Conceptual Design Of A Floating Nuclear Power Plant In Eastern Indonesia: Feasibility And Economic Implications

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Abstract

Indonesia is a vast archipelagic country with thousands of islands stretching from west to east; however, the distribution and accessibility of electricity supply remain uneven across regions. This challenge necessitates reliable, sustainable, and affordable energy solutions, particularly in the eastern part of the country. To address the energy crisis and climate change mitigation, the Floating Nuclear Power Plant (FNPP) has emerged as a potential alternative due to its ability to generate large-scale electricity with low emissions, more efficient construction compared to land-based plants, and accessible cooling processes. This study evaluates the feasibility of implementing the FNPP design in the waters surrounding Halmahera Island, North Maluku Province. In addition to technical feasibility, the study also highlights economic implications, where the proposed 300 MW capacity not only has the potential to reduce energy disparities but also to provide affordable electricity (SDGs 7), support sustainable infrastructure development (SDGs 9), and promote the blue economy through enhanced access to electricity, strengthened fisheries, port activities, and the maritime industry. Accordingly, the conceptual design of the FNPP is expected to serve as a strategic solution to improve national energy security while supporting Indonesia's sustainable development agenda. Furthermore, this design recommendation is anticipated to serve as a strategic reference to reduce energy disparities in remote areas, strengthen national energy resilience, and contribute to the global development agenda.

Keywords: Eastern Indonesia, Energy Feasibility, Floating Nuclear Power Plant, Sustainable Development Goals, Economic Implications, Energy Security

INTRODUCTION

As the world's largest archipelagic country, with more than 17,000 islands, Indonesia faces a serious challenge in achieving equitable access to electricity, particularly in its eastern region. Limited infrastructure and vast geographical distances leave electricity supply in several areas unstable and frequently in deficit. This situation not only affects the socioeconomic activities of local communities but also hinders efforts to accelerate development in the 3T regions (frontier, outermost, and underdeveloped areas). With population growth and rising energy demand, the need for reliable, sustainable, and environmentally friendly energy sources is becoming increasingly urgent. In this context, the Floating Nuclear Power Plant (FNPP) based on Small Modular Reactor (SMR) technology has emerged as a promising option. The technology is designed with mobility, modularity, and a high level of safety in mind, and it has relatively low carbon emissions. These advantages make the FNPP suitable for meeting baseload energy demand in remote island regions, including North Maluku. The deployment of FNPPs is also consistent with national policy directions on energy diversification and reduced dependence on fossil fuels. This study focuses on the waters of Central Halmahera, specifically off Dote Village, whose characteristics are favorable for FNPP implementation. The assessment evaluates the technical and economic feasibility of the FNPP, covering the conceptual design, an analysis of electricity demand, and a financial feasibility evaluation using Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and Levelized Cost of Energy (LCOE). In addition, the study highlights the strategic solutions required for the FNPP to be socially and economically accepted in island regions. Through this approach, the study is expected to contribute to the understanding of the prospects of floating nuclear energy as an alternative for sustainable energy supply in eastern Indonesia

METHODOLOGY

This study employs a quantitative approach based on engineering economic analysis to assess the financial feasibility of a Floating Nuclear Power Plant (FNPP) project in North Maluku. The evaluation uses four main parameters: Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and Levelized Cost

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of Energy (LCOE).

Net Present Value (NPV)

NPV is used to calculate the difference between the present value of cash inflows and cash outflows over the project life at a given discount rate. Mathematically, NPV is expressed as:

$$NPV = \sum_{t=0}^{n} CF_t \tag{1}$$

A project is considered feasible if NPV > 0.

Internal Rate of Return (IRR)

IRR is the discount rate at which the NPV equals zero. In other words, IRR represents the internal rate of return earned from an investment. The IRR equation is written as:

$$IRR = \sum_{t=1}^{n} \frac{CF_t}{(1+k)^1} - Io \tag{2}$$

A project is considered feasible if IRR > MARR (Minimum Attractive Rate of Return), as determined by the investor or financing institution.

Payback Period (PBP)

PBP is used to determine the time required for the cumulative net cash inflow to equal the initial investment. The formula is:

$$= \frac{Payback\ Period}{\frac{initial\ investment}{net\ annual\ cash\ flow}} \times 1\ year \tag{3}$$

The shorter the PBP relative to the project life, the more feasible the project is.

Levelized Cost of Energy (LCOE)

LCOE is used to calculate the average cost of electricity production over the technical life of the power plant. This parameter accounts for all investment, operation, and maintenance costs, divided by the total electrical energy generated:

$$LCOE = \frac{\sum_{t=0}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}} \tag{4}$$

Alternatively, it can be simplified as:.

$$LCOE = \frac{Total\ Annualized\ Cost}{Annual\ Energy\ Production} \tag{5}$$

In addition to economic aspects, this study considers technical design factors, particularly the mooring system, which strongly influences the stability of the FNPP at sea. A 3×3 mooring system is designed to counteract excessive motion caused by extreme waves, while also accounting for the soft soil conditions in the waters off Dote Village and the FNPP site depth of approximately 150 m. The mooring line specifications are given in Table

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Table 1. Mooring Line Specifications

Length (m)	420
Mass/Unit Length (Kg/m)	370
Equivalent CSA (m^2)	0.09
Stiffness, EA (kN)	800,000
Maximum Tension (kN)	11,981
Added Mass Coefficient	1
Transverse Drag Coefficient	2.4
Equivalent Diameter (m)	0.13
Longitudinal Drag Coefficient	1.15

RESULTS AND DISCUSSION

FNPP Design

The development of the Floating Nuclear Power Plant (FNPP) in Indonesia is driven by growing energy demand, particularly in the eastern region, where electricity infrastructure remains limited. As an archipelagic country with more than 17,000 islands, Indonesia's main challenge is distributing energy equitably to remote areas that conventional power grids cannot easily reach. The FNPP therefore emerges as a strategic solution, offering high mobility, efficient installation, and a large, dependable power capacity to support the electrification of the 3T regions (frontier, outermost, and underdeveloped areas).

In terms of resource availability, Indonesia holds substantial domestic nuclear fuel reserves, estimated at approximately 90 thousand tonnes of uranium and 140 thousand tonnes of thorium. This potential strengthens the case for implementing FNPPs in the eastern region, as it can support national energy self-sufficiency without complete dependence on fuel imports. In addition, policy support from the Ministry of Energy and Mineral Resources (ESDM) and stringent oversight by the Nuclear Energy Regulatory Agency (BAPETEN) ensure that every stage of FNPP design and operation complies with nuclear safety, security, and safeguards standards in line with international regulations.

The FNPP design in this study adopts the ThorCon Small Modular Reactor (SMR) technology, which is based on a Molten Salt Reactor (MSR) fission design. This technology was selected because it offers several advantages over conventional nuclear power plants, including low-pressure operation, passive cooling systems, and the ability to minimize the risk of radiation leakage. With a thermal capacity of 557 MWt that can generate up to 250 MWe of electricity, the design not only meets local energy needs but is also capable of producing surplus power to support regional economic growth.

The FNPP structure is designed as a cylinder with a diameter of 45 m, a total height of 73 m, and a draft of 48.5 m. These dimensions were chosen to maintain hydrostatic stability and structural strength under extreme wave loads with a 100-year return period (Hs of 1.16 m and Tp of 7.16 s). The design also incorporates a minimum freeboard of 15 m to prevent seawater from overtopping the platform in severe weather.

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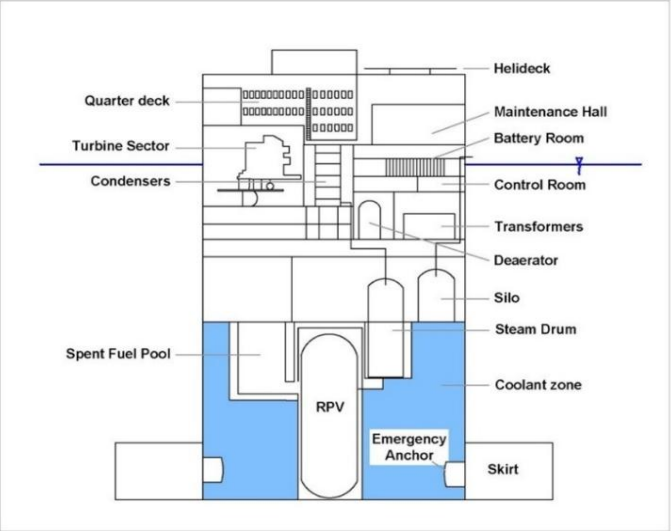


Figure 1. Side view of the Floating Nuclear Power Plant (FNPP) design Implications of alternative unit scales

Figure 1 shows the main arrangement of components in the FNPP. Inside the cylindrical structure are the reactor pressure vessel (RPV), which serves as the center of the fission process, together with a steam drum that generates steam, a turbine section, and a condenser that returns the steam to cooling water. The structure also houses a control room as the operational control center, a transformer for energy distribution, and a new-fuel storage facility and a spent fuel pool for the temporary storage of spent fuel.

The component layout is designed with ease of maintenance access, system safety, and load distribution in mind, so that each unit can operate optimally. The upper part of the structure is equipped with a helideck, which facilitates logistics mobilization and emergency response by air. The relatively large diameter of the cylinder also provides sufficient space for air circulation and equipment placement, resulting in a configuration that is compact yet safe for long-term operation

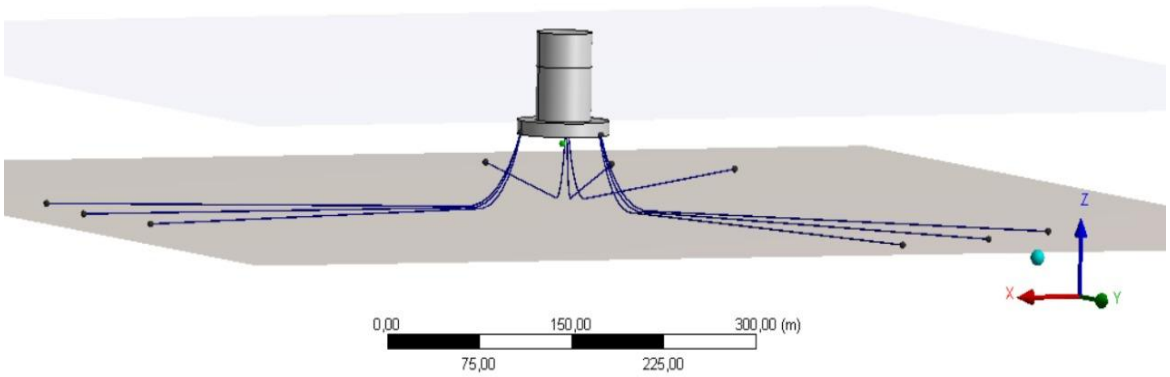


Figure 2. Structural design and mooring lines of the FNPP

A spread mooring system with nine radially arranged mooring lines is designed to counteract excessive motion caused by extreme waves, while accounting for the soft soil conditions in the waters off Dote Village and the FNPP site depth of approximately 150 m.

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Electricity Demand in North Maluku Province

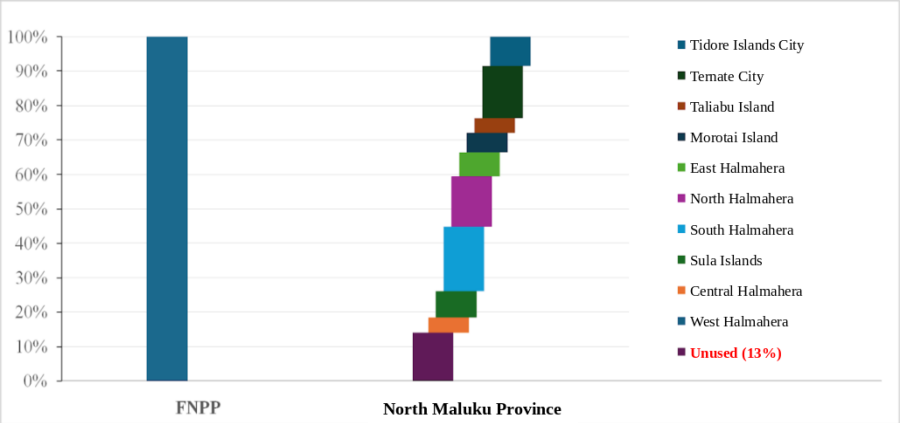


Figure 3. Distribution of FNPP power output relative to electricity demand by regency/city in North Maluku Province

The electricity demand in North Maluku appears much smaller than the power capacity that the FNPP can supply. The plant generates an energy supply that exceeds the province's total electricity consumption, so the share of demand in each regency appears relatively small when plotted. This indicates that the FNPP is not only sufficient to guarantee electricity availability but also provides a significant power reserve.

Examined in more detail, the areas with the highest electricity consumption are Ternate City, North Halmahera, and South Halmahera, whereas areas such as Taliabu Island, East Halmahera, and Tidore Islands City account for lower shares. Notably, approximately 13% of the capacity remains unused. The portion marked in red in the chart represents excess power that can be used to stimulate the growth of new economic sectors. The FNPP's energy surplus essentially has two important implications. First, the availability of reserve power would improve the reliability of the electricity system, minimizing the risk of outages. Second, the unused capacity creates room for the development of energy-based industries, such as mineral processing, large-scale fisheries, and maritime activities.

FNPP Feasibility Analysis

The economic feasibility assessment of the Floating Nuclear Power Plant (FNPP) project was conducted using several standard evaluation parameters in engineering economic analysis, namely Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and Levelized Cost of Energy (LCOE). These parameters were selected because together they describe profitability, the speed of capital recovery, and the overall cost efficiency of energy production.

Table 2. Economic feasibility study of the FNPP

Criterion	Feasibility Condition	Result			Status
NPV	NPV > 0	$4,719,259,670	>	0	Feasible
IRR	IRR > MARR	6%	<	8.28%	Not feasible
Payback Period	PBP < Project Operational Life	14.2 years	<	80 years	Feasible

The economic feasibility analysis yields a Net Present Value (NPV) of $4,719,259,670, indicating that the project is financially feasible. However, the Internal Rate of Return (IRR) of 6% is below the Minimum Acceptable Rate of Return (MARR) of 8.28%, indicating a challenge in terms of investment return. The Payback Period (PBP) of 14.2 years is shorter than the project's operational life of 80 years, as shown in Table 2.

Net Present Value (NPV)

The calculation yields an NPV of $4,719,259,670. Under the evaluation criterion, a project is considered feasible if NPV > 0, meaning that the present value of all cash inflows over the project life exceeds the present value of the cash outflows. The FNPP is therefore deemed financially feasible based on the NPV indicator.

This sizeable positive value also indicates that the project can generate net revenue after all investment,

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operating, and maintenance costs are accounted for. In practical terms, the result shows that the FNPP can not only recover its entire capital expenditure but also create economic value added during its operating life:

Internal Rate of Return (IRR)

The IRR calculation yields a value of 6%, while the Minimum Acceptable Rate of Return (MARR) is set at 8.28%. Because IRR < MARR, the project does not meet the feasibility criterion under the IRR indicator.

This implies that the FNPP's rate of return on investment is below the profit standard generally expected by investors. Under these conditions, strictly speaking, the FNPP would struggle to attract purely commercial investment without additional incentives. However, in the evaluation of mutually exclusive projects, NPV is often regarded as a more reliable indicator than IRR when the IRR is not close to the MARR, because NPV focuses on maximizing net wealth, whereas IRR reflects only a relative rate of return. With a large positive NPV, the FNPP project can still be classified as feasible, since total revenue over the project life is sufficient to cover the investment cost and provide added value even though the rate of return is below the MARR:

Payback Period (PBP)

The analysis shows that the payback period of the FNPP is 14.2 years, which is considerably shorter than the project's operational life of 80 years. Based on the PBP criterion, the project is therefore feasible, since the invested capital can be recovered well before the end of its operational life.

This relatively short payback period indicates that, after year 15, all revenue from electricity sales can be regarded as net profit. Given the long project life, the FNPP can generate positive cash flows for more than six decades after capital recovery, which strengthens the project's long-term financial prospect

LCOE (Levelized Cost of Energy) Analysis

The calculation shows that the FNPP's electricity production cost is approximately Rp 1,877/kWh. This is relatively high compared with fossil-based and large-scale renewable power plants in Indonesia, and it could therefore become a barrier if applied directly as a retail electricity tariff. To address this challenge and ensure public acceptance, comprehensive solutions are needed, such as highly stable electricity service, inclusive monthly tariff packages (electricity, maintenance, and warranty), fixed subscription systems, or cooperation with the North Maluku Provincial Government on tariff subsidies. In the evaluation of mutually exclusive projects, NPV is often considered a more reliable criterion than IRR when the IRR is not close to the MARR, because NPV focuses on wealth maximization.

CONCLUSION

The Floating Nuclear Power Plant (FNPP) design for the waters of Halmahera, North Maluku, is considered feasible as an energy supply option for eastern Indonesia. The 300 MW electricity capacity not only meets the province's demand but also yields an energy surplus that can be used to develop regional economic sectors. A positive NPV of USD 4.7 billion and a Payback Period of 14.2 years demonstrate the project's feasibility. Although the IRR of 6% is below the MARR of 8.28%, NPV is considered more representative for long-term infrastructure projects. The electricity tariff of Rp 1,877/kWh remains relatively high and therefore requires policy support, such as subsidies or special tariff schemes, to keep it affordable. Overall, the FNPP has the potential to be a strategic solution for reducing energy inequality, strengthening national energy security, and supporting the achievement of SDGs 7 and 9.

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