

# Nuclear Power Plant Development in Java-Madura-Bali Area: The Indonesian Long-term Electricity Planning Perspective

Yusak Tanoto<sup>1</sup>, Muhammad Ery Wijaya<sup>2</sup>

<sup>#</sup>Electrical Engineering Department, Petra Christian University  
Siwalankerto 121-131, P Building 3<sup>rd</sup> Floor, Surabaya 60236, Indonesia

<sup>1</sup>tanyusak@petra.ac.id

<sup>\*</sup>Graduate School of Energy Science, Kyoto University  
Engineering Building No.2, Yoshida-Honmachi, Sakyo-Ku, Kyoto 606-8501, Japan

<sup>2</sup>m.wijaya@at2.ecs.kyoto-u.ac.jp

**Abstract**-This paper studies the nuclear power plant development in Java-Madura-Bali area in the Indonesian Long-term electricity planning perspective. Indonesian electricity demand has continuously risen year by year particularly in the Java-Madura-Bali area, or often known as “JaMaLi” area. Holding the largest share for economic activities in the country, it is served by the largest electricity grid in Indonesia called the JaMaLi interconnection system. It is found that the electricity demand in JaMaLi area will increase to 308 TWh in 2025, of which the demand will be dominated by the household sector with 131 TWh or 42% of total electricity consumption. To meet this future demand, a total of 66 GW of installed power plant capacity have to be developed, being fuelled by various energy resources available in Indonesia, excluding nuclear. This paper explores the possibility of long-term electricity expansion planning in the JaMaLi area by including nuclear power plant in order to meet the future demand and environmental protection concern as well as to increase the supply security up to 2027. During the study period, the potential of energy resources available for JaMaLi area along with two electricity supply scenarios based on nuclear and non-nuclear sources are assessed. At the end of the projection, the nuclear power plants may contribute to the reducing of the fossil power plants requirement such as coal and natural gas by 2 GW and 1.9 GW respectively. Meanwhile, the total emission reduction achieved by nuclear scenario is estimated 16.8 million tons of CO<sub>2</sub> equivalent.

**Keywords**-Electricity Planning; Emission Mitigation; Energy Policy; Energy Security; Nuclear Energy

## I. INTRODUCTION

Indonesia power sector is currently under the slow moving to an unbundling system since the Law No. 30/2009 governing national electricity has been issued. According to the law, the regional government enterprise as well as Non-Government Organization will be eligible into services. In addition, the electricity tariff will be decided differently throughout regions. This situation may lead to a partly power deregulation with the generation sector is wider opened. However, PT. Perusahaan Listrik Negara or PLN, which is a state-owned electricity enterprise, will still play significant roles in provisioning electricity services as the company still holds the dominant share in power generation as well as controls exclusively the distribution and end-user electricity sales. In 2009, PLN national electricity production achieved 156,797 GWh or 4.93% increase from year 2008 which reached 149,437 GWh [1]. Meanwhile, the JaMaLi areas consumed almost 78% of the total national electricity sales. In 2007, total installed capacity in JaMaLi was 22,906 MW, about 70% to the total national. In

2009, it provided the net peak load of 17,211 MW which has resulted in a load factor of 77.7%. In addition, the JaMaLi electrification ratio was 69.8% [3]. This paper explores the possibilities of long-term electricity expansion planning in JaMaLi area by including nuclear power plant in order to meet the future demand and environmental protection concern as well as to increase the supply security up to 2027. This paper is organized as follows: energy resources in JaMaLi area along with nuclear energy development and post Fukushima incident response is discussed in the following section, followed by research methodology. Result and discussion are presented subsequently followed by conclusion.



Fig. 1 The map of JaMaLi area consists of Java, Madura, and Bali Island

## II. ENERGY RESOURCES AND NUCLEAR DEVELOPMENT

### A. Energy Resources

Indonesia is blessed with abundant energy resources that can be utilized to support economic development of the country. As per 1 January 2010, the coal reserves, of which dominated by low-rank coal was 21,131 million tons [2]. However, none of this reserve is located in JaMaLi. In the oil sector, East Java Province, which is a province located in JaMaLi area, has the sixth largest volume of oil reserve in Indonesia among a total of 4.30 billion barrel national proven reserve and 3.70 billion barrel potential reserve. Meanwhile, Indonesian geothermal potential and reserves as per February 2009 was 13,440 MW and 14,730 MW, respectively, which were almost 40% of world potential. Note that potential resources is comprised of speculative and hypothesis resources, meanwhile reserves consists of probable, possible, and proven reserves. Despite the huge potential, the total system installed

capacity in early 2009 was only 1,189 MW or 2.24% of the total national installed capacity. JaMaLi region takes the second national largest reserve with 4,076 MW potential resources and 6,191 MW reserves. In the gas sector, JaMaLi has only few reserves, accounting only 10.10 TSCF, or less than 10% of total national gas reserves. Hydropower, which is the only renewable based generation technology implemented in the JaMaLi area, contributed to around 2,500 MW or 11.3%, despite the significant potential. The map of JaMaLi area is shown in Fig.1.

### B. Nuclear Energy Development in JaMaLi

Nuclear technology is currently under development since its first introduction in 1954, followed with establishment of National Nuclear Agency in 1964. Increasing mastery of nuclear technology continued with the construction of the first atomic reactor, TRIGA Mark II reactor in Bandung, with 250 kW power. Several other research reactors are then constructed a 100 kW reactor in Yogyakarta and The Siwabessy reactor with 30 MW power output in Serpong. In 1975, the commission for nuclear power plant preparation and development was established. The commission suggested that a nuclear power plant need to be built in the Muria Peninsula, Central Java. Along with nuclear development efforts, Indonesia has also started to develop nuclear technology for education in more than 30 years ago. ICRP, in cooperation with the Gadjah Mada University Nuclear Engineering Department established in 1977. In addition to the UGM, some universities also has conducted research and education in the field of nuclear technology, including in Bandung Institute of Technology and in University of Indonesia, even the ICRP itself has established the High School of Nuclear Technology in Yogyakarta. Initiated more than 30 years ago, there is no exact signal when the first nuclear power plant will be built in Indonesia.

### C. Post Fukushima Incident Response to Nuclear Plant

Indonesia's nuclear-reactor plans may have been thinkable before Fukushima. In an after Fukushima world, it is that earthquake-prone nations should be aggressively pursuing non-nuclear options to fuel growth. Fear of nuclear crisis events in Japan has promoted the strengthening rejection on nuclear power plant development in Indonesia. Various organizations opposed to the construction of nuclear power plants take advantage of this momentum by becoming more active in campaigning for the movement rejects nuclear power plant, while the pro with the construction of nuclear power plants are also becoming increasingly overwhelmed to answer all questions about the security guarantees if the nuclear power plant built in Indonesia, given the character of Indonesian territory is similar to Japan, which has high intensity earthquakes.

## III. RESEARCH METHODOLOGY

### A. Energy Modelling

The Long-range Energy Alternatives Planning (LEAP) model used in this study is a scenario-based energy-environment modeling tool which was developed by the Stockholm Environment Institute. The main concept of LEAP is the end-use driven scenario based analysis. Its scenarios are based on comprehensive accounting of how energy is consumed, converted, and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology and so on. The

LEAP model contains the technology and environmental database (TED) that is used to estimate the environmental emissions of energy utilization. Unlike macroeconomic models, LEAP does not attempt to estimate the impact of energy policies on employment or Gross Domestic Product (GDP), although such models can be run in conjunction with LEAP. Similarly, LEAP does not automatically generate optimum or market-equilibrium scenarios, although it can be used to identify least-cost scenarios. Important advantages of LEAP are its flexibility and ease-of-use, which allows decision makers to move rapidly from policy ideas to policy analysis without having to resort to more complex models [5].

### B. Final Energy Demand Analysis

The LEAP energy demand analysis is calculated as the product of the total activity level and energy intensity at each technology branch. Energy demand is calculated for the current accounts year and for each future year in each scenario, as given by:

$$D_{b,s,t} = TA_{b,s,t} EI_{b,s,t} \quad (1)$$

Where  $D$  is energy demand,  $TA$  is total activity,  $EI$  is energy intensity,  $b$  is the branch,  $s$  is scenario and  $t$  is year (ranging from the base year to the end year). Energy intensity is the annual average final energy consumption ( $EC$ ) per unit activity, or in other words:

$$EI = \frac{EC}{\text{activity level}} \quad (2)$$

The total activity level for a technology is the product of the activity levels in all branches from the technology branch back up to the original demand branch.

$$TA_{b,s,t} = A_{b',s,t} A_{b'',s,t} A_{b''',s,t} \dots \quad (3)$$

Where  $A_b$  is the activity level in a particular branch  $b$ ,  $b'$  is the parent of branch  $b$ ,  $b''$  is the grandparent, etc.

### C. Electricity Transformation

The planning reserve margin is used by LEAP to decide automatically when to add additional endogenous capacity. LEAP will add sufficient additional capacity to maintain the planning reserve margin at or above the value that has been set. Planning reserve margin is defined as follows:

$$PRM = \frac{100 (MC - PL)}{PL} \quad (4)$$

Where  $PRM$  is the planning reserve margin (%),  $MC$  is the module capacity in MW and  $PL$  is the peak load in MW. Module capacity for all processes in the module is defined as:

$$MC = \text{Sum}(\text{Capacity} \cdot \text{Capacity value}) \quad (5)$$

Exogenous capacity values are used to reflect existing capacity as well as planned/committed capacity additions and retirements, while endogenous capacity values are those which are internally calculated by LEAP in order to maintain a minimum planning reserve margin. Endogenous capacity additions occur in addition to the exogenous level of capacity specified on the exogenous capacity. Peak system power requirements on the module are calculated as a function of the total energy requirements and the system load factor.

$$PR = \frac{ER}{LF \cdot 8,760} \quad (6)$$

Where  $PR$  is peak requirement in MW,  $ER$  is energy requirement in MWh, and  $LF$  is the load factor. The reserve margin before the addition of endogenously calculated additions is calculated as follows:

$$RM_{BA} = \left[ \frac{CA_{BA} - PR}{PR} \right] \quad (7)$$

Where  $RM_{BA}$  is the reserve margin before additions and  $CA_{BA}$  is capacity before additions. The amount of endogenous capacity additions required ( $EC_{AR}$ ) is calculated as follows:

$$EC_{AR} = (PRM - RM_{BA}) \cdot PR \quad (8)$$

#### D. Emission from Electricity Production

The LEAP uses the most up-to-date global warming potential (GWP) factors recommended by the IPCC (Intergovernmental Panel on Climate Change). The emission is calculated as:

$$Emissions_{t,y,p} = EC_{t,y} \cdot EF_{t,y,p} \quad (9)$$

Where  $EF$  is the emission factor,  $t$  is type of technology (fuel),  $y$  is year, and  $p$  is pollutant. The LEAP contains data on the GWPs for carbon dioxide, methane, nitrous oxide and the most common non-energy sector gases with high GWPs (SF<sub>6</sub>, CFCs, HCFCs and HFCs).

#### E. Modelling Assumption

In demand assumption, JaMaLi's electricity sales in 2007 according to data from Ministry of Energy and Mineral Resources (MEMR) are used in the analysis [6]. The sectoral demand were 34 TWh for residential sector, 41 TWh for industrial sector, 15 TWh for commercial sector and 5 TWh for public sector. The annual electricity demand growth is expected to increase as much as 12.6%, 3.4% 11.4%, and 11.4% for residential, industrial, commercial and public sectors, respectively, from 2008 to 2027. In the same period, the economic development is projected to be about 6.1% per year. Meanwhile, the population growth is assumed to be 1% per year and the electrification ratio is expected to be 100% by 2020. Meanwhile, the supply assumption considers several aspects in order to meet vast electricity demand as the power generation is planned by following the demand requirement. The planning reserve margin to secure the electricity supply must be meeting 30% by 2027. The transmission and distribution losses in 2007 is 13.6%, this will be reduced to be 12% by 2027. The dispatch of power plant in the JaMaLi system is ordered as follows; coal-steam, geothermal and combined cycle power plants in the base load; hydropower and gas turbine power plants in the middle load; and diesel-engine power plants in the peak load. Moreover, the efficiencies of power plant are 80% for hydropower and geothermal, 22% for gas turbine, 35% for combined cycle, 37% for diesel engine, and 32% for coal steam.

### IV. RESULT AND DISCUSSION

#### A. Government Plan

Slowly but surely, the domination of the industrial sector from the base year will be overtaken by the residential sector in 2010 and thereafter, looking from the demand projection side.

Fig. 2 presents the electricity demand projection in JaMaLi system from 2008 to 2027. In 2008, the industrial sector consumed 42 TWh, and it will consume about 79.4 TWh in the end of projection period. On the other hand, the residential sector only consumed 38 TWh in 2008 but later, the consumption increases significantly to be 362 TWh in the end of planning horizon.

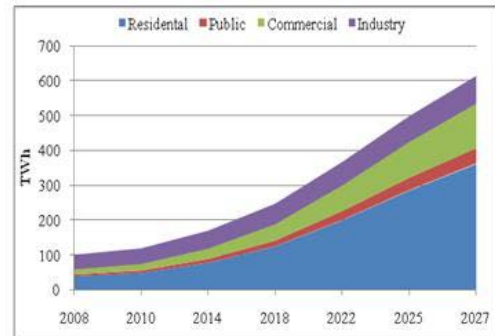


Fig. 2 Electricity demand projection in JaMaLi system from 2008-2027

Electricity demand growth of the industrial sector is projected being constant in the near future in the JaMaLi area; it is due to the decentralization policy in Indonesia, including in the economic development. In the years to come, the economic development shall be encouraged more intensively for the area outside JaMaLi region. It means that the economic growth will not only be focused in JaMaLi, but also spread out to the whole country. The change of the demand dominator in the future is a good opportunity to put concern in applying energy conservation in the residential sector. Meanwhile, the rapid development of domestic market has been boosted electricity energy demand in the industrial sector. However, due to structural change effect in the economy, which is expected to reduce fossil fuel dependency, the electricity energy demand in the commercial sector is projected to overrun the demand in the industrial sector starting in 2018. In consequence of the increasing of electricity demand in the future, the power generation capacity in the JaMaLi system must also be increased.

In supply projection, nuclear is not considered in the projection, as it is the case for the government's plan. Due to the rapid increasing of electricity demand, the urgent action is needed to build several new power plants; otherwise, imbalance of demand-supply in electricity sector will disrupt the economic development. In the base year, 2008, the electricity supply is dominated by coal and gas, which are 43% and 42% respectively. The coal is then increasing sharply year after year. Moreover, the power sector energy mix will be much focusing on how to reduce the country's oil dependency due its decreasing in domestic reserve and high crude oil price in the global market.

In Fig. 3, coal dominating the electricity supply by 52% of installed capacity in 2027, or about 69 GW. Gas becomes second largest electricity supplier, in the end of period, it contributes to 43% of expected capacity or accounted as 57 GW. Meanwhile, installed capacity of hydropower in the JaMaLi system is already constant, since the government policy to stop the new development of hydropower due to the environmental concern. The only renewable energy considered by government to enter into system is geothermal. As government intents, geothermal capacity in 2027 is increasing to be 4.3 GW from 1 GW in 2008. By considering several

factors such as the efficiency of power plants, losses during the transmission, and also the reserved margin, the required capacity to fulfil future demand is 133 GW in 2027.

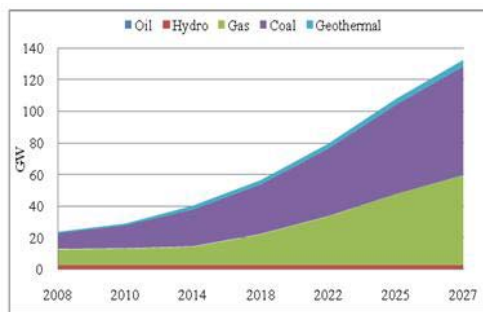


Fig. 3 Projection of electricity supply in JaMaLi system from 2008-2027

### B. Future Story of Nuclear Contribution in Indonesia

By looking back to the JaMaLi's origin energy resources, it is clear that JaMaLi could not rely on their own potential. Lack of its local energy potential, the JaMaLi should depend on "energy import" from the other Islands such as Sumatra and Kalimantan, which are rich with coal, natural gas and oil. However, the transportation of such energy resources from those Islands is the main obstacle; it requires high capital cost for piping transmission and also high risk of sea transport. In order to increase energy security and reducing supply uncertainty, the decision makers need to reconsider the nuclear power plant development in the JaMaLi system. Fig. 4 shows penetration of nuclear power plants in the JaMaLi system up to 2027, according to LEAP.

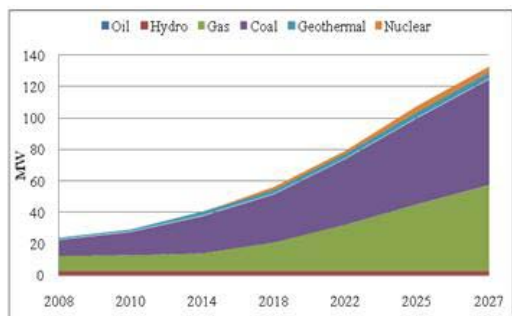


Fig. 4 Penetration of nuclear power plants in JaMaLi system

In this scenario, the development of nuclear power plant is back to the National Energy Management Blueprint 2005-2025 [7], which was mentioned that first electricity from nuclear power plant had been expected to be produced in 2006. The second nuclear power plant would follow in 2017. This is the first phase of nuclear power plant development. The second phase will have a third nuclear power plant contributing to the JaMaLi system by 2023 followed by a fourth in 2024, with an additional capacity of 1,000 MW for each year. Figure 3 presents the projection of the JaMaLi electricity supply system by considering nuclear power plants. In the end of projection, nuclear power plants contribute about 3% of total installed capacity. Compared to the government plan, considering nuclear power plants will reduce the fossil power plants such as coal and natural gas by 2 GW and 1.9 GW respectively.

### C. Environmental Issue

As the increasing of people's awareness to the global environment to reduce global warming effects, emissions from power plants become a critical issue in current society. The

scientific researchers have shown the evidence result that nuclear power plant does not release emissions to atmosphere during electricity production; CO<sub>2</sub> is the main contributor of greenhouses gas, which causes global warming. The comparison of emission between government plan and nuclear scenario is presented in Fig. 4.

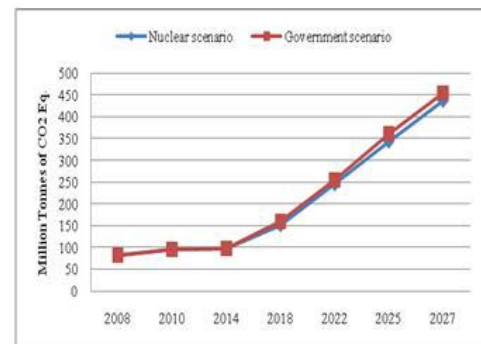


Fig. 5 Comparison of emission between government plan and nuclear scenario

If we compare the emissions from government plan and nuclear scenario as seen in Fig. 5, the emissions from nuclear scenario starts to be reduced from the year 2016, when electricity from nuclear power plant is produced for the first time. The emission reduction will remain continuous until 2027 due to increasing installed capacity from nuclear power, the total reduction by nuclear scenario is 16.8 million tons of CO<sub>2</sub> equivalents.

### V. CONCLUSION

Indonesian economy growth showed encouraging results in this decade after the monetary crisis that hit Asia in 1997. Amid the rising demand for electricity and economic growth as well as concern for the environment, the government must soon decide what form of the energy mix will be used in the future. With good planning and appropriate energy, then the fears of future energy crisis will be avoided along with the positive contribution shown in environmental preservation concern. Considering current power generation technology with its safety issue, nuclear power plants are able to produce large and reliable electricity with high efficiency, fuel efficiency, and environmentally friendly emissions. The assessment reveals that the nuclear power plant is likely to have a good prospect to secure Indonesian electricity supply in a sustainable way.

### REFERENCES

- [1] CS PT. PLN (Persero), PLN Annual Report 2009, Jakarta: Corporate Secretary PT. Perusahaan Listrik Negara, 2010.
- [2] CEMRDI, Handbook of Energy Economic Statistic of Indonesia 2010, Jakarta: Center for Energy and Mineral Resources Data Information, 2010.
- [3] (2011) Energy Efficiency Indonesia Website. [Online]. Available: <http://www.energyefficiencyindonesia.info/energy-conservation-and-efficie/energy-efficiency-in-indonesia/vision-2525>.
- [4] M. E. Wijaya and B. Limmeechokchai, "Supply Security Improvement of Long Term Electricity Expansion Planning of Java-Madura-Bali System in Indonesia," *Thammasat International Journal of Science and Technology*, Vol. 14(4), Oct-Nov. 2009.
- [5] SEI, Long-range Energy Alternative Planning System, User Guide, Boston: Stockholm Environment Institute, 2006.
- [6] MEMRRI, National Electricity Master Plan 2008-2027, Jakarta: Ministry of Energy and Mineral Resources of Republic Indonesia, 2008.
- [7] MEMRRI, National Energy Management Blueprint 2005 – 2025, Jakarta: Ministry of Energy and Mineral Resources, 2005.