plants are subject to different constraints and gain different dispatch priorities. The dispatches of hydropower plants, for example, depend on the availability of water in dams, which is in excess of that reserved for agriculture. The dispatches of biomass plants are mainly due to the availability of biomass. Apart from the availability of resources, the contracted power plants, which are obligated to deliver the minimum take-or-pay amounts, are prioritized to avoid the undelivered power charges. Fig. 5 illustrates the planned capacity by fuel type from 2018 to 2037.

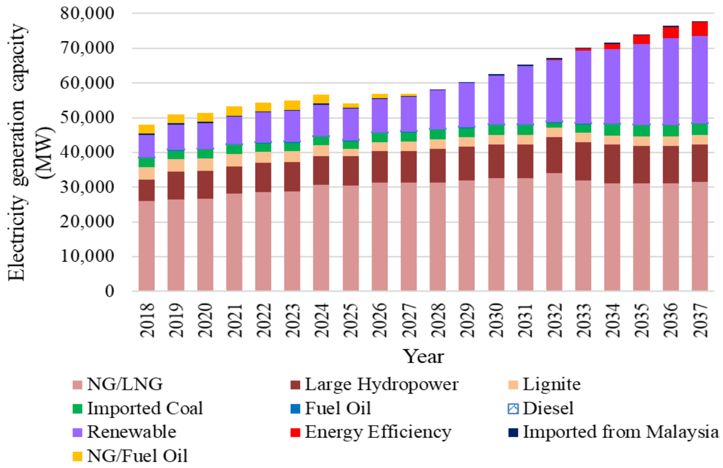


Fig. 5. Planned capacity by fuel type from 2018 to 2037 (PDP 2018).

2.2. Electricity demands

An average annual GDP growth of 3.8% and an average population growth of -0.02%, during 2017-2037, were used to forecast the electricity demands of the same period. It has been forecasted that from 2018-2037 the capacity demand rises with an annual average rate of 2.93%, and the energy demand increases with an annual average rate of 3.13%. The peak demand of electricity is expected to increase from 29,969 MW in 2018 to 53,997 MW in 2037, while the energy demand increases from 203,203 GWh in 2018 to 367,458 GWh in 2037, as shown in Fig. 6.

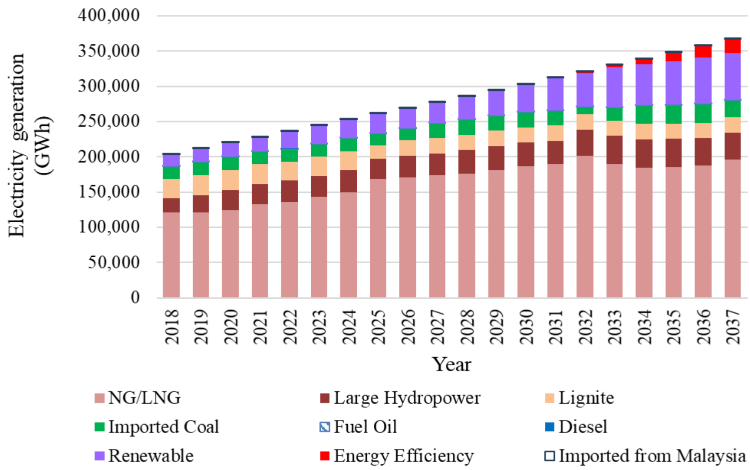


Fig. 6. Planned generation by fuel type from 2018 to 2037 (PDP 2018).

2.3. Costs of electricity generation by fuel

Costs of electricity mainly comprise initial investment costs, fixed operation and maintenance costs, variable operation and maintenance costs, and fuel costs. In order to determine unit costs of electricity generation of different technologies over the period of time of interest, the initial investment costs are levelized by the discounted generation units over the plant life, while fixed O&M costs, variable O&M costs, and fuel costs are escalated with 2% annual rate. The information of costs of different technologies in Table 1 are obtained from many sources, such as IEA, EIA, FAO, EGAT, and others as detailed in the notes of the cost table.

Table 1. Electricity generation cost by fuel type.

Year	Large Hydro[a]	Natural Gas[b,c]	Fuel Oil[d]	Diesel Oil[d]	Lignite[e,f]	Imported coal[g]	Renewable Energy[h]	Energy Efficiency[i]	Import from Malaysia[j]
2018	123.22	70.69	239.00	239.00	75.56	75.24	73.40	20.40	63.00
2019	123.52	67.49	243.78	243.78	76.04	75.71	74.87	20.81	64.26
2020	123.83	68.25	248.66	248.66	76.52	76.18	76.37	21.22	65.55
2021	124.15	69.01	253.63	253.63	77.02	76.67	77.89	21.65	66.86
2022	124.47	69.78	258.70	258.70	77.51	77.16	79.45	22.08	68.19
2023	124.80	70.54	263.88	263.88	78.04	77.68	81.04	22.52	69.56
2024	125.14	71.31	269.15	269.15	78.55	78.19	82.66	22.97	70.95
2025	125.48	72.08	274.54	274.54	79.09	78.72	84.31	23.43	72.37
2026	125.83	72.86	280.03	280.03	79.64	79.26	86.00	23.90	73.81
2027	126.19	73.63	285.63	285.63	80.20	79.81	87.72	24.38	75.29
2028	126.55	74.41	291.34	291.34	80.76	80.36	89.47	24.87	76.80
2029	126.92	75.19	297.17	297.17	81.34	80.93	91.26	25.36	78.33
2030	127.30	75.98	303.11	303.11	81.93	81.52	93.09	25.87	79.90
2031	127.69	76.76	309.17	309.17	82.54	82.12	94.95	26.39	81.50
2032	128.08	77.55	315.36	315.36	83.15	82.72	96.85	26.92	83.13
2033	128.48	78.34	321.66	321.66	83.78	83.35	98.79	27.46	84.79
2034	128.89	79.13	328.10	328.10	84.42	83.97	100.76	28.00	86.49
2035	129.31	79.93	334.66	334.66	85.07	84.61	102.78	28.56	88.22
2036	129.74	80.73	341.35	341.35	85.74	85.27	104.83	29.14	89.98
2037	130.17	81.53	348.18	348.18	86.41	85.94	106.93	29.72	91.78

Notes :

a. Hydro, Typical capacity = 50 MW, installation cost = $4,000/kW, fixed & variable O&M = $60/kW, 30 service years, load capacity = 45% [12].
b. Combined cycle, Typical capacity = 702 MW, Heat rate = 6,600 Btu/kWh, overnight cost = $978/kW, variable O&M = $3.5/MWh, fixed O&M = $11/kW, 20 service years, load capacity = 87% [13].
c. LNG, Japan ($/mmBtu) : 2018-2025, 10.7, 7.4, 7.5, 7.6, 7.7, 7.8, 7.9, 8.0, (2030:8.5) [14].
d. Diesel reciprocating engine, LCOE: $197-$281 per MWh [15].
e. Coal power plant, Ultra Supercritical Coal, capacity 650 MW, Heat rate 8,800 Btu/kWh, Overnight capital cost = $3,636/kW, Fixed O&M cost = $42.1/kW-yr, Variable O&M cost = $4.6/MWh [13].
f. Mae Moh unit 4-7, ultra supercritical, Capacity 655 MW, 30 service years, Coal consumption 3.23 mil. Tons per year, HHV lignite 2,800 kcal/kg., load capacity 85% or 7,446 hr per year [16].
g. Coal power plant, Ultra Supercritical Coal, Imported bituminous $55.60/ton [13], Calorific value 5,800-8,000 kcal/kg [17].
h. Renewable energy, average cost is calculated by renewable energy proportion provided in PDP 2018 [1] and LCOE of each technology [18].
i. Program administration cost of saved electricity [19].
j. Adopted from Laos-Thailand-Malaysia purchase agreement [20].

The estimated generation costs of various fuel types are plotted in Fig. 7.

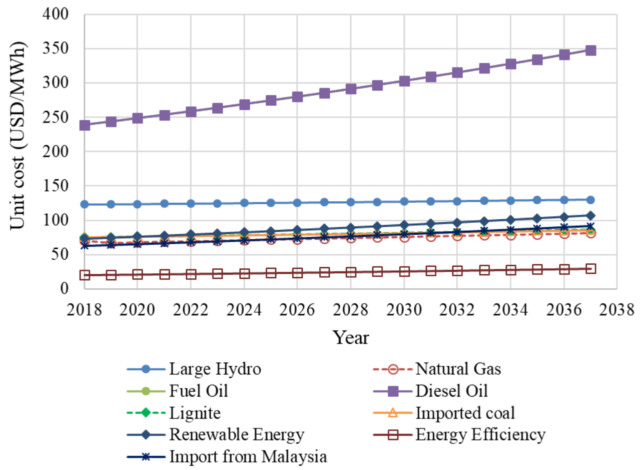


Fig. 7. Estimated electricity generation cost by fuel type from 2018 to 2037.

3. Results and Discussion

As described above, the energy market in Thailand is considered as the enhanced single buyer with multiple groups of suppliers. Dispatches of electricity of different suppliers are subject to different constraints. Load factors of various technologies, which indicate how efficient the power plants of different technologies are utilized, and the average costs of electricity generation over the period covered by PDP 2018 can be of interest and useful for policy makers for their future planning.

3.1. Capacity utilization factors

A capacity utilization factor is calculated as a proportion of the average capacity utilized for electricity generation to the total installed capacity, as equation (1). Capacity utilization factors of power plants using various fuels are calculated and plotted in Fig. 8.

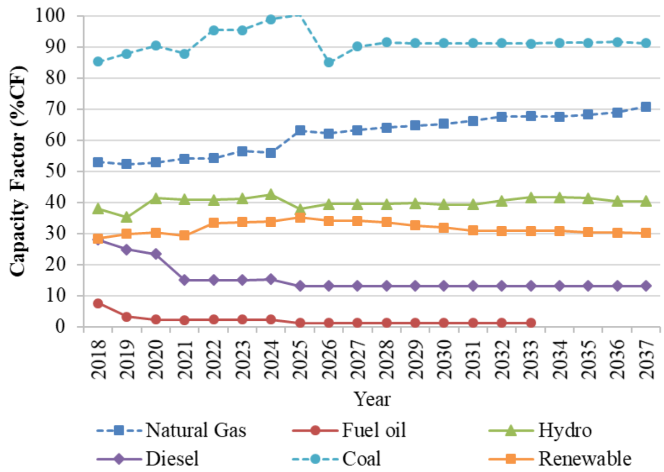
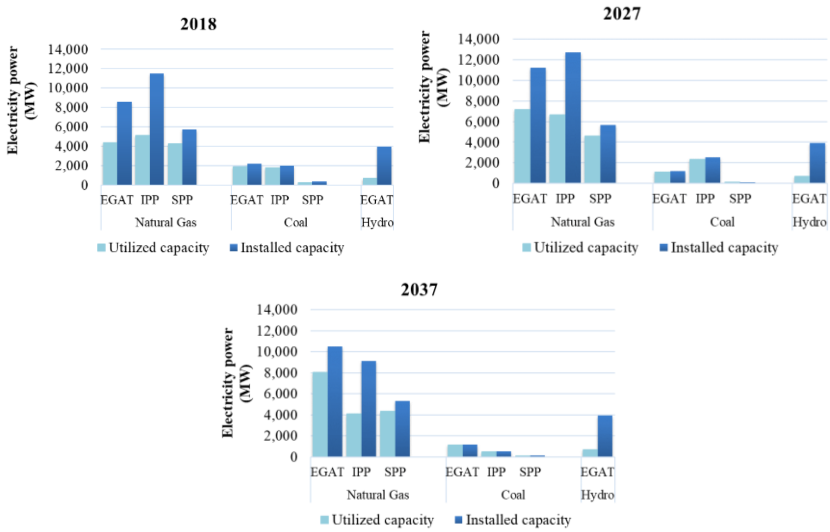


Fig. 8. Calculated capacity factors of power plants using various fuels from 2018 to 2037.



a). b). c).

Fig. 9. Utilization of power plants of various fuels in 2018, 2027, and 2037.

It is obvious that natural gas fired power plants dominate the country power generation system, and are followed by coal fired power plants, as shown in Fig. 9. Most of the power plants are planned to operate either less than the installed capacities or less hours in the year. Average powers for power plants with different types of fuels in 2018, 2027, and 2037 are calculated by the formala.

$$Average\ power = \frac{Generated\ energy}{8{,}760} \qquad \ldots\ldots\ldots\ldots\ldots\ (1)$$

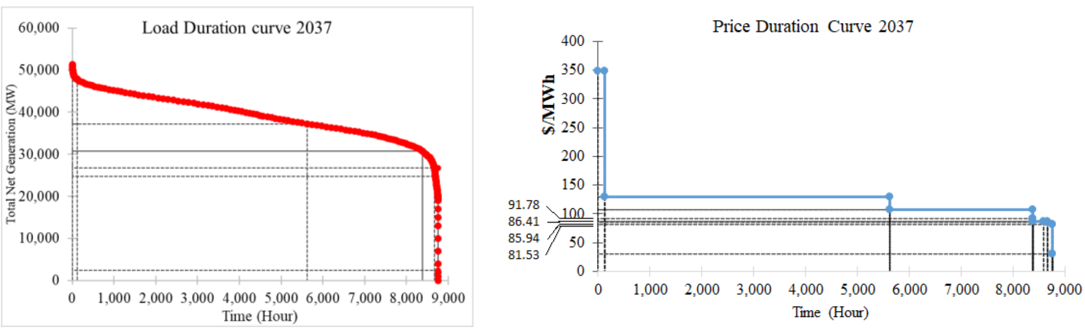
$$Capacity\ factor = \frac{Generated\ energy}{(Total\ installed\ capacity \times 8{,}760)} \qquad \ldots\ldots\ldots\ldots\ldots\ (2)$$

In 2018, the average power of EGAT's natural gas fired power plants was 4,367 MW, which was 50.7% of the installed capacity of 8,582 MW. That was the capacity factor of EGAT's natural gas fired power plants in 2018 was 50.7%. In the same manner, the capacity factors of the natural gas fired power plants, which belong to IPP and SPP, in 2018 were 44.2% and 73.0%, respectively. The capacity factors of coal fired power plants of EGAT and IPP were higher than those with natural gas firing, which were 85.4% and 89.4% respectively. Oppositely, the capacity factor of SPP coal fired power plants was 67.9%, lower than the SPP natural gas fired power plants. The capacity utilization of hydro power plants was rather low at 16.7% due to limited supply of water.

The capacity factors of EGAT's power plants, both with natural gas and coal firing, is improved over the years till 2037. For EGAT natural gas fired power plants, their capacity factors increase to 64.1% in 2027, and 76.7% in 2037, while the capacity factors for EGAT coal fired power plants grow to 92.3% in 2027 and 2037. IPP's natural gas fired power plants are planned for less utilization, which results in lower capacity factors of 52.5% in 2027, and 44.9% in 2037, while IPP's coal fired power plants are planned for the same rate of utilization at around 90.6% throughout 2037. The capacity factors of SPP's natural gas fired power plants increase slightly to 78.6% in 2027 and 79.3% in 2037. SPP's coal fired power plants are expected to similar increase in the capacity factors to 77.8% in 2027 and 2037. The plan for energy delivery from hydropower plants remains the same till 2037.

3.2. Price duration curves

A price duration curve illustrates the relationship between cost of electricity generation in descending order and annual capacity utilization. The plants with lower generating costs are preferred to operate for base loads, while those with high generating costs deliver for peak load. The lower cost plants are basically planned to deliver more electricity than those with high costs to minimize the average electricity cost. As a result, as in Fig. 10, natural gas fired power plants and coal fired power plants, both with lignite and imported coal, are planned for base loads and intermediate loads. Large hydropower plants and oil fired power plants are dispatched for less operating hours to cover peak loads.



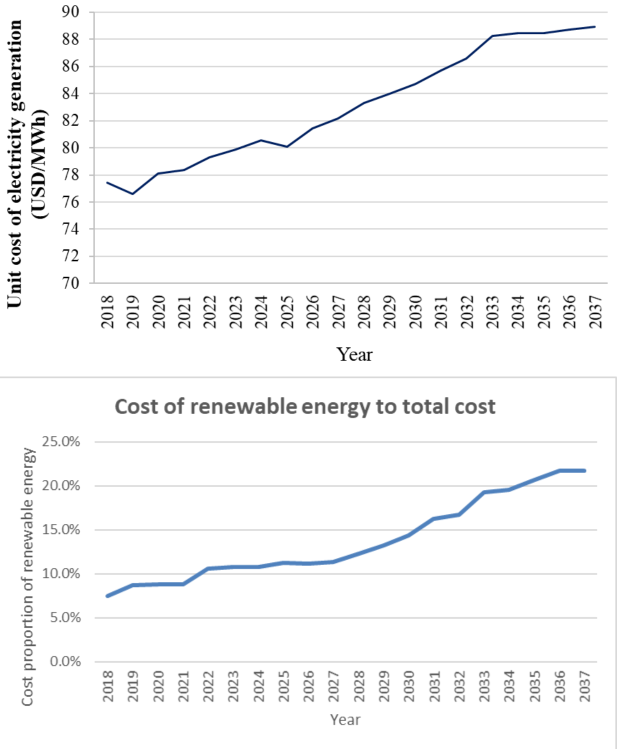
a) b).

Fig. 10. Load duration curve and price duration curve for electricity generation in 2037.

For instance, power generation planned for 2037 is used as an example to elaborate the price duration curve. In 2037, PDP indicates that the lowest cost of electricity is generated by natural gas and liquefied natural gas, at US$81.53/MWh, and followed by imported coal and lignite at US$85.94/MWh and US$86.41/MWh, respectively. Fuel oil and diesel oil are the fuels that result in the highest cost of electricity generation, at US$348.18/MWh. Oil is used for emergency requirement or when the main generators are shut down for maintenance. The cost of electricity from large hydro is US$130.71/MWh, while the average cost of electricity generation from renewable energy, including biomass, biogas, solar PV, wind, waste, small hydro, and geothermal, is US$106.93/MWh. The cost of imported power from Malaysia is estimated to be US$91.78/MWh.

3.3. Generation cost projection

The generation costs of electricity vary by technologies and types of fuel. The weighted average cost can be used to represent the generation cost of the system. The weighted average generation costs of electricity during 2018-2037, which are determined from the price duration curves, are shown in Fig. 11a. The proportion of renewable energy for the power generation is planned to increase from 7.5% in 2018 to 21.7% in 2037, as shown in Fig. 11b.



a). Unit cost of electricity generation b). Cost proportion of electricity generation from renewable energy

Fig. 11 Estimated unit cost of electricity and cost proportion of electricity generation from renewable energy to total cost of electricity generation from 2018 to 2037.

4. Conclusions

Electricity generation cost during 2018 to 2037 is estimated from information provided in PDP 2018. Certain points can be drawn for attention and some issues are recommended for further improvement as follows:

4.1 Although diversification of fuels used for electricity generation has been one of the major objectives in PDP 2018, new natural gas fired power plants are planned during the course of the PDP. For the fact that the capacities of the existing plants have not been fully utilized, both EGAT's and IPP's, additional power plants are planned and cause surplus in the supply and excess in investment.

4.2 It is stated in PDP 2018 that residential roof top photovoltaic systems (solar PV) are promoted and limited to approximately 100 MW per year, from 2019 to 2027, up to 1,000 MW. It is also included in the PDP 2018 that there will be an increase in solar PV by approximately 1,000 MW per year from 2028 onwards, which adds up to a total of 10,000 MW in 2036. Despite the unspecified mean of addition of solar PV, the amount of energy generated from the installed capacity is not detailed.

4.3 As there is not cost information provided in the PDP 2018, this study employs cost information obtained from other sources. If cost information is available, the more accurate cost of electricity generation can be projected.

4.4 The increase in renewable energy planned in PDP2018 results in larger cost proportion of renewable energy, from 7.5% in 2018 to 21.7% in 2037, which indicates a clear direction to move toward green energy.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Both authors equally contributed their time and efforts in the research, which include analysis of the data, writing of the paper, and approval of the final version.

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