Nuclear energy contribution potential to secure electricity demand with low carbon emission and low risk of power plant in Indonesia

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Abstract. The Government of Indonesia has shifted the paradigm to envisage energy as capital to develop the country. By far, the electricity produced from the power plant, which reaches 283.8 TWh in 2018, mostly originated from coal-fired power plants (56.4%). The remains produced by gas power plant (20.2%), diesel (6.3%), and renewable energy (17.1%). In National Energy General Plan, it stated that the new and renewable energy should be utilized at least 23% by 2025 and 31% by 2050. The NRE potential which Indonesia has is around 431,745 MW. However, the installed capacity was only around 6,830 MW. Despite the large NRE potential, only a small portion of the capacity which already utilized for electricity production. In the 2014 National Energy Policy (KEN), the government-mandated five policy points regarding priority directions for national energy development, including nuclear as a last resort. Nuclear is one of the environmentally friendly energy sources and has considerable power potential, which can contribute 25% of total energy supply based on capacity factor and based load power plant approaches and synergy with other new and renewable energy resources for about 70% contribution from the total electricity supply. Nuclear energy has several features compared to other energy sources, including a cleaner and safer life cycle, high density energy as well as low cost for generating levelized cost and external cost. It is recommended that Indonesia consider nuclear energy as a potential new energy source to accelerate the country's development.

1. Introduction
The Government of Indonesia shifted the paradigm related to energy in which the energy considered as foreign exchange reserves in the past. Currently, the Government of Indonesia is considering energy as the capital to develop the country. The shifted paradigm reflected in the Presidential Decree of the Republic of Indonesia No. 22 of 2017 on the National Energy General Plan and Government Regulation No. 74 of 2014 on the National Energy Policy which derived from Law No. 3 of 2007 on Energy [1]. According to the new paradigm, the energy no longer considered as the source of foreign exchange, however it envisaged as the fundamental strength in many fields of domestic economy activities, which in turn could enhance the country's revenues. Therefore, national energy resource management towards sustainable development becomes an essential task for Indonesia to deal with.
Nowadays, the fulfilment of Indonesia’s energy demand is still dominated by the non-renewable energy source, which originated from fossil energy. In terms of electricity generation, the data record shows that among the 64.5 GW installed capacity of electric power plant (as of 2018), most of them fuelled by fossil energy. Coal contributes to the highest energy mix of around 50%, followed by gas (29%), diesel (7%), and renewable energy (14%). By far, the electricity produced from the power plant, which reaches 283.8 TWh in 2018, mostly originated from coal-fired power plants (56.4%). The remains produced by gas power plant (20.2%), diesel (6.3%), and renewable energy (17.1%) [2].

The data record implies the relative high dependency on fossil energy. Further, the utilization of fossil energy will remain the first option to fulfil the national energy demand in the future. In RUEN, it stated that the new and renewable energy should be utilized at least 23% by 2025 and 31% by 2050. Further, the utilization of crude oil should be reduced to at most 25% by 2025 and 29% by 2050. The utilization of natural gas shall be optimized to at least 22% by 2025 and 24% by 2050. Coal will be the significant national energy source in the future if the shortage of energy supply occurs [1]. On the other hand, as one of the countries that signed the Paris Agreement and one of 164 countries who ratified it, Indonesia commits to reduce the greenhouse gas effect in which required the consistent development of environmentally friendly energy sources.

One of the potential and prospective new energy sources in Indonesia is nuclear energy. However, nuclear energy is not prioritized in the development of energy sources, especially for future electricity generation. The nuclear power plant considered as one of the clean, safe, and long life energy sources. The developed countries, including the United States, Japan, and France, have been utilizing nuclear energy sources for an extended period as the primary power plant in their country. Indonesia, as a country with a large area, a large population, and increasing economic activity, need to consider nuclear as one of the energy sources that will support and accelerate the national development in the future with its role as an environmentally friendly energy source.

2. New and renewable energy potential in Indonesia

The new and renewable energy (NRE) is an alternative to the energy source which commonly used to fulfill the energy demand. Indonesia has various new and renewable energy potential, i.e., hydropower, geothermal, solar, ocean energy, wind, micro-hydro, and biomass/waste. The NRE potential, which Indonesia has, is around 431,745 MW, however, the installed capacity was around 6,830 MW [3]. Figure 1 shows that the NRE potential in Indonesia is quite immense. For more details, the data shown in Figure 2 illustrates that hydropower has potential of 75,091 MW, geothermal 17,546 MW, bioenergy 32,654 MW, solar power 207,898 MW, wind 60,647 MW, and ocean energy 17,988 MW [3].

![Figure 1 Distribution of NRE potential in each province in Indonesia [3]](image)
Figure 2 NRE potential in Indonesia based on the type of energy sources [3]

Despite the considerable NRE potential, only a small portion of the capacity which already utilized for electricity production. In a press release, the General Director of Electricity of the Ministry of Energy and Mineral Resources (ESDM) on 7 February 2020 said that the capacity of the power plant in Indonesia is increasing by almost 15 GW from 54.7 GW to 69.9 GW in the last five years. Of these, 10.3 GW came from renewable energy sources or around 14.8%. Coal-fired power plants still plays a dominant role with an installed capacity of 34.7 GW or 49.9%, followed by gas-fired power plants of 19.9 GW or around 28.6%, and diesel power plants of 4.6 GW or about 6.7% [4].

Meanwhile, the Geothermal Director of the Directorate General of New and Renewable Energy, Ministry of Energy and Mineral Resources, stated that the installed capacity of renewable energy power plants up to the first semester of 2020 is around 10.4 GW. The main realization is driven by 6.07 GW hydroelectric power plants and 2.13 GW geothermal power plant [5]. Further, the General Regional Energy Plan (RUED) prepared by 34 provincial governments indicates that the total installed capacity of renewable energy in 2025 will reach 48 GW. The majority of existing and planned renewable energy power plants rely on hydro or geothermal power. Likewise, among the 29 GW plans for addition in the RUPTL, 50% and 26% of them will be hydroelectric power plants and geothermal power plants, respectively. On the other hand, the plan to build a Solar Power Plant (PLTS) is only 7%, even though the potential is nearly 50% of the potential for renewable energy in Indonesia. In RUED, the PLTS development plan has a larger proportion, i.e., 16%. Solar energy has a potential of more than 200 GW with the efficiency of currently available photovoltaic technologies. However, the use of solar energy in electricity generation is still less than 100 MW. The potential for solar power spread throughout Indonesia, with the most tremendous potential in West Kalimantan (20 GW), South Sumatra (17 GW), and East Kalimantan (13 GW) [3].

3. Nuclear energy resources and the potential in Indonesia

In the 2014 National Energy Policy, the government-mandated five policy points regarding priority directions for national energy development, including nuclear as a last resort. Nuclear is one of the energy sources that are environmentally friendly and has considerable power potential. Nuclear and hydropower have become the backbone of low-carbon energy sources, replenishing globally around three low-carbon energy sources in the world. Specifically, nuclear energy in 2018 has contributed around 10% of the electricity supply worldwide. Besides, according to data as of May 2019, there are around 452 nuclear power plants worldwide, with a combined range of up to 400 GW. In general, apart from being an environmentally friendly energy source, energy also has a significant economic impact because nuclear-based power plants have a longer service life. Hence, they are cheaper to maintain so that they are financially more competitive than other energy sources [6].
Indonesia, as a country with a lot of mineral resources, has nuclear resources, i.e., the potential for uranium and thorium. Thorium, for example, as an element that compounded with rare earth metals, is found in the mineral monazite. Monazite has fairly high thorium content and emits the radioactive α rays. Meanwhile, thorium emits low levels of radiation. Other minerals that contain thorium are xenotime and zircon. The third mineral that contains rare earth metals discovered in the Bangka-Belitung Islands and Riau Islands. Apart from thorium, the nuclear material discovered in Indonesia is uranium. Besides being discovered in the Bangka-Belitung Islands, uranium and thorium are also found in Bengkayang Regency, West Kalimantan, in Seruyan and Lamandau areas, Central Kalimantan, and Mamuju Regency, West Sulawesi [7].

Nuclear energy derived from the fission of uranium and plutonium (transmuted from U-238) can replace most, if not all, of the stationary tasks now performed by the combustion of fossil fuels (thorium might also have a future application). It generates power through fission, which is the process of splitting uranium atoms to produce energy. The heat released by fission utilized to create steam that spins a turbine to generate electricity without the harmful by-products emitted by fossil fuels. According to the Nuclear Energy Institute (NEI), the United States avoided more than 476 million metric tons of carbon dioxide emissions in 2019. That amount is equivalent to removing 100 million cars from the road and more than all other clean energy sources combined. It also keeps the air clean by removing thousands of tons of harmful air pollutants each year that contribute to acid rain, smog, lung cancer, and cardiovascular disease.

4. Comparative features of nuclear energy and other energy resources
Nuclear energy has several features compared to other energy sources. First, nuclear energy is relatively more environmentally friendly since nuclear fuel does not release greenhouse gases (GHG). It releases the GHG only during the mining and processing of nuclear fuel. However, the amount of GHG emissions, such as CO₂, is relatively small compared to other fuel types, i.e., oil, gas, or coal.

![Figure 3](image_url) Life cycle inventory results of the production of 1 kWh of electricity for important air pollutants contributing to particulate matter (PM) exposure, the leading cause of health impact from air pollution.

Figure 3 depicts the comparison of life cycle inventory results of the production of 1 kWh of electricity for essential air pollutants contributing to particulate matter (PM) exposure, the leading
cause of health impact from air pollution. The emissions of gas pollutants and particulate matters coming from the life cycle of the pressurized water reactor (PWR) are much smaller than those from other energy source. The coal-fired power plant released the highest amount of ammonia, nitrogen dioxides, and PM2.5 in their life cycle.

Figure 3 was adapted from [9]. Some abbreviations: PC = pulverized coal, PV = photovoltaic, CSP = concentrating solar power, Poly-Si = polycrystalline silicon, CIGS = copper indium gallium selenide thin film, CdTe = cadmium telluride thin-film, IGCC = integrated gasification combined cycle, CCS = CO₂ capture and storage, SCPC = supercritical pulverized coal, NGCC = natural gas combined cycle, PWR = pressurized water reactor.

Table 1 also shows the comparison of CO₂ emission released from the life cycle of power plants with various generation methods. CO₂ emissions of nuclear power plants are among the lowest of any electricity generation method and, on a life cycle basis, are comparable to wind, hydropower, and biomass. Life cycle emissions of coal generation are 30 times greater than nuclear [8].

![Figure 4](image)

**Figure 4** Schematic illustration focused on the energy density comparison between nuclear fuel and other kinds of fuel.

From the safety viewpoint, the nuclear power plant has the highest standard of safety on their operation. Anil Markandya and Paul Wilkinson analyzed and compared the death rates from the primary energy sources. The study considered deaths from accidents, such as the Chernobyl nuclear disaster, occupational accidents in mining or power plant operations, and premature deaths from air pollution.
pollution [11]. As shown in Figure 5, the death rate from energy production per terawatt-hours from brown coal and coal is much larger than nuclear. Nuclear energy is by far the safest energy source in this comparison. It results in more than 442 times fewer deaths than the ‘dirtiest’ forms of coal; 330 times fewer than coal; 250 times less than oil; and 38 times fewer than gas.

As shown in Figure 6 and 7, nuclear energy shows its competitive cost to other energy resources for power generating levelized cost and for external costs projections. It shows nuclear energy requires low cost for generating levelized cost as total cost which shows less than 50 USD/MWh for capital interest 10% and it becomes less the cost for lower capital interest. Similar to generating levelized cost, for external cost, nuclear energy show the cost is low and it competitive with hydroelectric, solar PV dan wind.

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Figure 7. External costs (€/MWh) of current and more advanced electricity systems associated with emissions from the operation of the power plant and the rest of the fuel-supply chain (EU, 2005). ‘Rest’ is the external cost related to the fuel cycle (1 € = 1.3 US$ approximately). [13]

5. Nuclear energy potential for electricity supply based on capacity factor
Various energy resources have been used for electricity power generation which has their own characteristics, such as capacity factor and baseload of electricity. Baseload electricity of power plants, as well as medium and peak load approaches, are one of the electricity capacity supplies based on their capability to produce electricity from power plant operation and its stability of supply over time. The baseload approach for electricity supply, in general, can be categorized based on a high capacity factors such as coal power plant, nuclear power plant, geothermal plant, and hydropower, as shown in Table 2. The others power plants can be categorized as medium and peak load electricity.

Table 2 Various Electric Power Plant Based on Capacity Factor and Baseload Approach

| Electric Power Plant       | Capacity Factor [%] | Loss 10% | Hour-Year | Baseload [%] | Percentage Contribution [%] |
|----------------------------|---------------------|----------|-----------|--------------|-----------------------------|
| Coal Power Plant           | 0.63                | 0.9      | 8760      | 0.7          | 18                          |
| Petroleum Plant            | 0.13                | 0.9      | 8760      | 0.7          | 4                           |
| LNG Plant                  | 0.42                | 0.9      | 8760      | 0.3          | 5                           |
| Nuclear Power Plant        | 0.9                 | 0.9      | 8760      | 0.7          | 25                          |
| Biomass Plant              | 0.55                | 0.9      | 8760      | 0.3          | 7                           |
| Geothermal Plant           | 0.66                | 0.9      | 8760      | 0.3          | 8                           |
| Waste Power Plant          | 0.7                 | 0.9      | 8760      | 0.3          | 8                           |
| Wind Power Plant           | 0.35                | 0.9      | 8760      | 0.3          | 4                           |
| Hydro Power Plant          | 0.44                | 0.9      | 8760      | 0.7          | 12                          |
| Solar Power Plant          | 0.25                | 0.9      | 8760      | 0.3          | 3                           |
| Micro-Hydro Power Plant    | 0.44                | 0.9      | 8760      | 0.3          | 5                           |
Figure 8 Estimation level for contribution of various electric power plant based on capacity factor and baseload approach

Capacity Factor and Baseload approaches can be utilized to estimate the contribution level for various energy resources, as shown in Table 2 and Figure 6. These estimation values can be obtained by normalized electricity potential production, which is corresponding to capacity factor and categorization of based load factor. Normalized energy factor was used based on the same power capacity of energy to a level of 1000 MW and by conversion value process from power capacity to electricity production based on their energy properties of capacity factor, baseload assumption energy classification, as well as loss of transmission and distribution. Each electricity production from all energy resources tabulated as total electricity supply, and the total value of electricity production will be used as a normalized value to be used to obtain the contribution level of each energy resources in percentage. The coal power plant, nuclear power plants, hydropower, and geothermal are categorized as baseload electric can supply more than 60%, and others can contribute to medium load and peak load electricity. Nuclear can contribute 25% of the total energy supply and followed by coal and hydropower power plants for 18% and 12% contribution, respectively. When classified as fossils fuel resources contributions, based on this approach, it will contribute to a less than 30% of total electricity supply and the contribution of new and renewable energy (NRE) as defined in Indonesia point of view, those NRE contributions will be more than 70%.

Figure 9 Power plant capacity [MW] and its electric production [GWh]
The correlation power plant capacity with electric production is obtained based on a 63% capacity factor and 10% loss for a year of electric production as shown in Figure 7. The figure shows an estimation level for power plant capacity and its potential electric supply can be obtained. For instance, 10,000 MW of power capacity will produce about 50 TWh and when it requires power capacity 60,000 MW will produce about 280 TWh. This estimated data can be utilized to predict when for the future electricity need. To obtain a total electricity production, various energy resources will contribute as energy mix approach as shown in Figure 8. These various contributions of electricity production are based on some contribution level as mentioned in Figure 6. It is shown that nuclear power plant contributes the highest energy level in comparing to other resources and it will consistently increase with increasing energy demand when the level of contribution is kept in a constant value to total electricity supply, and, in this case nuclear contributes to a 25% of total electricity supply. Moreover, when the energy resources classified as NRE, the contribution will be more than 70% of the total electricity supply and fossil fuel will be less than 30%. In case of baseload energy supply categorization of mix energy from coal, nuclear, hydro, and geothermal energy resources, it will contribute to more than 60% of electricity supply, and part of this baseload supply contribution in term of NRE contribution will be at around 45% of total electricity supply.

Power Plant Contribution to Total Electric Production [GWh]

Figure 10 Various power plant contribution to total electric production as a function of power capacity power plant [GWh]

6. Conclusions
Some potential resources of new and renewable energy (NRE) including nuclear energy has been shown to be utilized for Indonesian energy mix. To ensure the potential of those energy resources It is necessary to carry out detailed geological mapping and detailed geophysical surveys in areas that have the potential of energy, including for nuclear energy such as thorium and uranium nuclear materials to obtain accurate information about the potential of these two materials and a more measured volume calculation can be carried out. As mandated in the 2014 National Energy Policy (KEN), regarding the priority directions for national energy development, it is suggested for Indonesia to consider the use of nuclear energy and mastering the technology of nuclear power plants to accelerate the achievement of the NRE energy mix by 2050.
As an alternative energy supply, nuclear has some advantages including low carbon emission, high density energy production, safer in term of very low level of the death rate from energy production per terawatt-hours as well as it shows a quite low energy cost for generating levelized cost and external cost. By adopting the capacity factor of the power plant and based load power plant approaches, new and renewable energy (NRE) can contribute to more than 45% of total electricity supply as based load electricity contributor, including 25% of the nuclear contributor as one of the NRE contributor.

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