# Selection of Large-scale Nuclear Power Plant based on Economic and Reliability Aspects in Indonesian Power System

**Rizki Firmansyah Setya Budi[1], Moch. Djoko Birmano[2]\*, Elok Satiti Amitayani[2]**

[1]Department of Electrical and Information Engineering, Gadjah Mada University, Indonesia; [2]Center for Nuclear Energy System. National Nuclear Energy Agency Of Indonesia, Jakarta, Indonesia. \*Email: birmano@batan.go.id

**ABSTRACT**

Choosing the Indonesia's power systems that are suitable with the large-scale nuclear power plant (NPP) and the NPP's vendor country are crucial problems faced by Indonesian government. Therefore, this research analyzes the NPP impact on the power system reliability to choose the suitable power systems and the NPP economics of each possible vendor country to choose the optimal vendor that provides minimize cost. This research uses two electricity price scenarios: electricity production cost (scenario 1) and adjustment tariff (scenario 2). The results show that only Sumatra and Java-Bali system can be connected with the NPP. For both of these systems, Japanese NPP is not economical to be developed because it provides a levelized unit electricity cost (LUEC) of 0.116 USD/kWh, which is higher than the electricity prices. Meanwhile, Chinese and South Korean NPP is economical to be developed in both systems. For the Java-Bali system, Chinese NPP is the best choice in scenario 1 with a LUEC of 0.036 USD/kWh. In scenario 2, South Korean NPP that has a LUEC of 0.058 USD/kWh becomes the best choice because it has better public perception than Chinese. For the Sumatra system, South Korean NPP is the best choice in both scenarios.

**Keywords:** Large-scale NPP Selection, Indonesia Power System, Reliability, Minimize Cost, ELECTRICITY price
**JEL classifications:** D21, D22, E39

## 1. INTRODUCTION

Indonesia's power system is a large power system that is divided into three operating areas, i.e., Sumatera, Java-Bali, and East Indonesia (Budi et al., 2017). The East Indonesia areas consist of Kalimantan, Sulawesi, Papua, and other islands. The installed capacities of each operation area are Sumatra 6.5 GW, Java-Bali 32.5 GWe, and East Indonesia 4.4 GW. Based on the electricity supply business plan of PT. PLN 2017-2026, by 2026, the forecast of installed capacity in each area is Sumatra 25.6 GWe, Java-Bali 70.5 GWe, and East Indonesia 16.5 GWe. The total installed capacity will reach 112.6 GW in 2026. This leads to the need for optimal utilization of all energy sources by considering the aspects of reliability and economics.

Indonesia's power plants are dominated by fossil power plants that have high $CO_2$ emissions (Dutu, 2016). Also, the power

generation sector is the second-largest $CO_2$ contributor, so $CO_2$ reduction in this sector will have a significant impact (Hejazi, 2017). And in some regions, oil power plants that depend on oil imports still dominated (Silberglitt and Kimmel, 2015; Handayani et al., 2017). These conditions make the Indonesia energy security index (ESI) low. Indonesia ESI rank is 55th from 71 countries with an ESI value of 0.475 (Erahman et al., 2016). It is certain that a sufficient, economical, and environmentally friendly energy supply is needed to improve the ESI.

The new and renewable energy (NRE) especially nuclear can be one of the most attractive options to supply Indonesia's electricity demand in the future due to low $CO_2$ emissions and nuclear can generate enormous amounts of energy (Hejazi, 2017; Prăvălie and Bandoc, 2018; Kumar, 2016). By using nuclear energy, ESI can be increased and it has a direct impact on energy adequacy and

economic growth (Bakirtas and Akpolat 2018). Also, Indonesia has the most advance progress on nuclear power infrastructure development, has the highest public acceptance in Southeast Asia, and has a lot of experience in operating a nuclear research reactor (Putra, 2017).

From 2010 to 2016, public acceptance showed a positive trend from year to year and reached 77.53% in 2016 (BATAN, 2017). From 77.53% of respondents who accepted NPP, the reasons why they accepted NPP are that NPP increases power system reliability and NPP decreases electricity price in Indonesia. From 22.47% who declined NPP development, the reason why they declined is that they are worried about a nuclear accident and radioactive contamination (BATAN, 2017). Based on those reasons, we can conclude three important points that great effect on NPP development, i.e., economy, reliability, and safety. The Indonesian government should concern about those points to make a successful NPP project.

Some research mentioned that NPP was a favorable power plant to utilize in Indonesia (Budi et al., 2011, Aritonang et al., 2018, Pioro and Duffey, 2015). In addition, based on Indonesia's national energy policy (NEP), the opportunity for utilization of NPP to realize the target of the NRE portion is widely open (Jaelani et al., 2017; Khairunnisa et al., 2017). Therefore, an NPP study on reliability and economy is needed. The reliability analysis is needed because the NPP capacity is big enough to disrupt the reliability system while the economic analysis is needed because the NPP has a massive investment cost.

Research (Budi et al., 2015) has performed an analysis on improving the LOLP index in the Bangka power system. The research's results showed that using NPP was necessary to improve the LOLP. While in research (Nuryanti et al., 2014), it was conducted an economic analysis of the small-medium reactor (SMR) by using levelized unit electricity cost (LUEC). The analysis was conducted using 3 models, i.e., Puslitbang PLN model, Mini G4ECONS model, and Levelized Cost model. The research results showed that the LUEC was not much different between the three models, which were 14.59 (Puslitbang PLN model), 15.06 (Mini G4ECONS), and 14.24 (levelized cost) cents USD/kWh.

Other research has conducted an economic analysis on SMR with varying investment costs (Nasrullah, 2014). The research's results showed the LUEC of SMR was ranging from 9.31 cents USD/kWh up to 19.07 cents USD/kWh.

The economic analysis of NPP has been done not only in SMR but also in large-scale NPP (Nasrullah and Sriyana, 2010). In addition, some research included uncertainty factor to the economic analysis of large scale NPP (Nuryanti et al., 2012).

Research showed that large-scale NPP gave lower LUEC than SMR. It showed that large-scale NPP was more economical and suitable to be developed in Indonesia than SMR (Budi et al., 2015; Nuryanti et al., 2014; Nasrullah, 2014; Nasrullah and Sriyana 2010; Nuryanti et al., 2012). But the calculation in research (Budi et al., 2015; Nuryanti et al., 2014; Nasrullah, 2014; Nasrullah and Sriyana, 2010; Nuryanti et al., 2012) used old data. While the NPP investment cost increases in line with escalation, inflation, and improvement of safety system specifications (OECD, 2015), the old data will make imprecise calculations because the data is different from factual data. Therefore, a research conducting an economic analysis of large-scale NPP based on factual data and Indonesia's condition is needed.

Many previous studies have discussed the reliability and the economics of NPP. But none of them discussed the power systems in Indonesia that can be connected to large-scale NPP and the vendor country that potentially can build the NPP. Choosing the proper power system that can be connected to the NPP is an important factor in supporting the government policy on nuclear energy development. Based on the report (OECD, 2015), there are 10 vendor countries in the world. The economic analysis is needed to help the Indonesian government to choose the NPP vendor country.

Therefore, this research conducted reliability and economic analysis of large-scale NPP. This research analyzed the impact of large-scale NPP operation on the system reliability and analyzed the economics of large-scale NPP by using the latest data based on Indonesia's condition. Reliability analysis was used as a constraint for NPP location. If in the reliability analysis, NPP caused the LOLP index greater than its standard, the NPP will not be developed and will not need the economic analysis. In other words, reliability analysis determined the NPP location. The location determined the electricity tariff that used in the economic calculation of large-scale NPP. This was because based on Minister of Energy and Mineral Resources's (MoEMR) decision No. 1404 K/20/MEM/2017, each region in Indonesia had different electricity production costs. For the economic analysis, this research used 1000 MWe NPP from China, South Korea, and Japan as reference power plants. Based on the economic analysis results, the NPP of specific country feasible to be developed in Indonesia power systems was obtained.
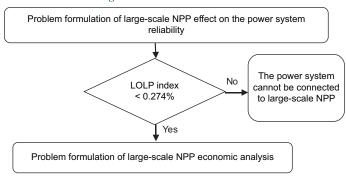
The purposes of this research are to determine the power system in Indonesia that can be connected to large-scale NPP and to determine the NPP vendor country. The research's results can be used as a stakeholder's consideration in deciding the nuclear energy policy in Indonesia. By using this research's result, the Indonesian government can choose where they will build NPP and from which country the NPP comes from.

## 2. RESEARCH METHOD

This research was conducted using a method as shown in Figure 1. This research was started with making a problem formulation of large-scale NPP effect to each Indonesia power system reliability.

The detailed problem formulation was explained in the subchapter problem formulation. From the subchapter, it was got a LOLP index when large-scale NPP connected to the power system and it can be known that the system is still reliable or not when it is connected with the NPP.

Figure 1: Research's Flowchart



Figure 2: LOLP Calculation's Flowchart



To ensure the quality of service, PT. PLN applied LOLP index <0.274% as a reliability standard (Budi et al., 2017). LOLP <0.274% means the maximum number of the system allowed to not supply is 1 day/year. Based on those values, we conclude that the power system can be connected to the NPP or not. If the NPP made the LOLP index equal to or more than 0.274%, the power system was not reliable to be connected with the NPP and the economic analysis of NPP was not done. If the LOLP index remains below 0.274%, the power system was still reliable when it is connected to the NPP, and we continued the process with its economic analysis. The detailed problem formulation of the NPP economic analysis discussed in the subchapter problem formulation.
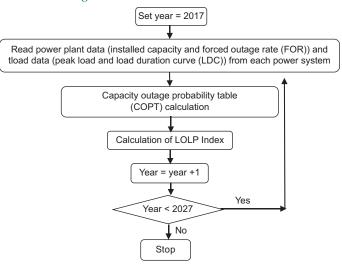
The NPP used as reference plants is 1000 MWe NPP originating from China, South Korea, and Japan. The countries are selected based on a recommendation from the International Atomic Energy Agency, i.e., a country that will build its first NPP should do an affiliation with NPP vendor countries in their regional area and they are major nuclear states (Nian, 2018). The discount rate used was 10% by considering the inflation rate in Indonesia was around 6-7% and risk margin around 3-4%.

## 2.1. Problem Formulation of Large-scale NPP Effect on the Power System Reliability

The analysis of the large-scale NPP effect on the reliability was done by replacing the biggest power plant at each power system with the NPP. The replacement was done each year starting from 2017 until 2026, so it can be known the impact of NPP on the system reliability at each power system in each year. The impact can be known from the LOLP index. LOLP is a reliability index based on the probabilistic method (Yu et al., 2019). The calculation of the LOLP index that is used to analyze the large-scale NPP effect to the power system was conducted by using the Matlab program and followed flowchart as shown in Figure 2.

Collecting the power systems data (installed capacity and FOR) and load data (peak load and LDC) was the first step of the LOLP index calculation. The installed capacity and load data were typically for each Indonesia's power system. Indonesia's power system divided into three operational areas, i.e., Sumatra, Java-Bali, and East Indonesia. Each area divided into several regions. The Sumatra area consists of only one region, i.e., Sumatra region. The Java-Bali area consists of only one region, i.e., Java-Bali region. The East Indonesia area consists of 3 regions,

i.e., Kalimantan, Sulawesi Nusa Tenggara, and Maluku Papua region (Budi et al., 2017).

### 2.1.1. Sumatra region
Sumatra region currently consists of 2 interconnection systems, 2 isolated systems that have peak loads above 50 MWe, and some isolated systems that have peak loads below 10 MWe. The two interconnection systems are Sumbagut and Sumbagselteng power systems. Both systems will be interconnected in 2022 and become the Sumatra system. The isolated systems that have peak loads above 50 MWe are Bangka and Tanjung Pinang.

In 2017, the Sumbagut system had power plant capacity 2.8 GW and peak load 2.3 GW, while the Sumbagselteng system has power plant capacity 4.1 GW and peak load 3.6 GW. In 2026, Sumatra system which is an interconnection of Sumbagut and Sumbagselteng will have power plant capacity 25.6 GW and peak load 15 GW. In addition, the LDC of the Sumatera power system is shown in Figure 3. The LDC data was obtained from PT. PLN.

### 2.1.2. Java-bali region
Java-Bali region consists of 1 interconnection power system, i.e., the Java-Bali system. In 2017, the system had a peak load of 26.6 GW and it becomes 49.9 GW in 2026. While the power plant capacity is 33.9 GW in 2017 and becomes 70.5 GW in 2026. In addition, the LDC of Java Bali is shown in Figure 4. The LDC data was obtained from PT. PLN.

### 2.1.3. Kalimantan region
Kalimantan region consists of two power systems, i.e., Kalbar system and Kalseltengtimra system. Until 2026, there has been no plan to interconnect the systems. In 2017, the Kalbar system had power plant capacity 0.64 GW and a peak load of 0.38 GW, while the Kalseltengtimra system has power plant capacity 1.71 GW and a peak load of 1.26 GW. In 2026, the Kalbar system will have power plant capacity 1.58 GW and a peak load of 1.06 GW, while the Kalseltengtimra system will have power plant capacity 5.92 GW and peak load 3.39 GW. In addition, the LDC of the

Kalimantan region is shown in Figure 5. The LDC data was obtained from PT. PLN.

### 2.1.4. Sulawesi Nusa Tenggara Region
Sulawesi Nusa Tenggara region consists of Sulbagut, Sulbagsel, Lombok, and Timor system. The systems have not yet planned to be interconnected by PT. PLN due to small peak load and archipelago area. The largest system in the region is Sulbagsel. The system will have power plant capacity 5.57 GW and a peak load of 3.94 GW in 2026.

### 2.1.5. Maluku Papua Region
Maluku Papua region consists of Ambon and Jayapura systems. Both systems are small. In 2026, power plant capacity will reach 0.25 GW in Ambon and 0.39 GW in Jayapura. The LDC of Sulawesi Nusatenggara and Maluku Papua Region is shown in Figure 6. The LDC data was got from PT. PLN.

The installed capacity and load data were typical for each Indonesia's power system. While FOR is assumed to have the same value for each plant with the same technology all over Indonesia. Table 1 shows the FOR for each power plant in Indonesia.

After getting the data, the next step was the COPT calculation. The calculation can be done by using a traditional method (Budi et al., 2015; Budi et al., 2017) or recursive method (Widiastuti
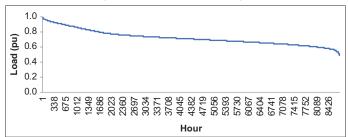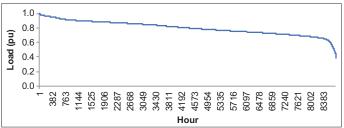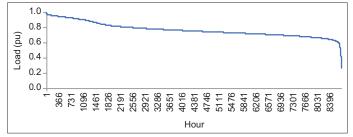
et al., 2017). By considering the effectiveness, this research used the recursive method. The calculation using the recursive method is shown in equation (1) (Widiastuti et al., 2017; Marko, 2019).

$$P(x)=(1–U) P'(x) + U P'(x–c) \qquad (1)$$

where:
x = capacity outage (MWe)
c = new capacity that has been added (MWe)
P(x) = cumulative probability when the outage is x MWe after a power plant c MWe is added
P'(x) = cumulative probability when the outage is x MWe before a power plant c MWe is added
U = forced outage rate (FOR) (%)

By using the COPT and LDC, the LOLP index can be calculated using equation (2). Equation (2) means that the LOLP index is calculated by summing the value of all possibility outage that makes the demand not being able to be supplied by the system (Sarjiya et al., 2019; Adefarati et al., 2017).

$$LOLP = \sum_{x=0}^{n} P_x t_x \qquad (2)$$

where
n = maximum number of capacity outage (MWe)
$P_x$ = cumulative probability of power plant when the outage is x MWe (%)
$t_x$ = load loss duration when the outage is x MWe (hours)

## 2.2. Problem Formulation of Large-scale NPP Economic Analysis
Large-scale NPP economic analysis was done by the following flowchart as shown in Figure 7. The economic analysis was done if the LOLP of the power system was <0.274%. If the LOLP was equal or larger than 0.274%, it could be concluded that the power system cannot be connected to the NPP.

The economic parameters used in the economic analysis were investment cost, O & M cost, fuel cost, and external cost (Samadi, 2017; Lovering et al., 2016; Qvist and Brook, 2015). The parameters were almost the same as those used in large-scale NPP, the differences lay on the structure of fuel cost and decommissioning cost. The decommissioning cost can be included in the external cost.

Contingency cost is an additional cost that must be prepared to accommodate the possibility of uncertainties and risks in the project (Ortiz et al., 2019; Traynor and Mahmoodian, 2019).

**Figure 3:** LDC of Sumatra Region



**Figure 4:** LDC of java bali region



**Figure 5:** LDC of Kalimantan region



**Table 1: FOR value of power plants in Indonesia**

| Powerplant | FOR |
| --- | --- |
| Nuclear power plant | 0.015 |
| Coal power plant | 0.05 |
| Combined cycle power plant | 0.023 |
| Gas power plant | 0.023 |
| Hydro power plant | 0.03 |
| Geothermal power plant | 0.03 |
| Diesel power plant | 0.09 |

In this research. contingency cost was not included in other costs but was separated. Contingency cost simply calculated by adding some percent of OC to the value of OC, i.e., 20% (Zhang et al., 2019). The value of contingency cost has a range between 5% and 25% of OC. This research used 20% of OC as a contingency cost.

### 2.2.1. O & M cost

O & M cost is divided into two kinds, namely variable O & M cost and fixed O & M cost (Cebulla and Jacobson, 2018). Fixed O & M cost is a routine operational cost that includes employee cost, property tax, plant insurance, and life-cycle maintenance. Life-cycle maintenance cost includes back-end cost and decommissioning cost. The decommissioning cost is treated as an O & M cost by setting aside a sum of money each year from the beginning of NPP operating until the end of NPP's lifetime. The same treatment is also done for back-end costs. Variable O & M cost is a cost that depends on the production function of the NPP includes consumables materials.

### 2.2.2. Fuel cost

Nuclear fuel cost consists of front-end cost and back-end cost (Ganda et al., 2016). Front-end cost is a cost associated with fuel processes before used in a reactor. Front-end cost consists of uranium purchase cost, conversion cost, enrichment cost, and fabrication cost. Back-end cost is a cost associated with fuel processes after used in the reactor. The back-end cost is determined by the type of fuel cycle that used, whether open cycle or closed cycle. On a closed cycle, the back-end cost includes all costs after the fuel is used in the reactor to the reprocessing cost. While on an open cycle, the back-end cost consists of all costs after the fuel is used in the reactor to the ultimate disposal (Kim et al., 2015). This research used an open cycle based on a consideration that natural uranium prices still lower than the reprocessing cost. Back-end costs in this research were interim storage cost and ultimate disposal cost.

### 2.2.3. Decommissioning cost

Decommissioning cost represents the amount of money that must be allocated yearly from the first operating year of NPP. The money is accumulated as a reserve fund for the NPP decommissioning at the end of the operation (Khattak et al., 2018; Torp and Klakegg, 2016). A study has been calculated decommissioning cost of NPP in Indonesia (PT.PLN, 2013). The calculated decommissioning cost is 0.17-0.2 cents USD/kWh. While the decommissioning cost of NPP in the USA is between 0.1 and 0.2 cents USD/kWh, while the average decommissioning cost in Europe is 0.4 cents Euro/kWh (Moore et al., 2017).

Another study showed that the decommissioning cost of NPP is varied depending on the investment cost and the vendor country (OECD, 2015). The study (PT.PLN, 2013) used ATMEA and AP1000 as a reference power plant. ATMEA manufactured by a joint venture of Mitsubishi Heavy Industry-Areva and has overnight costs between 6261 and 6396 USD/kWe. AP1000 manufactured by Westinghouse owned by Toshiba Japan and has overnight costs between 5840 and 6111 USD/kWe. While this research used reference plants from China, South Korea, and Japan that have different overnight costs. Therefore, we assumed the decommissioning cost for this research was 0.1 USD cent/kWh.

By using the economic parameters, we calculated the LUEC and IRR. The LUEC calculation was done by using Equation (3) (WNA, 2017). The data used in the LUEC calculation was shown in Table 2.

**Figure 6:** LDC of Sulawesi Nusatenggara and Maluku Papua Region



**Figure 7:** Flowchart of large-scale NPP economic analysis



$$LUEC = \frac{\sum_t \dfrac{(C_t \, x \, Cap) + ((O_t + F_t + D_t) x \, E_t)}{(1+r)^t}}{\sum_t \dfrac{E_t}{(1+r)^t}}$$

(3)

**Table 2: Main parameters used in LUEC (OECD, 2015; PT.PLN, 2013; Moore et al., 2017)**

| Parameter | NPP | | |
|---|---|---|---|
| | South Korea | Jepang | China |
| Construction (year) | 6 | 6 | 6 |
| Capacity (MWe) | 1343 | 1152 | 1080 |
| Disc. Rate | 10% | 10% | 10% |
| NPP lifetime (year) | 60 | 60 | 60 |
| Overnight cost (US$/kW) | 2021 | 3883 | 1087 |
| Fuel price (cent *US$/kWh*) | 0.467 | 0.467 | 0.467 |
| Waste management (*cent US$//kWh*) | 0.1 | 0.1 | 0.1 |
| O&M cost (*cent US$//kWh*) | 0.965 | 0.65 | 0.274 |
| Decommissioning cost (*cent US$//kWh*) | 0.1 | 0.1 | 0.1 |
| Capacity factor | 90% | 90% | 90% |
| Own use | 5% | 5% | 5% |

where:

Cap = capacity (MWe)

$C_t$ = overnight cost in year t (USD/kWe)

$O_t$ = O & M cost in year t (USD/kWh)

$F_t$ = fuel cost in year t (USD/kWh)

$D_t$ = decommissioning costs in year t (USD/kWh)

$E_t$ = electricity power generated in year t (kWh)

r = discount rate (%)

Net present value (NPV) and internal rate of return (IRR) can be known by using the LUEC and the electricity sale price. The value of NPV and IRR will indicate whether the NPP is profitable to use or not. NPV is a difference of total income to the total outcome by considering the time value of money. NPV calculation was done by using Equation 3. r is a discount rate. IRR is the rate of capital return. The function of IRR is to measure the rate of return on investment by considering the time value of money. IRR is obtained when the NPV value is equal to zero. The r-value when NPV is zero is the IRR value. Equation (4) was used to calculate NPV and equation (5) was used to calculate IRR. Revenue was obtained from electrical power that sold multiplied by electricity price. The electricity that sold is the generated electric minus own use.

$$NPV = \sum_t \left[ \frac{Revenue_t}{(1+r)^t} - \frac{Cost_t}{(1+r)^t} \right]$$

$$= \sum_t \left[ \frac{0.95 \, x \, E_t \, x \, price}{(1+r)^t} - \frac{(C_t \, x \, Cap) + ((O_t + F_t + D_t) \, x \, E_t)}{(1+r)^t} \right] \quad (4)$$

$$NPV = 0$$

$$\sum_t \left[ \frac{0.95 \, x \, E_t \, x \, price}{(1+IRR)^t} - \frac{(C_t \, x \, Cap) + ((O_t + F_t + D_t) \, x \, E_t)}{(1+IRR)^t} \right] = 0 \quad (5)$$

where:

$Revenue_t$ = revenue at year t (USD)

$Cost_t$ = Cost at year t (USD)

r = discount rate (%)

$E_t$ = electricity power generated in year t (kWh)

price = Electricity price (cent USD/kWh)

Cap = capacity (MWe)

$C_t$ = overnight cost in year t (USD/kWe)

$O_t$ = O & M cost in year t (USD/kWh)

$F_t$ = fuel cost in year t (USD/kWh)

$D_t$ = decommissioning costs in year t (USD/kWh)

NPV = Net present value (USD)

IRR = Internal rate of return (%)

This research used 2 electricity price scenarios. Scenario 1 used each regional electricity production cost as the electricity price. Scenario 2 used the PLN adjustment tariff as the electricity price. The scenarios affected the value of NPV and IRR. Table 3 shows the electricity production cost of each region and the PLN adjustment tariff.

## 3. RESULTS AND DISCUSSION

Large-scale NPP has capacity 1000 MWe. The capacity is too large for some power systems in Indonesia. In addition, NPP 1000 MWe has relatively expensive investment costs. The capacity and investment cost will affect the power system reliability and economic feasibility. This research has analyzed the effect of large-scale NPP on reliability and economic analysis. Based on the reliability analysis, it can be obtained results as shown in Table 4.

The red color in Table 4 shows that the LOLP index exceeds the standard. Large-scale NPP makes the Sumbagut and Sumbagselteng unreliable (LOLP≥0.274%). In 2022, both systems will be interconnected so the status becomes not available (NA). Sumatra system is a new system that is an interconnection between Sumbagut and Sumbagselteng systems. The Sumatra system will be formed in 2022, so the status becomes NA before 2022. Large-scale NPP can be connected to the Sumatra system without makes the LOLP index exceeding the standard because the power plant installed capacity is large.

The NPP cannot be connected to Sumbagut and Sumbagselteng because the installed capacity is not too large for NPP 1000 MWe. The installed capacity will become 7238 MWe for Sumbagut and 8256 MWe for Sumbagselteng in 2021 while the installed capacity of the Sumatra system will reach 17,807 MWe in 2022. These results are in accordance with the planning that has been done by PT.PLN. In the planning, the largest power plant added by PT.PLN is 500 MWe for the Sumbagut system and 600 MWe for the Sumbagselteng system. As for the Sumatra system, the largest capacity added is 1000 MWe.

For Sumbagut and Sumbagselteng system, there is a possibility to connect the systems with NPP that has a capacity of fewer than 600 MWe (Small-medium reactor = SMR) because of PT.PLN has been planned to add a Coal power plant 600 MWe. The PT. PLN's plan shows that a power plant with capacity 600 MWe did not make the reliability out of standard. But it needs research that calculates the impact of SMR on the reliability index of the power system to prove the possibility. Besides the reliability analysis, the implementation of SMR will change the economic feasibility because SMR relatively more expensive than large-scale NPP. Those problems are beyond this research problem.

In the Java-Bali region, large-scale NPP can be connected to the power system. This is indicated by the LOLP index. The LOLP index is still in the PLN standard. Java-Bali system is a power

**Table 3: Electricity production cost of each region and the PLN adjustment tariff based on MoEMR regulations**

| Region | Elec. prod. Cost (cent USD/kWh) | Tarif Adjust. PLN (cent USD/kWh) |
|---|---|---|
| Sumatra | 8.98 | 11.28 |
| Java-Bali | 6.52 | 11.28 |
| Kalimantan | 10.31 | 11.28 |
| Sulawesi Nusatenggara | 10.68 | 11.28 |
| Maluku Papua | 15.09 | 11.28 |

**Table 4: The effect of large-scale NPP on the LOLP index on each power**

| Year | Sumatra region | | | Java-Bali Region | Kalimantan region | | Sulawesi Nusa Tenggara region | | | | Maluku Papua region | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sumbagut | Sumbagselteng | Sumatera | Jawa-Bali | Kalbar | Kalseltengtimr'a | Sulbagut | Sulbagsel | Lombok | Timor | Ambon | Jayapura |
| 2017 | ≥0.274% | ≥0.274% | NA | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |
| 2018 | ≥0.274% | ≥0.274% | NA | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |
| 2019 | ≥0.274% | ≥0.274% | NA | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |
| 2020 | ≥0.274% | ≥0.274% | NA | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |
| 2021 | ≥0.274% | ≥0.274% | NA | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |
| 2022 | NA | NA | <0.274% | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |
| 2023 | NA | NA | <0.274% | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |
| 2024 | NA | NA | <0.274% | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |
| 2025 | NA | NA | <0.274% | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |
| 2026 | NA | NA | <0.274% | <0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% | ≥0.274% |

system that has installed capacity 33.89 GW in 2017 so the NPP does not cause the LOLP index out of the standard. This is in accordance with the PT. PLN planning has added a 1000 MWe power plant that has the same capacity as large-scale NPP into the Java-Bali system.

NPP cannot connect to the systems in other regions. The NPP will cause the LOLP index out from the standard because the capacity of the systems is not too big. This is in accordance with the planning of PT. PLN which used 450 MWe as the largest power plant to be added to the systems.
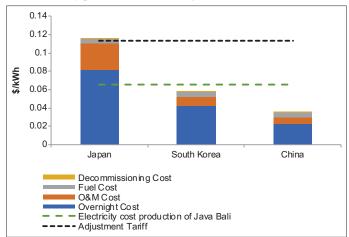
SMR that has a capacity of fewer than 450 MWe. To prove the possibility, it needs future research on reliability and economic analysis of SMR as an alternative of NPP large scale.

Based on the reliability analysis. it can be seen that only two power systems in Indonesia that can be connected to the NPP 1000 MWe. The systems are Sumatra and Java-Bali. The Sumatra system will able to be connected with the NPP starting in 2022, while for Java-Bali starting in 2017. By using the construction time 6 years, the fastest time of NPP to be operated is in 2027.

The economic analysis was performed in Sumatra and Java-Bali system. The electricity sale price used for the analysis were electricity production cost of each system and the PLN adjustment tariff. The electricity production cost in the Sumatra system is 0.0898 USD/kWh. The electricity production cost in Java-Bali is 0.0652 USD/kWh. While the PLN adjustment tariff is 0.1128 USD/kWh.

Figure 8 shows the comparison of the LUEC of NPP 1000 MWe of the three countries in Java Bali. NPP 1000 MWe from South Korea and China are economically feasible to use in the Java-Bali power system. This is indicated by the LUEC that is smaller than the electricity production cost and the adjustment tariff. NPP 1000 MWe from Japan is not economically feasible to use in the Java-Bali system because the LUEC is higher than the electricity production cost and the adjustment tariff. If the Japanese NPP will be built in Java-Bali systems, then a subsidy

**Figure 8:** Comparison of NPP's LUEC on each country to the electricity production cost and adjustment tariff in Java Bali

is needed to cover the difference between the LUEC and the electricity price.

The higher LUEC of Japanese NPP is caused by the overnight cost (OC). The OC of Japanese NPP is greater than NPP from South Korea and China. The OC of Japanese NPP is almost 2 times higher than NPP from South Korea and 3.5 times higher than NPP from China. The difference in OC is due to differences in labor wage, experience, licensing, regulation and NPP specifications of each country (Nasrullah and Sriyana, 2010). Japan which is in the ring of fire will make their NPP more resistant to an earthquake that causes the OC increases. The OC increment will have a major impact on NPP LUEC because OC has the largest portion in LUEC. OC has a 70% portion of LUEC in Japanese NPP, 72% portion of LUEC in South Korean NPP, and 64% portion of LUEC in Chinese NPP.

The South Korean and Chinese NPP is economically feasible to use in the Java-Bali system. By looking at the NPV and IRR values, it can be known the economic feasibility. Table 5 shows the value of NPV and IRR of South Korean and Chinese NPP for 2 types of the electricity sale price. South Korean and Chinese NPP provides a benefit. It can be known by looking at their LUEC and NPV. In scenario 1 (electricity production cost as electricity sale price), South Korean NPP provides only a small profit margin (IRR 11.4% and NPV 467.6 million USD). The IRR is almost closer to the discount rate. It will make the feasibility more vulnerable to the changes in economic conditions. The changing of the economic condition will affect the discount rate. If the discount rate increases, the IRR will decrease and makes the IRR lower than the discount rate. The lower IRR will make NPV becomes minus while the Chinese NPP provides IRR 19% and NPV 1,503.6 million USD. The Chinese NPP is a promising NPP to be developed in the Java-Bali system. However, it is necessary to consider again the risks of a public perception who think that Chinese technology has poor quality. The perception is building from the fact that many products from China have poor quality. The perception is also supported by many power plant accidents in Indonesia which show that many Chinese power plants in Indonesia have poor performance and poor quality (PT PJBS, 2015).

The perception can make public acceptance low and public acceptance is an important key to the NPP development in Indonesia. By using Chinese NPP, we need more effort to keep public acceptance high and to change the perception of Chinese technology.

When the adjustment tariff is used as the electricity sale price, south Korean and Chinese NPP provides higher IRR dan NPV. The IRR for South Korean NPP is 18.9% and 28.8% for Chinese NPP. In this condition, both NPP is equally profitable to be developed in the Java-Bali system. South Korean provides a lower IRR than the Chinese. but the public perception of South Korean technology is much better than Chinese technology.

Economic analysis in the Sumatra system has been done by using 2 scenarios. Figure 9 shows the comparison of the LUEC of NPP 1000 MWe of the three countries in the Sumatra system.

NPP 1000 MWe from South Korea and China are economically feasible to use in the Sumatra because the LUEC is smaller than the electricity production cost and the adjustment tariff. NPP 1000 MWe from Japan is not economically feasible to use in the Java-Bali system because the LUEC is higher than the electricity production cost and the adjustment tariff. If the Japanese NPP will be built in Java-Bali systems, then a subsidy is needed to cover the difference between the LUEC and the electricity price.

Electricity production cost in Sumatra is higher than Java-Bali because there are many oil-fueled power plants in the Sumatra system. With higher-production cost, South Korean NPP will provide a greater profit. Table 6 shows a comparison of NPV and IRR of South Korea and China NPP based on 2 scenarios in the Sumatra system. Whether using the electricity production cost or adjustment tariff, South Korean and Chinese NPP will give profit with an acceptable margin. South Korean NPP will give NPV 1999 million USD and IRR 15.6% when using electricity production cost scenarios. Chinese NPP will give NPV 2735.1 million USD
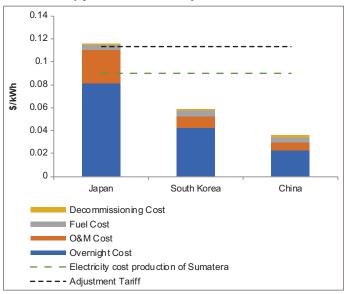
**Table 5: NPV and IRR of South Korean and Chinese NPP in Java-Bali**

| Project Feasibility Parameter | South Korea | | China | |
| --- | --- | --- | --- | --- |
| | Elect. Cost Prod. | Adjust. Tariff | Elec. Cost Prod. | Adjust. Tariff |
| NPV (10⁶ USD) | 467.6 | 3433.6 | 1503.6 | 3888.8 |
| IRR (%) | 11.4 | 18.9 | 19.0 | 28.8 |

**Table 6: NPV and IRR of South Korean and Chinese NPP in Sumatra**

| Project Feasibility Parameter | South Korea | | China | |
| --- | --- | --- | --- | --- |
| | Elec. Cost Prod. | Adjust. Tariff | Elec. Cost Prod. | Adjust. Tariff |
| NPV (10⁶ USD) | 1999.0 | 3433.6 | 2735.1 | 3888.8 |
| IRR (%) | 15.6 | 18.9 | 24.5 | 28.8 |

**Figure 9:** Comparison of NPP's LUEC on each country to the electricity production cost and adjustment tariff in Sumatra

and IRR 24.5% when using the electricity production cost scenario. When used adjustment tariff as electricity sale price, South Korean NPP will give NPV 3433.6 million USD and IRR 18.9%, while Chinese NPP gives NPV 3888.8 million USD and IRR 28.8%.

Public acceptance is an important factor in nuclear energy development in Indonesia (Wang and Kim, 2018; Sugiawan and Managi, 2019; Zhu et al., 2018; Bisconti, 2018). The acceptance has a linear correlation with the public perception of technology. So the public perception is important, especially in a sensitive matter such as nuclear energy (Yuan et al., 2017). Based on Indonesia's public acceptance, the most reason why people disagree to develop NPP is a safety factor. Report (PT. PJBS, 2015) show that Chinese power plant in Indonesia has poor quality, especially in safety factor.

By considering people's perception of Chinese technology, Indonesia's public acceptance, and historical data of Chinese power plants in Indonesia, South Korean NPP is a better choice than Chinese NPP to be developed in the Sumatra system. Although the NPV and IRR are less than Chinese, the risk of public acceptance will be smaller.

## 4. CONCLUSION AND POLICY IMPLICATIONS

Sumatra and Java-Bali systems are the power system that can be connected to large-scale NPP. Sumatra system can be connected starting in 2022 and the Java-Bali system can be connected starting in 2017. Japanese NPP is not economically feasible to be developed in Sumatra and Java-Bali systems. Chinese and South Korean NPP are economically feasible to be developed in both systems.

For the Java-Bali system, Chinese NPP is the best choice when using electricity production cost as electricity sale price because it gives an acceptable margin of profit, while South Korean NPP just gives a slight profit margin so it's more vulnerable to the economic situation. When used adjustment tariff as electricity sale price, South Korean NPP gives an acceptable profit margin and becomes the best choice. Although South Korean NPP gives less NPV and IRR, public perception is better than Chinese technology. For the Sumatra system, South Korean NPP is the best choice when using electricity production cost or adjustment tariff as the electricity sale price. Although South Korean NPP gives less NPV and IRR. the public perception of South Korean technology is better than Chinese technology.

## 5. ACKNOWLEDGMENT

## REFERENCES

Adefarati, T., Bansal, R.C., Justo, J.J. (2017), Reliability and economic evaluation of a microgrid power system. Energy Procedia, 142, 43-48.

Aritonang, S., Parlina, N., Kuntjoro, Y.D. (2018), Government strategy to improve public acceptance toward nuclear power plant. Jurnal Pertahanan, 4(1), 61-75.

Bakirtas, T., Akpolat, A.G. (2018), The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries. Energy, 147, 110-121.

BATAN. (2017), Survei Jajak Pendapat Iptek Nuklir Tahun 2016.

Bisconti, A.S. (2018), Changing public attitudes toward nuclear energy. Progress in Nuclear Energy, 102, 103-113.

Budi, R.F.S., Birmano, M.D., Bastori, I. (2017), Pemodelan perhitungan indeks lost of load probability untuk N unit pembangkit pada sistem kelistrikan opsi nuklir. Jurnal Pengembangan Energi Nuklir, 19(2), 61-68.

Budi, R.F.S., Sarjiya, S., Hadi, S.P. (2017), A review of potential method for optimization of power plant expansion planning in Jawa-Madura-Bali electricity system. Communications in Science and Technology, 2(1), 29-36.

Budi, R.F.S., Suparman, Amitayani, E.S. (2015), Peran PLTN dalam meningkatkan indeks keandalan lost of load probability (LOLP) sistem kelistrikan bangka. In: Seminar Nasional XI SDM Teknologi Nuklir. p169-179.

Budi, R.F.S., Suparman, Salimy, D.H. (2011), The analysis of $CO_2$ emission at the study of electricity generation development planning with nuclear option for Bangka Belitung region. Jurnal Pengembangan Energi Nuklir, 13(1), 44-55.

Cebulla, F., Jacobson, M.Z. (2018), Carbon emissions and costs associated with subsidizing New York nuclear instead of replacing it with renewables. Journal of Cleaner Production, 205, 884-894.

Dutu, R. (2016), Challenges and policies in Indonesia's energy sector. Energy Policy, 98, 513-519.

Erahman, Q.F., Purwanto, W.W., Sudibandriyo, M., Hidayatno, A. (2016), An assessment of Indonesia's energy security index and comparison with seventy countries. Energy, 111, 364-376.

Ganda, F., Dixon, B., Hoffman, E., Kim, T.K., Taiwo, T., Wigeland, R. (2016), Economic analysis of complex nuclear fuel cycles with NE-COST. Nuclear Technology, 193(2), 219-233.

Handayani, K., Krozer, Y., Filatova, T. (2017), Trade-offs between electrification and climate change mitigation: An analysis of the Java-Bali power system in Indonesia. Applied Energy, 208, 1020-1037.

Hejazi, R. (2017), Nuclear energy: Sense or nonsense for environmental challenges. International Journal of Sustainable Built Environment, 6(2), 693-700.

Jaelani, A., Firdaus, S., Jumena, J. (2017), Renewable energy policy in Indonesia: The Qur'anic scientific signals in Islamic economics perspective. International Journal of Energy Economics and Policy, 7(4), 193-204.

Khairunnisa, N.F., Hasanuddin, U., Maskun, M., Hasanuddin, U. (2017), Indonesian implementation of nuclear energy for sustainable development. Journal of Law, Policy and Globalization, 67. 102-109.

Khattak, M.A., Omran, A.A.B., Khan, M.S., Ali, H.M., Nawaz, S., Khan, Z. (2018), Cost evaluation of proposed decommissioning plan of CANDU reactor. Journal of Engineering Science and Technology, 13(10), 3173-3189.

Kim, S.K., Ko, W.I., Youn, S.R., Gao, R.X. (2015), Nuclear fuel cycle cost estimation and sensitivity analysis of unit costs on the basis of an equilibrium model. Nuclear Engineering and Technology, 47, 306-314.

Kumar, S. (2016), Assessment of renewables for energy security and carbon mitigation in Southeast Asia: The case of Indonesia and Thailand. Applied Energy, 163, 63-70.

Lovering, J.R., Yip, A., Nordhaus, T. (2016), Historical construction costs of global nuclear power reactors. Energy Policy, 91, 371-382.

Marko, Č. (2019), Evaluation of the power system reliability if a

nuclear power plant is replaced with wind power plants. Reliability Engineering and System Safety, 185, 455-464.

Moore, M., Korinny, A., Shropshire, D., Sadhankar, R. (2017), Benchmarking of nuclear economics tools. Annals of Nuclear Energy, 103, 122-129.

Nasrullah, M. (2014), Perhitungan ekonomi dan pendanaan PLTN SMR 100 MWe. In: Seminar Nasional Teknologi Energi Nuklir. p107-116.

Nasrullah, M., Sriyana, S. (2010), Harga dan tarif listrik PLTN di dunia. Jurnal Pengembangan Energi Nuklir, 12(1), 20-30.

Nian, V. (2018), Technology perspectives from 1950 to 2100 and policy implications for the global nuclear power industry. Progress in Nuclear Energy, 105, 83-98.

Nuryanti, N., Hidayanto, A., Suparman, S., Muslim, E., Moeis, A.O. (2012), Analisis probabilistik pada perhitungan biaya pembangkitan listrik teraras PLTN. Jurnal Pengembangan Energi Nuklir, 14(1), 23-33.

Nuryanti, N., Nasrullah, M., Suparman, S. (2014), Studi komparasi model perhitungan biaya pembangkitan listrik teraras PLTN. Jurnal Pengembangan Energi Nuklir, 16(2), 95-105.

OECD. (2015), Projected Costs of Generating Electricity. Paris, France: OECD.

Ortiz, J.I., Pellicer, E., Molenaar, K.R. (2019), Determining contingencies in the management of construction projects. Project Management Journal, 50(2), 226-242.

Pioro, I., Duffey, R. (2015), Nuclear power as a basis for future electricity generation. Journal of Nuclear Engineering and Radiation Science, 1(1), 1-19.

Prăvălie, R., Bandoc, G. (2018), Nuclear energy: Between global electricity demand, worldwide decarbonisation imperativeness, and planetary environmental implications. Journal of Environmental Management, 209, 81-92.

PT Pembangkitan Jawa Bali Services. (2015), PT Pembangkitan Jawa Bali Services Annual Report 2014.

PT.PLN, JAPC, LAPI-ITB. (2013), Feasibility Study for Bangka Nuclear Power Plant Project-Non Site Aspect.

Putra, N.A. (2017), The dynamics of nuclear energy among ASEAN member states. Energy Procedia, 143, 585-590.

Qvist, S.A., Brook, B.W. (2015), Potential for worldwide displacement of fossil-fuel electricity by nuclear energy in three decades based on extrapolation of regional deployment data. PLoS One, 10(5), 1-10.

Samadi, S. (2017), The social costs of electricity generation-categorising different types of costs and evaluating their respective relevance. Energies, 10(356), 1-37.

Sarjiya, Budi, R.F.S., Hadi, S.P. (2019), Game theory for multi-objective and multi-period framework generation expansion planning in deregulated markets. Energy, 174, 323-330.

Silberglitt, R., Kimmel, S. (2015), Energy scenarios for Southeast Asia. Technological Forecasting and Social Change, 101, 251-262.

Sugiawan, Y., Managi, S. (2019), Public acceptance of nuclear power plants in Indonesia: Portraying the role of a multilevel governance system. Energy Strategy Reviews, 26, 100427.

Torp, O., Klakegg, O. (2016), Challenges in cost estimation under uncertainty-a case study of the decommissioning of barsebäck nuclear power plant. Administrative Sciences, 6(4), 14.

Traynor, B.A., Mahmoodian, M. (2019), Time and cost contingency management using Monte Carlo simulation. Australian Journal of Civil Engineering, 17(1), 11-18.

Wang, J., Kim, S. (2018), Comparative analysis of public attitudes toward nuclear power energy across 27 European countries by applying the multilevel model. Sustainability, 10(5), 1-21.

Widiastuti, A.N., Sarjiya, S., Pinanditho, K.A., Prastyo, E.T. (2017), Evaluasi keandalan perencanaan pembangkit Wilayah Jawa-Bali dengan mempertimbangkan ketidakpastian peramalan beban. Jurnal Nasional Teknik Elektro dan Teknologi Informasi, 6(2), 230-234.

World Nuclear Association. (2017), Nuclear Power Economics-Nuclear Energy Costs. Available from: http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx. [Last accessed on 2017 Oct 12].

Yu, H.H., Chang, K.H., Hsu, H.W., Cuckler, R. (2019), A monte carlo simulation-based decision support system for reliability analysis of Taiwan's power system: Framework and empirical study. Energy, 178, 252-262.

Yuan, X., Zuo, J., Ma, R., Wang, Y. (2017), How would social acceptance affect nuclear power development? A study from China. Journal of Cleaner Production, 163, 179-186.

Zhang, D., Liu, G., Chen, C., Zhang, Y., Hao, Y., Casazza, M. (2019), Medium-to-long-term coupled strategies for energy efficiency and greenhouse gas emissions reduction in Beijing (China), Energy Policy, 127, 350-360.

Zhu, W., Lu, S., Huang, Z., Zeng, J., Wei, J. (2018), Study on public acceptance of nuclear power plants: Evidence from China. Human and Ecological Risk Assessment, 1(1), 1-17.