

Conceptual Pre-Feasibility Study of a 250 MWe Floating Nuclear Power Plant in North Maluku: Electrical System Integration, Site Safety, and Economic Analysis

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Abstract

Electricity supply disparities in archipelagic systems create demand for low-emission baseload generation, yet plant capacity must be compatible with grid size, site safety, and financing conditions. This study develops a conceptual pre-feasibility assessment of a 250 MWe floating nuclear power plant (FNPP) for North Maluku by integrating energy-demand screening, floating-structure design basis, nuclear-maritime siting requirements, stationkeeping, and engineering-economic analysis. At a 90% capacity factor, annual generation is estimated at 1,971 GWh, compared with approximately 1,356.62 GWh of electricity distributed in North Maluku. The proposed unit would therefore produce 45.3% more annual energy than current distribution and its rated output would exceed the system's average load, making interconnection, firm industrial off-take, reserve provision, or a smaller modular unit essential. An illustrative economic screening based on USD 7,000/kW CAPEX, a 60-year operating life, five-year construction, an 8.28% discount rate, a 90% capacity factor, and a tariff of IDR 1,877/kWh yields an NPV of USD 48.6 million, an IRR of 8.52%, a 14-year payback period from project start, and an LCOE of approximately IDR 1,831/kWh. The project is only marginally viable and remains highly sensitive to capital cost, tariff, capacity factor, and financing rate. The Halmahera offshore area cannot be declared suitable based only on water depth and available space; seismic, volcanic, tsunami, metocean, geotechnical, radiological dispersion, navigation, physical security, and emergency preparedness assessments are required. FNPP may be retained as a long-term option, but an investment decision requires grid-compatible unit sizing, staged site investigation, integrated nuclear-maritime safety design, and a bankable off-take model.

Keywords: economic analysis, floating nuclear power plant, North Maluku, site safety, small modular reactor.

INTRODUCTION

Indonesia faces different electricity supply challenges in its large interconnected systems and in its relatively small island systems. North Maluku consists of islands with dispersed load centers, a growing mineral-processing industry, ports, fisheries, and settlements that are not always close to generation sources. Regional statistics indicate that electricity service coverage has expanded, yet strengthening reliability and capacity remains relevant to regional economic development [1]. At the provincial level, distributed electricity reached approximately 1,356.62 GWh in the latest data published by Statistics Indonesia (BPS) [2]. This annual figure must be interpreted together with the daily load profile, peak demand, operating reserves, and network constraints, because annual energy does not directly reflect the system's ability to accommodate a single large generating unit.

National electricity policy has begun to position nuclear energy as one of the low-carbon supply options over a long-term planning horizon [3]. The development of small modular reactors (SMRs) and the floating nuclear power plant (FNPP) concept broadens the possibilities for siting power plants in coastal or archipelagic regions. FNPPs offer centralized shipyard fabrication, reduced civil works at the site, access to seawater as a heat sink, and the possibility of relocating the unit at the end of its operating life. However, these advantages come with more complex regulatory interfaces, as nuclear safety must be integrated with maritime safety, physical protection, safeguards, emergency preparedness and response, legal liability, and the management of fuel and waste [4].

IAEA publications show that SMR designs are evolving across a range of technologies, including light-water reactors, high-temperature gas-cooled reactors, fast reactors, and molten-salt reactors, at differing levels of maturity [5]. Therefore, the label SMR or FNPP does not automatically guarantee commercial readiness. A feasibility study must determine the reactor type, unit capacity, grid requirements, supply chain, fuel strategy, owner-operator organization, and licensing pathway. Recent IAEA guidance also emphasizes that a nuclear power plant feasibility study must integrate the electrical system, site, technology, economics, financing, human resources, national participation, and safety, rather than merely comparing the cost of electricity [6].

The initial manuscript proposed a floating unit in the waters around Halmahera and presented NPV, IRR, payback period, and LCOE indicators. However, two issues need to be corrected. First, the capacity is stated as



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300 MW in some sections and 250 MWe in others. Second, a positive NPV at a discount rate of 8.28% is reported alongside an IRR of 6%; for a conventional cash flow pattern, this combination is inconsistent, since an IRR lower than the discount rate should yield a negative NPV. The nuclear economics literature emphasizes that NPV, IRR, and LCOE are comparable only when they use the same cash flow basis, monetary value, construction time, and discount rate [7], [8].

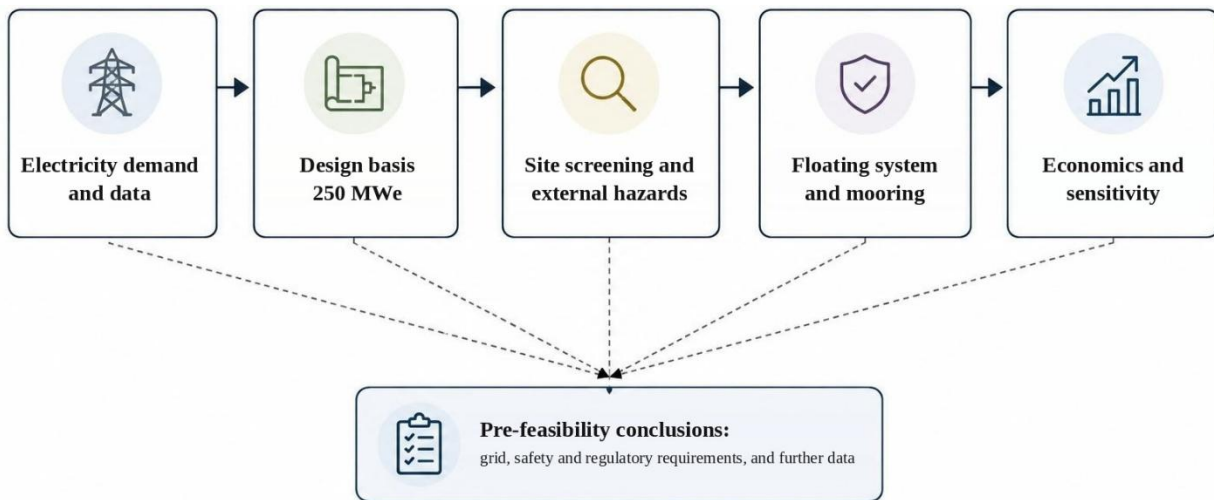


Figure 1. Integrated framework of the FNPP pre-feasibility study

Based on these issues, this study reconstructs the assessment as a conceptual pre-feasibility study. Its objectives are: (1) to examine the suitability of a 250 MWe capacity relative to the scale of the North Maluku electricity system; (2) to formulate a preliminary design basis for the floating structure and its mooring; (3) to identify site safety and regulatory requirements; (4) to develop a consistent and transparent economic model; and (5) to evaluate the sensitivity of the results to key assumptions. The term “pre-feasibility” is used to make clear that the results cannot be regarded as site approval, safety design approval, or an investment decision.

Figure 1. Integrated framework of the FNPP pre-feasibility study.

THEORETICAL BACKGROUND AND ASSESSMENT FRAMEWORK

FNPP Characteristics and Capacity Selection

An FNPP is a nuclear power installation placed on a floating structure, generally a barge, a ship-shaped hull, or a purpose-built platform, moored in sheltered waters or offshore. This concept differs from a nuclear-powered ship because its primary purpose is to supply electricity or heat to a land-based grid, while mobility is typically limited to transport from the shipyard to the operating site. The IAEA identifies potential benefits in serial fabrication, reduced on-site work, siting flexibility, and access to centralized decommissioning, but it also highlights issues of cross-jurisdictional licensing, security, safeguards, liability, and the interface between nuclear regulators and maritime authorities [4].

Unit capacity selection must begin with the capability of the electrical system. The IAEA states that a generating unit that is large relative to the minimum load can create frequency and voltage risks when it trips. A feasibility study needs to demonstrate how the system replaces the loss of a unit, including reserves, interconnection, controlled load shedding, and transmission reinforcement [6]. Accordingly, a 250 MWe unit cannot be justified merely because its energy output covers annual demand. The unit's output must be compared with peak load, minimum load, the capacity of the largest operating generator, spinning reserve, and grid stability.

The offshore floating nuclear plant concept developed in the academic literature shows that marine platforms can exploit passive cooling and move part of the hazard farther from populated areas, but such designs still require analyses of hydrodynamics, ship collision, internal flooding, loss of heat sink, and the integrity of the power cable to shore [17]. This conceptual study uses 250 MWe as a basis for comparison because that figure is consistent with the power configuration described in the initial manuscript, not as a final capacity recommendation for North Maluku.



Nuclear–Maritime Site Safety

Nuclear site safety is determined by the ability of the site and the design to withstand natural and human-induced hazards. IAEA SSR-1 requires the evaluation of seismic, geotechnical, meteorological, hydrological, flooding, tsunami, and volcanic hazards, human-induced external events, population distribution, and the feasibility of implementing emergency plans [9]. Site survey and selection proceed in stages, from regional survey and screening, through comparison, to detailed characterization [10]. For the Halmahera region, the evaluation of earthquakes and potential ground deformation must follow a seismic hazard methodology that considers seismic sources, uncertainties, and design ground motion [11]. Meteorological and hydrological hazards include extreme winds, waves, currents, tides, storm surge, rainfall, seawater temperature, and sea-level change [12].

Indonesia already has a licensing pathway for nuclear installations through Government Regulation No. 2 of 2014, which covers site, construction, commissioning, operation, and decommissioning licenses [13]. The evaluation of sites with respect to the dispersion of radioactive substances in air and water is further regulated by BAPETEN Regulation No. 4 of 2019 [14]. In 2026, BAPETEN also discussed amendments to the site safety regulations to make them more adaptive to SMRs and installations in the marine environment, including requirements for subsea surveys and for geotechnical, meteorological, hydrological, and dispersion aspects [15]. The fact that the site evaluation program documents and site evaluation management system of an FNPP proponent were once assessed as not yet meeting requirements shows that the licensing process cannot be replaced by a conceptual study [16].

From the maritime side, the Code of Safety for Nuclear Merchant Ships provides principles on ship design, reactor safety, radiation protection, electrical installations, fire protection, and emergency response [18]. SOLAS remains relevant to structural safety, stability, fire protection, safety management systems, and safety equipment, although a stationary FNPP requires specific interpretation and a specific allocation of authority [19]. The INF Code governs the carriage of packaged irradiated nuclear fuel, plutonium, and high-level radioactive waste on ships, and is therefore relevant mainly to fuel and waste logistics rather than as the sole basis for plant safety [20]. Recent classification requirements for marine nuclear power systems emphasize the need for an interface document that distinguishes the parts that are the responsibility of the nuclear regulator from those of the classification society [21].

Economic Feasibility and Uncertainty

The economic analysis of nuclear power plants differs from that of conventional generation projects because the share of capital cost is very large, construction periods are long, financing costs are significant, operating lives are long, and there are obligations for spent fuel and decommissioning. NPV measures the added value at a specified discount rate; IRR is the discount rate that sets NPV equal to zero; the payback period indicates the time required to recover the investment; and LCOE divides the present value of all costs by the present value of the energy generated [7]. A cost–benefit approach can also incorporate system benefits, emissions, energy security, and regional economic impacts that are not fully reflected in electricity sales revenue [8].

For FNPP projects, contract and ownership structures affect financing. Legal and institutional issues for transportable nuclear power plants include the supplier state, the host state, operator liability, cross-border transport, safeguards, security, and fuel ownership [22]. The IAEA SMR roadmap recommends staged development that links regulatory readiness, infrastructure, technology, supply chain, and business model [23]. Because the reference design in the initial manuscript is associated with a floating molten-salt reactor concept, vendor information may be used to understand the configuration but must not be treated as verification of safety or cost without independent review [24].

METHODOLOGY

Research Design and Data Sources



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This study uses a conceptual pre-feasibility approach with four groups of analysis: electricity demand and grid integration, floating technical design, site safety screening, and engineering economics. Secondary data were obtained from electricity statistics, IAEA publications, Indonesian regulations, maritime and offshore guidelines, and geometric parameters from the initial manuscript. Each result is classified as (a) published data, (b) calculation assumptions, (c) derived results, or (d) verification needs. This separation is necessary so that conceptual figures are not mistaken for site survey data.

The literature on Indonesia's nuclear development is used to place the study in a policy context. The World Nuclear Association notes that Indonesia continues to prepare nuclear power options and initial capacity plans, although schedules and locations may still change [25]. A 2025 policy statement from the Ministry of Energy and Mineral Resources (ESDM) places 500 MW of nuclear capacity in the Sumatra and Kalimantan system plans in the early 2030s, not in North Maluku, so this article is positioned as an academic exploration and not as a project designated by the government [26].

Electrical System Screening

Annual energy production is calculated using Equation (1):

$$E_{\text{annual}} = E_{\text{net}} \times 8,760 \times CF \quad (1)$$

where E_{annual} is in MWh/year, P_{net} is the net electrical capacity (MW), and CF is the capacity factor. For $P_{\text{net}} = 250$ MWe and $CF = 90\%$, the result is 1,971,000 MWh, or 1,971 GWh per year. This value is compared with the electricity distributed in North Maluku, 1,356.62 GWh [2]. The indicative average load, calculated as annual energy divided by 8,760 hours, is approximately 154.9 MW. This comparison is only a screening; an actual grid analysis requires hourly load curves, generation configuration, power flow, short circuit, transient stability, reserves, black start, and the largest-unit-loss scenario.

Floating Structure Design Basis and Mooring

The design basis retains the conceptual configuration of a cylindrical structure with a diameter of 45 m, a total height of 73 m, a draft of 48.5 m, and a minimum freeboard of 15 m. The functional layout comprises the reactor zone, steam drum, turbine, condenser, control room, transformers, battery room, fuel storage, spent fuel pool, maintenance facilities, accommodation, and helideck. These parameters are used as a preliminary envelope for discussion, not as a classified design.

The stationkeeping system refers to a nine-line spread mooring configuration arranged radially. The preliminary analysis checks the adequacy of the concept based on a water depth of 150 m and a line length of 420 m. The final design must follow a coupled platform–mooring–riser/cable analysis, combinations of environmental loads, intact and damaged conditions, fatigue, corrosion allowance, redundancy, anchor capacity, seabed interaction, and accidental line failure. DNV-RP-C205 is used as a reference for determining environmental conditions and loads [29], while API RP 2SK provides stationkeeping design principles, limit states, offsets, line tensions, and mooring system reliability [30].

Table 1. Conceptual geometric basis of the FNP.

Parameter	Reference value	Usage status
Net electrical capacity	250 MWe	Basis for grid and economic screening
Thermal capacity	approx. 557 MWt	Follows the initial manuscript; requires verification of the vendor design
Structure diameter	45 m	Conceptual envelope
Total height	73 m	Conceptual envelope
Draft	48.5 m	Requires verification of stability and clearances
Freeboard	minimum 15 m	Requires air gap and green water analysis
Site depth	approx. 150 m	Preliminary assumption; not yet verified by survey



Table 2. Mooring line parameters from the preliminary model

Parameter	Value
Line length	420 m
Mass per unit length	370 kg/m
Equivalent cross-sectional area	0.09 m ²
Axial stiffness EA	800,000 kN
Maximum tension	11,981 kN
Added mass coefficient	1.0
Transverse drag coefficient	2.4
Equivalent diameter	0.13 m
Longitudinal drag coefficient	1.15

Economic Model

The economic model is structured as a real cash-flow screening in USD with a five-year construction period and a 60-year operating life. The CAPEX distribution during construction is assumed to be 10%, 20%, 30%, 25%, and 15%. Operating cash flow is calculated as energy sales less fixed operating costs, fuel, waste management, and the decommissioning reserve. The analysis excludes taxes, inflation, cost escalation, transmission costs, owner's costs, separately itemized interest during construction, probabilistic contingency, and delay costs; therefore, the results are not a bankable financial model.

The equations follow engineering economics principles [27]. NPV is calculated using Equation (2), IRR using Equation (3), and LCOE using Equation (4). To maintain consistency, all indicators are calculated from the same cash flow. LCOE values are compared cautiously with the costs of other technologies because LCOE does not fully capture capacity value, flexibility, grid costs, and externalities. The OECD/NEA emphasizes that technology comparisons must consider system costs and dispatchability characteristics in addition to plant-level generation costs [28].

Table 3. Base-case economic assumptions for screening

Assumption	Value	Remarks
Net capacity	250 MWe	Consistent with the design basis
Capacity factor	90%	Target operating assumption
Annual production	1,971 GWh	Result of Equation (1)
CAPEX	USD 7,000/kW	Screening assumption; total USD 1.75 billion
Construction period	5 years	Distribution 10-20-30-25-15%
Operating life	60 years	Does not use the 80-year claim without design evidence
Fixed O&M cost	USD 100/kW-year	Screening assumption
Fuel, waste, variable	USD 14/MWh	Combined assumption
Selling tariff	IDR 1,877/kWh	Follows the figure in the initial manuscript
Exchange rate	IDR 16,200/USD	Fixed conversion assumption
Discount rate/MARR	8.28%	Follows the initial manuscript
End-of-life cost	10% of CAPEX	Conceptual decommissioning reserve

RESULTS AND DISCUSSION

Suitability of Capacity for the North Maluku System

The screening results show that the annual production of a 250 MWe FNPP at a 90% capacity factor is 1,971 GWh. This is 614.38 GWh, or 45.3%, higher than the electricity distributed in North Maluku. This comparison indicates that the plant could cover aggregate annual energy demand, but it also reveals the potential for oversizing. The average load derived from distribution data is only about 154.9 MW, whereas the FNPP unit operates at up to 250 MW. In a system that is not yet strongly interconnected, a unit trip could remove more power than the average load and cause serious frequency disturbances.

A 250 MWe capacity becomes rational only if at least one of four conditions is met. First, there is an inter-



island or regional interconnection able to export surplus power and provide reserves. Second, an industrial anchor load is available with long-term off-take contracts, for example mineral processing, fisheries cold chains, water production, or low-carbon fuels. Third, the plant configuration is divided into several smaller modules so that the loss of one module does not exceed the system's reserve capability. Fourth, construction is phased in line with load growth and grid reinforcement. Therefore, the conclusion that 250 MWe “meets demand” is not sufficient to state that this capacity is appropriate.

The IAEA feasibility guidance states that if the unit size exceeds 10% of the system's minimum demand, the study must explain how demand is met when the unit is offline and how voltage and frequency are maintained [6]. Given that 250 MW is very likely far above 10% of North Maluku's minimum load, grid integration analysis becomes one of the main gates before detailed design studies.

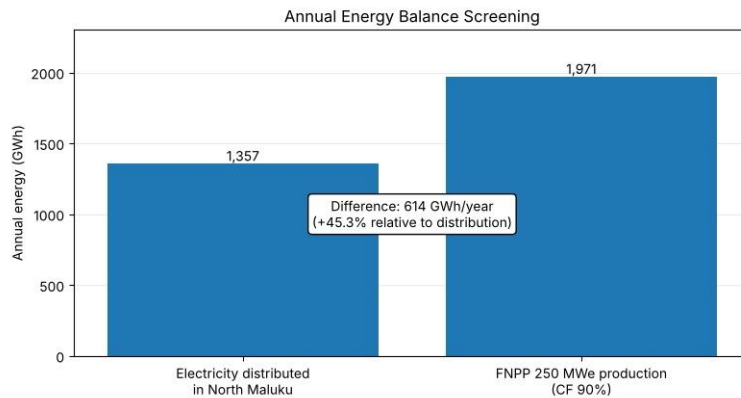


Figure 2. Comparison of the annual-energy screening of the FNPP with electricity distributed in North Maluku

Table 4. Implications of alternative unit scales

Alternative	Advantages	Limitations	Data required
1 × 250 MWe	Economies of scale and large output	Unit trip is dominant; reserve and transmission requirements are very large	Grid stability study, industrial offtake, interconnection
2 × 125 MWe	Better redundancy and phased commissioning	Still large for a small system; cost per kW may rise	Load curve, reserve margin, modularization cost
4 × 60-70 MWe	Incremental capacity additions and outage flexibility	Multi-module complexity and balance-of-plant cost	Availability of commercial designs, multi-module licensing
Micro/SMR <50 MWe	Better suited to small island systems	LCOE potentially higher and fewer mature designs	Local demand, logistics, availability, ownership model

Conceptual Technical Configuration

The cylindrical configuration provides a large internal volume and a symmetric geometry that can reduce sensitivity to wave direction. However, a draft of 48.5 m results in a very deep structure and requires evaluation of stability, freeboard, natural periods, added mass, damping, global strength, local strength, watertight subdivision, damage stability, and evacuation capability. The 15 m air gap cannot be set from generic values alone because it must be derived from extreme waves, tides, storm surge, settlement, trim, heel, and operating allowances.

The layout in Figure 3 places the nuclear system at the bottom, the turbine and condenser area in the middle, and operating and accommodation facilities at the top. The principle of segregation needs to be developed to prevent common-cause failure. Safety systems, cables, ventilation, fire zones, flooding boundaries, and evacuation routes must not be concentrated in a single area that could fail due to fire or flooding. The spent fuel pool and fuel storage require protection against impact, loss of cooling, and unauthorized access. Transformers and export cables must be separated from nuclear safety zones and provided with fire protection and redundancy.

The molten-salt reactor concept has operating characteristics and safety phenomena that differ from those of



light-water reactors. Vendor information can explain design intent, such as low-pressure operation and passive systems, but the safety evaluation must be based on a safety report, source term, defence-in-depth, probabilistic safety assessment, qualified materials, chemistry control, drain tank performance, and technology demonstration. The IAEA catalogue shows that the readiness level of each SMR design differs and that not all have obtained a license or operating experience [5].

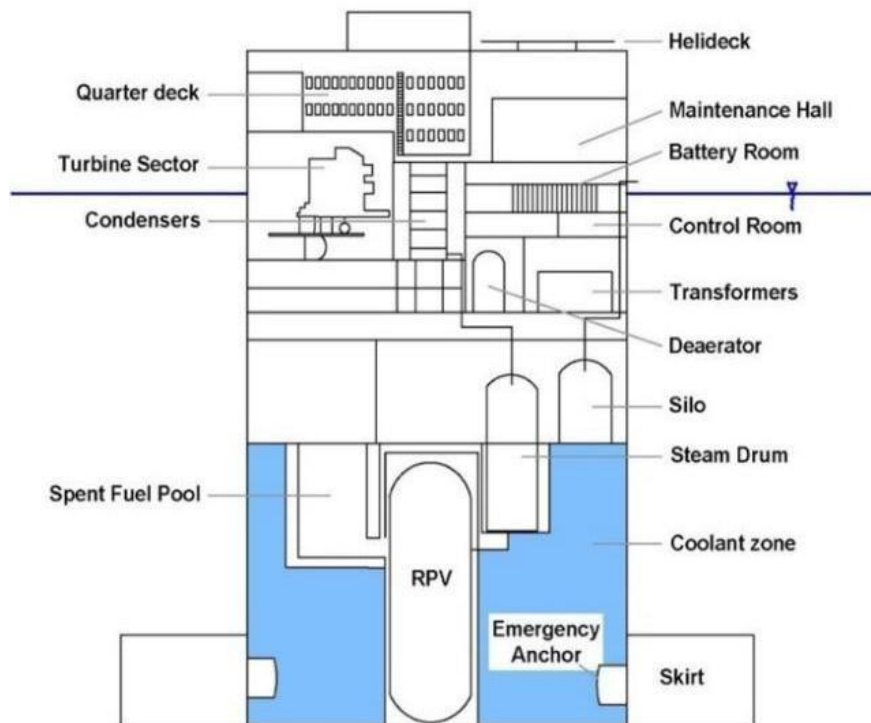


Figure 3. Conceptual FNPP layout from the initial manuscript (used as a basis for discussion, not a certified design)

Mooring System and Export Cable

The preliminary model uses nine radial mooring lines with a length of 420 m at a depth of approximately 150m. The line-length-to-depth ratio of about 2.8 indicates a relatively taut configuration compared with conventional catenary mooring, depending on the material type and pretension. The equivalent cross-sectional area of 0.09 m² and EA of 800,000 kN indicate high stiffness, but the maximum tension of 11,981 kN must be compared with the minimum breaking load, design factor, fatigue damage, corrosion, termination efficiency, and dynamic amplification. Without data on pretension, offset, environmental direction, and anchor characteristics, the safety of the system cannot yet be assessed.

Nine lines provide redundancy, but the 3×3 pattern must be reviewed against the dominant directions of waves, currents, and wind. The design analysis should cover the intact condition, one-line damaged condition, transient line break, anchor failure, seabed trenching, vortex-induced vibration, and interference with the export cable. Environmental loads are derived from the wind-wave-current joint probability in accordance with DNV-RP-C205 principles [29]. Offset and tension criteria must follow the applicable stationkeeping limit states, including operating, extreme, abnormal, and fatigue conditions [30].

The power cable to shore is a critical component because loss of the cable can eliminate the energy export route and affect off-site power. The design must consider the dynamic cable section, bend stiffener, hang-off, touch-down zone, burial/protection, ship anchors, fisheries, undersea earthquakes, and circuit redundancy. The positions of the mooring lines, cable corridor, shipping lanes, and security zones need to be designed together so that they do not interact with one another.

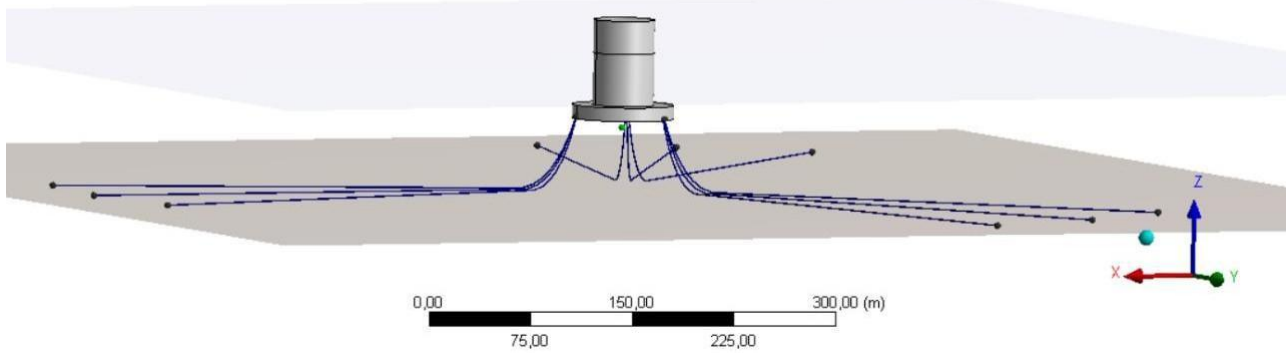


Figure 4. Initial configuration of the structure and nine-line spread mooring

Table 5. Checks that must be completed before the mooring design can be declared adequate

Group	Main checks	Minimum output
Metoccean	Extreme value, scatter diagram, combined wind–wave–current direction, tide and surge	Design environmental conditions and load cases
Structural response	Six-degree-of-freedom RAOs, nonlinear drift, coupled time-domain analysis	Maximum offset, accelerations, air gap
Mooring lines	Pretension, MBL, fatigue, corrosion, termination, line dynamics	Utilization ratio and fatigue life
Anchor/foundation	Geotechnics, holding capacity, cyclic degradation, installation	Anchor capacity and safety factor
Damaged condition	One-line failure, transient snap load, damaged stability	Ability to maintain safety functions
Export cable	Dynamic section, touchdown, burial, crossing, redundancy	Electrical and mechanical integrity of the cable

Site Screening and External Hazards

A water depth of 150 m and available space are not sufficient indicators to declare a site feasible. The Halmahera region lies in an active tectonic and volcanic environment, so candidate sites must be screened for earthquake sources, active faults, tsunamis, seabed deformation, submarine landslides, volcanic activity, and the potential for seiches. In addition, tropical waters require evaluation of high seawater temperature, corrosion, biofouling, local storms, extreme waves, and debris. Human-induced hazards include ship collision, dropped anchors, fire or explosion on nearby vessels, sabotage, and disruption of communication or power cables.

Geotechnical characterization needs to determine stratigraphy, soil strength, cyclic degradation, liquefaction, slope stability, and anchor capacity. Multibeam bathymetric surveys, side-scan sonar, sub-bottom profilers, geophysical hazard mapping, and boreholes and cone penetration tests are needed to confirm seabed conditions. For nuclear installations, the data must have quality assurance, traceability, calibration, and an adequate observation period. The IAEA emphasizes that site surveys must explicitly document data sources and uncertainties [10].

Radioactive dispersion in air and water requires models of meteorology, ocean circulation, sediment transport, food-chain pathways, and population distribution. BAPETEN Regulation No. 4 of 2019 requires data collection, dispersion modeling, dose evaluation, and preparedness assessment [14]. Because the FNPP is located at sea, emergency planning must cover evacuation of platform personnel, protection of coastal communities, exclusion zones, access for rescue vessels, communications, shelters, medical response, and inter-agency coordination.

Table 6. FNPP site hazard screening matrix

Hazard	Screening question	Verification method
Earthquakes and active faults	Can ground motion, fault displacement, or soil failure exceed the design basis?	PSHA, geological–geophysical surveys, SSG-9 Rev. 1



Hazard	Screening question	Verification method
Tsunami and coastal flooding	Do water level, currents, debris, and drawdown disrupt structures or safety systems?	Tsunami source and inundation modeling, probabilistic analysis
Volcanic	Are ash, flows, volcanic tsunamis, or logistical disruption relevant?	Regional hazard screening and scenario analysis
Extreme metocean	Do wind, waves, currents, tides, and surge exceed stationkeeping capacity?	Hindcast, buoy, joint probability, DNV-RP-C205
Geotechnical	Can the soil withstand anchor and cyclic loads?	CPT, borehole, laboratory cyclic tests
Navigation and collision	Do shipping lanes, ports, or anchoring create risk?	AIS traffic study, collision risk analysis
Radioactive dispersion	How do air and sea pathways affect public dose?	Atmospheric-ocean dispersion and dose assessment
Physical security	Are protection zones, detection, response, and cyber security adequate?	Design basis threat and security plan

Base-Case Economic Results

Under the assumptions in Table 3, annual production is 1,971 GWh. Gross revenue at a tariff of IDR 1,877/kWh is approximately USD 228.4 million per year, while fixed operating costs plus fuel, waste, and variable costs are approximately USD 52.6 million per year. Operating cash flow before tax and financing is approximately USD 175.8 million per year.

A consistent calculation yields an NPV of USD 48.6 million at a discount rate of 8.28%, an IRR of 8.52%, a payback period of 14 years from the start of construction, and an LCOE of approximately USD 113.0/MWh, or IDR 1,831/kWh. Unlike the initial results, which showed a positive NPV but an IRR below the MARR, the reconstructed results satisfy the mathematical relationship: because the NPV is slightly positive at 8.28%, the IRR is slightly higher, at 8.52%. The margin between IRR and MARR is only about 0.24 percentage points. This means the project has little room for cost overruns, construction delays, a decline in capacity factor, or lower revenue. LCOE is close to the assumed selling tariff, so feasibility depends on a long-term power purchase contract, availability guarantees, low-cost financing, and CAPEX control.

Strategic benefits such as energy security, emission reduction, and industrial stimulus can strengthen the public justification, but they do not automatically make the project cash flow bankable.

Table 7. Consistent base-case economic results

Indicator	Result	Criterion/interpretation
NPV at 8.28%	USD 48.6 million	Positive, but a small margin
IRR	8.52%	Slightly above the MARR of 8.28%
Payback period	14 years from project start	About 10 years after operation begins
LCOE	USD 113.0/MWh	About IDR 1,831/kWh
Annual energy	1,971 GWh	Requires offtake and grid integration

Sensitivity Analysis

The sensitivity analysis shows that CAPEX and tariff are the largest drivers of NPV. A 20% increase in CAPEX makes NPV significantly negative, while a 20% decrease in CAPEX improves feasibility. A 10% reduction in the tariff also eliminates the investment margin. A capacity factor of 80% reduces production and revenue, while fixed costs must still be paid. A 10% discount rate lowers the present value of long-term revenue and renders the project infeasible, whereas 6% financing increases NPV.

These results reinforce the characterization of nuclear power plants as projects that are highly sensitive to capital cost and financing cost. Risk-reduction strategies may include serial fabrication, EPC contracts with clear risk allocation, sovereign support, green or transition finance, off-take guarantees, and completion of design and licensing before construction. However, subsidies must not mask safety uncertainty or a mismatch between capacity and the grid.



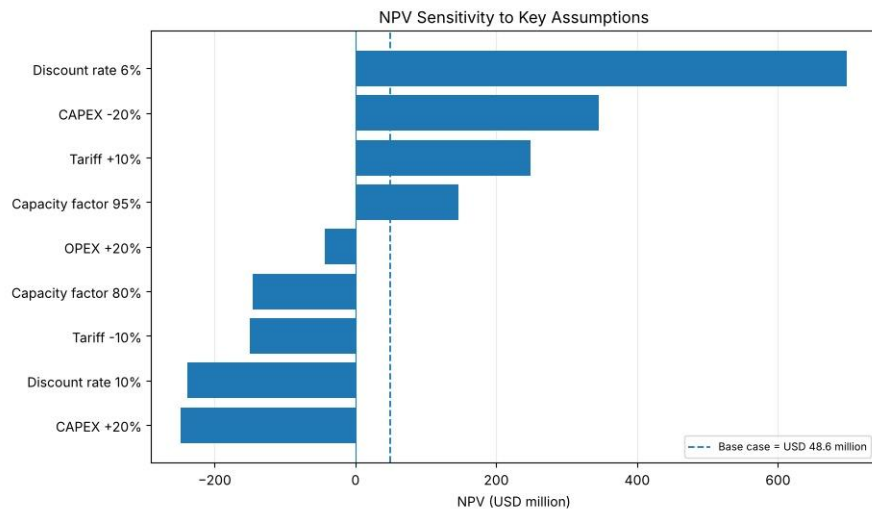


Figure 5. Sensitivity of NPV to changes in key assumptions

Table 8. Summary of economic sensitivity scenarios

Scenario	NPV (USD million)	IRR	LCOE (IDR/kWh)
CAPEX -20%	345	10.36%	1,551
CAPEX +20%	-248	7.21%	2,111
Capacity factor 80%	-146	7.53%	2,032
Capacity factor 95%	146	9.00%	1,747
Tarif -10%	-150	7.51%	1,831
Tarif +10%	248	9.49%	1,831
Discount rate 6%	698	8.52%	1,429
Discount rate 10%	-239	8.52%	2,165
OPEX +20%	-43	8.06%	1,918

Regional Economic Implications and Offtake Model

Excess energy must not be described as a benefit without demand. Production of 1,971 GWh/year requires customers that can absorb electricity stably. Off-take opportunities include the mineral-processing industry, cold storage and fisheries processing, desalination, hydrogen or ammonia production, shore power for ports, and transport electrification. Each requires a different power profile, power quality, price, location, and long-term contract.

An industrial anchor load can raise the capacity factor and revenue, but it also creates concentration risk if a dominant customer ceases operation. Contract structures may use take-or-pay, capacity payments, indexed tariffs, or a government-backed power purchase agreement. A regional benefit assessment needs to quantify employment, local value added, substitution of diesel generation, reduced costs of power outages, and impacts on fisheries and the use of marine space. Cost-benefit analysis allows these social benefits to be valued separately from the financial NPV [8].

National participation needs to be planned realistically. Domestic shipyards can contribute to the hull, non-nuclear structures, outfitting, cables, port works, and part of the balance of plant, while the nuclear island, fuel, safety instrumentation and control, and qualified components may require international suppliers. Localization programs must follow nuclear quality assurance and should not merely pursue a local-content (TKDN) percentage.

Regulatory Framework and Governance

An FNPP requires a clear division of responsibilities among BAPETEN, the Ministry of Energy and Mineral Resources, the Ministry of Transportation, port authorities, classification societies, local governments, security forces, grid operators, and the owner/operator. The nuclear regulator assesses the safety of the reactor and nuclear installation, while the classification society assesses structure, machinery, marine systems, and stationkeeping within the agreed scope. An interface document is required to prevent gaps or overlaps in requirements [21].

Staged licensing under Government Regulation No. 2 of 2014 must be integrated with environmental



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approval, marine space utilization, shipping safety, security, safeguards, and nuclear liability [13]. For a unit built in another country and then towed to Indonesia, jurisdiction must be clarified during fabrication, transportation, commissioning, operation, refuelling, and return of the unit. The IAEA study on transportable nuclear power plants shows that issues between the supplier state and the host state must be resolved before contracting [22].

Public engagement needs to begin at the screening stage. Risk communication must explain the difference between probability and consequence, defence-in-depth, emergency plans, thermal impacts, waste management, security, and the benefits and costs. Social acceptance cannot be assumed merely because a region needs electricity.

Limitations and Future Research Agenda

This study has several limitations. First, hourly grid data, minimum load, peak load, and reserve capacity are not available. Second, the location is not yet supported by final coordinates or by metocean, seismic, volcanic, geotechnical, or navigation surveys. Third, the reactor and platform designs are only conceptual envelopes without a safety analysis report. Fourth, the economic model uses deterministic assumptions and does not yet incorporate probability distributions of cost overrun, delay, taxes, financing, and exchange-rate risk. Fifth, the production estimate is compared with distributed electricity, not with long-term demand projections and load curves.

Further research should begin with capacity options rather than locking in 250 MWe directly. A least-cost generation expansion analysis can compare several SMR modules with gas, geothermal, hydro, energy storage, interconnection, and renewable generation. Candidate sites should then be screened using multiple criteria before detailed surveys. FEED should be undertaken only after the grid study, site screening, regulatory engagement, and offtake model show adequate prospects.

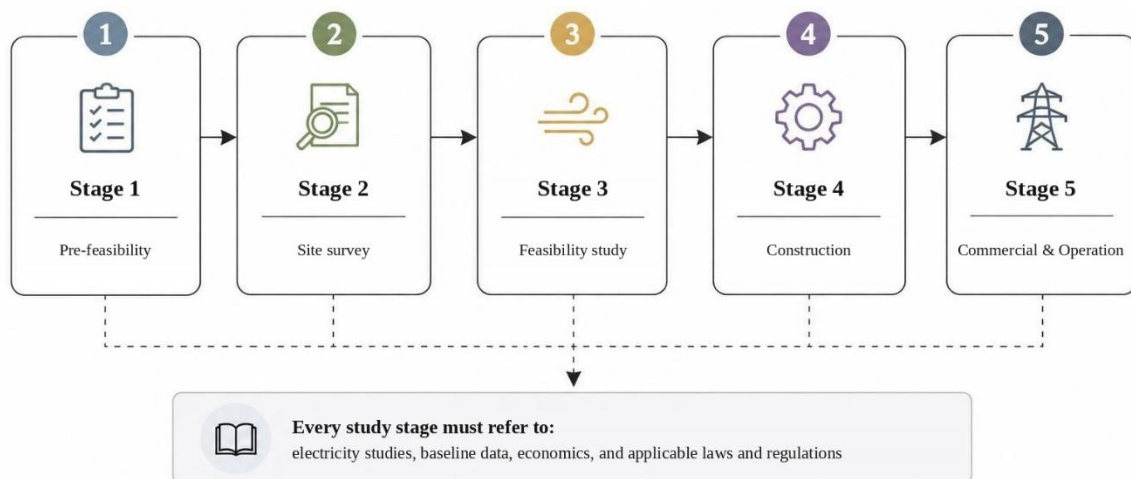


Figure 6. Recommended decision stages for FNPP development

CONCLUSION

The conceptual pre-feasibility study shows that an FNPP can be a low-carbon generation option for archipelagic regions, but a 250 MWe unit cannot yet be declared suitable for North Maluku. At a 90% capacity factor, production of 1,971 GWh/year is about 45.3% higher than the electricity distributed in the province. The unit's output is also higher than the indicative average load of about 154.9 MW, so grid integration, reserves against unit trips, interconnection, industrial off-take contracts, or the use of smaller modules are key prerequisites. The consistently reconstructed economic model yields an NPV of USD 48.6 million, an IRR of 8.52%, a payback period of 14 years from project start, and an LCOE of approximately IDR 1,831/kWh. The feasibility margin is very thin and can be eliminated by higher CAPEX, a lower tariff, a lower capacity factor, or higher financing costs. Technically, the cylindrical structure, the nine-line spread mooring, and the system layout can be regarded only as an initial concept. The Halmahera waters site cannot be declared feasible until seismic, volcanic, tsunami, metocean, geotechnical, dispersion, navigation, physical security, and emergency preparedness evaluations are available. FNPP development should follow a stage-gate process that combines grid studies, staged site surveys, nuclear-maritime safety design, licensing, public participation, and a bankable financing model.



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