COST-BENEFIT ANALYSIS OF SMALL MODULAR REACTOR DEPLOYMENT FOR ELECTRICITY GENERATION IN WEST KALIMANTAN

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Abstract

Small Modular Reactors Small Modular Reactors (SMRs) are indeed gaining increasing attention due to their potential to be commercially available in the near future. The interest in SMRs has grown because of their lower investment requirements compared to large Nuclear Power Plants (NPPs). SMRs offer the promise of faster development and revenue generation, which could help offset their higher capital costs and provide a generation cost comparable to larger NPPs. However, the smaller size of SMR may lead to a loss of economy of scale, which could impact the generation costs of electricity. Therefore, conducting an economic cost-benefit analysis of an SMR program is essential for decision-makers. This analysis helps in evaluating and predicting the value of the project, determining its economic efficiency, and assessing its viability based on the net benefit it generates. The research aims to critically analyses the SMR program and conduct a Cost-Benefit Analysis (CBA) specifically focused on deployment program of SMR in West Kalimantan. The results indicate that the NPP project does not offer additional benefits over the Coal Power Plant (CPP) due to the high investment cost of SMRs. The analysis points out that if the investment cost for SMR is reduced by 10% (5,595 USD/kWe), SMR would have a higher Net Present Value (NPV) than CPP, indicating a more favorable financial outcome for the SMR project. Furthermore, at a carbon tax rate of 20 USD/ton, the CPP would not be financially viable (negative Net Present Value), making the SMR a more attractive option under these conditions. At a discount rate of 5%, the NPV of SMR is higher than CPP. This information can be crucial for decision-makers when considering the economic viability of investing in SMRs as part of their energy strategy.

1. INTRODUCTION

The Indonesian government plans an energy transition roadmap toward NZE until 2060. The power sector will gradually replace all fossil power plants with new and renewable energy (NRE) power plants. Indonesia is currently exploring the potential of nuclear energy as a means to achieve NZE [1]. While the country has not built any nuclear power plants yet, it has been conducting research and feasibility studies on the use of nuclear energy for power generation. The Indonesian government is considering small modular reactors (SMRs) as a possible solution for providing clean and reliable electricity to its growing population while reducing greenhouse gas emissions.

Economic analysis is a crucial step to determine the feasibility of energy projects, including NPP construction. Its main purpose is to create and select projects that will contribute to social welfare. The energy economy aspect is full of complexity, especially for developing countries. Economic analysis is a systematic analytical approach to determine the optimal allocation of resources. One of the planning instruments often used is to conduct a policy impact analysis by observing conditions before and after the policy. Such analysis can also produce indications about the disadvantages and even the advantages of a policy in a broader context.

Cost Benefit Analysis (CBA)-based approaches have, over the recent years, been applied to assess the economic viability of energy system development and planning strategies toward greener and cleaner energy systems through the adaptation of renewable energy and smart energy technologies. Kennedy applies CBA to carry out an economic assessment of the feasibility of building new nuclear power plants in the United Kingdom. The evaluation was carried out through comparative and scenario analysis between the costs and benefits of the nuclear power plant, conventional gas-fired power plants and low carbon energy technologies [2].

The Small Modular Reactor (SMR) technology offers several advantages, such as being environmentally friendly, efficient in fuel use, reliable, and potentially contributing to economic growth. However, it is important to conduct a comprehensive cost-benefit analysis to determine its overall viability compared to other power generation options.

By evaluating the benefits of SMR against its costs (cost benefit analysis), decision-makers can gain a clearer understanding of its potential advantages and drawbacks. If the results of the analysis demonstrate that the benefits outweigh the costs, then SMR could be a compelling option for consideration.

This paper addresses the economic feasibility of launching an SMR deployment programme for West Kalimantan by conducting the economic cost-benefit analysis (CBA). The purpose of this research is to perform a critical analysis on the economics of SMR deployment programme in West Kalimantan.

2. COST BENEFIT ANALYSIS ON NPP PROJECT

Cost-benefit analysis (CBA) is a decision-making tool used to evaluate the potential benefits and costs of a project or investment. It compares the expected benefits of a project or investment with the expected costs, and if the benefits outweigh the costs, the project is considered worthwhile. By quantifying all benefits in monetary terms, cost-benefit analysis provides a clear and objective basis for decision-making. This helps to ensure that decisions are made based on sound economic principles, leading to the most efficient allocation of resources [3].

Cost benefit analysis of nuclear power plants is a method of evaluating the potential advantages and disadvantages of building and operating a nuclear power plant. It involves comparing the costs of construction, operation, and maintenance against the benefits of the electricity produced, such as reduced greenhouse gas emissions and energy security.

The European Commission [4] and IAEA [5] provides guidance on conducting CBA for investment projects including NPP project. It covers a wide range of topics, including the principles of CBA, the identification and measurement of costs and benefits, and the use of CBA in decision-making.

2.1 Incremental approach

CBA compares one or more potential projects with a counterfactual “status quo” scenario that describes what would happen in the absence of the project. Using an incremental approach, the net benefits of the project are assessed against a viable counterfactual status quo, or “without project”, scenario. This implies that the analyst must make an assumption about what would happen in the absence of the project [5].

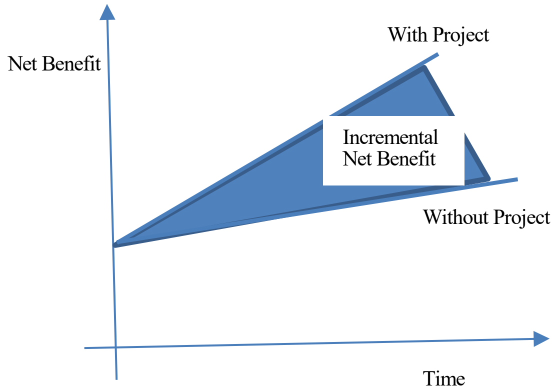


FIG1. Incremental approach

2.2 Monetizing social costs and benefits

CBA aims to assign a monetary value to a project's full range of costs and benefits, including both private and external costs and benefits. This comprehensive approach helps decision-makers understand the project's overall economic impact [3].

The full cost of electricity refers to the total cost of generating (plant-level cost), transmitting, distributing, and consuming electricity (grid-level system costs), including both the direct costs and external costs such as environmental and social impacts [6].

In terms of social impacts, the full cost of electricity can include health impacts from air pollution and exposure to hazardous materials, as well as economic impacts such as job creation or loss in the energy sector. Additionally, access to affordable and reliable electricity can have significant impacts on quality of life, particularly in developing countries.

2.3 Economic performance indicators

Net Present Value (NPV) and Internal Rate of Return (IRR) are both financial performance indicators used to evaluate investment opportunities.

NPV is the difference between the present value of cash inflows and the present value of cash outflows. In other words, it measures the net gain or loss of an investment in today's dollars. A positive NPV indicates that the investment is profitable, while a negative NPV indicates that the investment is not profitable.

IRR, on the other hand, is the discount rate at which the present value of cash inflows equals the present value of cash outflows. In other words, it is the rate at which an investment breaks even. A higher IRR indicates a more profitable investment opportunity.

In the CBA, the financial and economic performance indicators are calculated on the incremental cash flows only**,** difference between the cash flows in the with-the-project and the counterfactual scenarios [7].

3. DATA AND ASSUMPTION

In this study, the project is the SMR development while the counterpart is the CPP which already exists in West Kalimantan. The benefits of nuclear power plant considered in this CBA are environmental benefits which include externality costs and CO2 costs, as well as security of supply.

3.1 Project Costs of NPP

The CBA uses the assumptions of overnight cost of SMR as 5,000 $/kWe. Overnight capital cost, owner cost, taxes, and transportation cost will be summed which will result in EPC cost (Engineering, Procurement, and Construction) or can be called as capital expenditure (CAPEX) to 6,217 $/KWe [8].

Capacity factor of NPP used is 93% and assumption of *lifetime* of NPP is 60 years. Assumption for *lifetime* of NPP is 60 years because if it exceeds the value, there will be addition of costs such as extension for re-operation for 20 years as stated in U.S. regulations which is not considered in this study.

3.2 Externality cost

According to the OECD, externalities are situations when the influence of production or consumption of goods and services imposes costs or benefits on people others that are not reflected in the prices of these goods and services [9]. There is There are 2 types of externalities, namely positive externalities (external economy) and negative externalities (external diseconomy). Meanwhile, the IMF defines externalities as activities consumption, production and investment by individuals, households and companies that influence other people who are not directly involved in transactions at large [9]. There are positive externalities in the form of benefits or gains received by society and negative externalities in the form of damage or costs borne by the community.

The International Atomic Energy Agency (IAEA) has developed a methodology called SIMPACTS to assess the environmental and health impacts of nuclear power plants [10]. **SIMPACTS** estimates and quantifies the health and environmental impacts and external costs of different electricity generation technologies.

Based on externality cost of SMR using SIMPACTS shows that externality cost of SMR is 8.838×10^{-6} cents$/kWh for the year. CPP's external cost was 0.0111 cents$/kWh, where the greatest impact is caused by sulphate compounds (47%) then PM10 (36%) and nitrate compounds (17%) [11].

3.3 CO_2 cost

In this study the cost of CO_2 emissions is expressed in the form of a carbon tax. Based on Law Number 7 of 2021 concerning Harmonization of Tax Regulations (UU HPP), the carbon tax was supposed to take effect on April 1 2022. Its implementation was postponed due to considering the global and domestic economic situation. The government finally postponed the implementation of the carbon tax. The implementation of the carbon tax would come into effect in 2025.

The Tax Harmonization Law notes that the lowest carbon tax rate is IDR 30 per kilogram of carbon dioxide equivalent or $ 2.5 per ton CO_2 equivalent. This tariff is actually much smaller than the initial proposal of IDR 75. With a tariff of IDR 30, Indonesia is one of the countries with the lowest tariff in the world for carbon taxes.

3.4 Security of fuel supply cost

Fuel supply security refers to the ability to ensure sufficient and stable fuel supplies to meet societal and economic needs. The cost of fuel supply security depends on a variety of factors, including the type of fuel used, the infrastructure required to produce, store, and distribute the fuel, and the security risks associated with the fuel supply. Changes in fuel prices can impact the security of fuel supply. If fuel prices rise significantly, then fuel supply could be disrupted as producers may have difficulty meeting consumer demand at high prices.

In this study, for security of energy supply, it is assumed that there will be an increase in fuel for both uranium and coal. The impact of the increase in raw materials, namely natural uranium and coal. A 15% increase in natural Uranium will result in nuclear fuel costs increasing by 4% percent. Meanwhile, an increase of 15% coal will result in an increase in CPP fuel costs by 15% percent also.

4. RESULTS

4.1 Results Analysis

Based on the calculation, the capital cost (CAPEX) for the SMR during the construction stage was 621,678,000, disbursed over 4 years. In comparison, the CAPEX for the CPP (Coal Power Plant) was 241,430,000, disbursed over 3 years. The SMR's CAPEX is almost three times that of the CPP. However, the operational costs incurred by the SMR are much lower than those of the CPP, resulting in greater operational benefits for the SMR. Additionally, the lifetime of the SMR is longer than that of the CPP, with a lifespan of 60 years for the SMR and 30 years for the CPP. These factors indicate that while the initial investment for the SMR is higher, its operational efficiency and longer lifespan contribute to greater benefits in the long run.

TABLE 13. OPERATION COST OF SMR AND CPP (USD/YEAR)

Item	SMR	CPP
O&M cost	12,220,200.00	4,621,104.00
Fuel cost	6,208,578.15	29,900,800.00
Decommissioning cost	1,384,956.00	
Externality cost	720,01	7,778.88
CO_2 cost	-	1,806,312.00
Security of supply cost	238,163.78	4,490,376.00
Total	20,052,617.94	40,826,370.88
LCOE (cent$/kWh)	8.94	8.40
NPV	91,259,927.34	127,843,436.91
IRR	8.63	12.69

Small Modular Reactors (SMRs) have economic advantages over conventional power plants (CPPs) as indicated by the information in the cash flow. Specifically, the annual operating costs of SMRs are approximately half of those for CPPs. This significant difference is primarily due to the lower fuel costs associated with SMRs, as they do not require the same quantity or type of fuel that CPPs do.

For SMRs, the major operating expense is operation and maintenance, which is stated to be $12,220,200.00 annually. In contrast, the primary cost for CPPs is fuel, which is considerably higher at $29,900,800.00 per year. This reflects the general trend that nuclear power plants, such as SMRs, have higher upfront capital costs but lower fuel costs over their operational life compared to fossil fuel-based power plants.

Additionally, while SMRs incur decommissioning costs at the end of their lifecycle, they do not bear any costs related to carbon emissions because they do not emit CO_2 during operation. This is a notable advantage in a global economy increasingly focused on reducing carbon footprints.

Moreover, the externalities—indirect costs to society not reflected in the direct cost of operation—such as environmental and health impacts from pollution, are lower for SMRs compared to CPPs. Security of supply costs, which can include factors like the cost of ensuring a stable and reliable energy source, are also lower for SMRs. These factors make SMRs an attractive option for sustainable energy generation from both an economic and environmental standpoint.

The NPV for the SMR project is reported to be $ 91,259,927.34, which is significantly lower than the CPP's NPV of $ 127,843,436.91. The negative incremental NPV of -$ 36,583,509.58 suggests that, from a cost-benefit analysis (CBA) perspective, the SMR project is less economically viable compared to the CPP when considering the value of money over time within the project's lifespan.

Additionally, the IRR for the SMR project is 8.63%, which is lower than the CPP's IRR of 12.69%. A higher IRR indicates a more profitable investment opportunity. Thus, based on this analysis, the CPP is considered to be a more attractive option than the SMR project in West Kalimantan.

Even SMR have lower annual operating costs compared to coal power plants (CPPs), the high upfront capital investment required results in a higher overall cost of generating electricity over the plant lifetime. The initial investment for an SMR plant is about 3 times higher than building a comparable CPP. This is largely due to the enhanced safety features, modular construction, and higher quality materials needed for nuclear plants. However, SMRs benefit from lower fuel costs and higher capacity factors over their 60-80 year lifetime.

Due to these higher costs, the revenue generated by an SMR over its lifetime may not be as high as that of a CPP, where the market price for electricity generated by both plant types is similar. This lower revenue impacts the NPV, which is the value of all future cash flows over the life of the project discounted back to present value. Similarly, the IRR, which is the interest rate at which the net present value of all the cash flows from a project or investment equal zero, would also be lower for SMRs under these conditions.

Another factor that makes SMR (Small Modular Reactors) less feasible compared to CPP (Coal Power Plants) is the implementation of carbon taxes that are too low. One of the advantages of nuclear power plants is not emitting CO_2. This is in line with the government's policy to reduce carbon emissions towards the Net Zero Emission target in 2060. If the implementation of carbon taxes is equal to other countries, SMR will be more feasible than CPP.

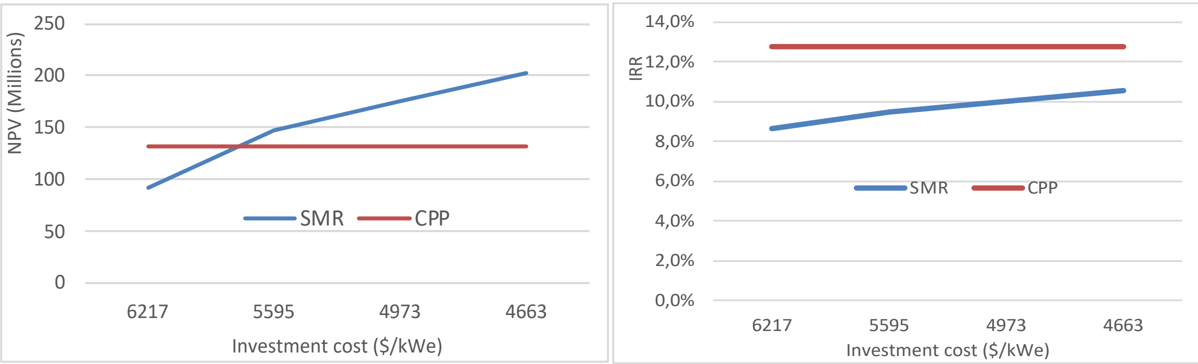
4.2 Sensitivity Analysis

Sensitivity analysis is a critical component in the realm of benefit-cost analysis. It functions as a pragmatic tool to evaluate the robustness of a project's financial outcomes against the fluctuations in input variables. By systematically modifying key parameters within their plausible boundaries, analysts can observe the effects on key financial indicators such as Net Present Value (NPV) and Internal Rate of Return (IRR).

4.2.1 Project Cost

A sensitivity analysis of investment costs is essential to understand how changes in capital expenditure can affect the NPV and IRR. Such an analysis helps in identifying the range within which a project remains financially viable and can endure fluctuations in investment costs. It also aids in risk assessment, strategic planning, and decision-making by highlighting the critical cost components that could impact the project's financial success.

The sensitivity analysis indicates that if small modular reactor (SMR) investment costs are 10-25% lower than the base estimate, the SMR's NPV exceeds the coal power plant's (CPP) NPV as shown in Fig 2(a). This means the SMR is more have benefit or feasible from an NPV perspective if costs can be reduced.



(a) *(b)*

FIG.2. Sensitivity analysis of investment on NPV (a) and IRR (b)

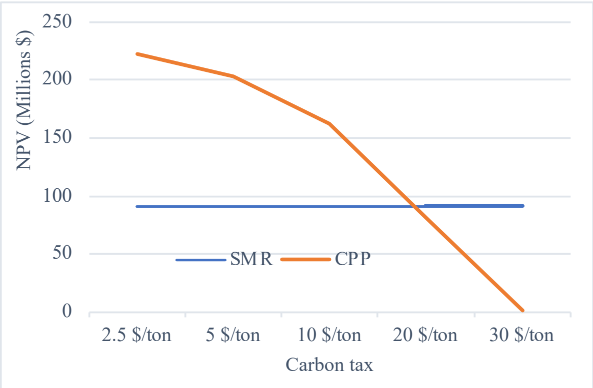
However, even with those lower costs, the SMR still has a lower IRR than the CPP as shown in Fig 2(b). Reducing investment costs improves the feasibility of nuclear options, but they may still lag other technologies in metrics like IRR that weight upfront expenditures more heavily. Continued cost declines through technological learning and economies of scale will be key to making SMRs and other nuclear options more financially viable.

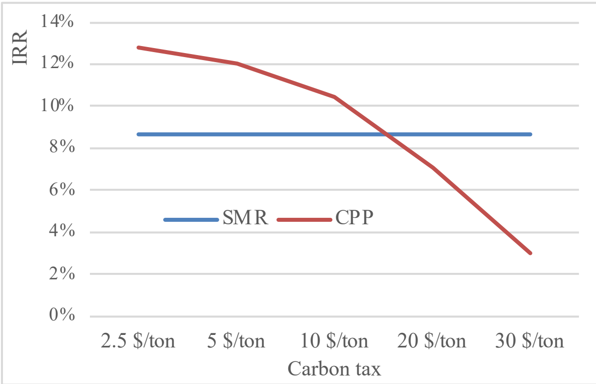
4.2.2 Carbon tax

Carbon tax in Indonesia, which is set at a minimum of IDR 30 per kilogram of CO_2-e or around 2.5 USD/kg, is lower than the carbon tax rate suggested by the World Bank and IMF, which is between US$30 to $100 per ton of CO_2-e for developing countries [12].

In this context, imposing a carbon tax of $20 per kilogram and above of carbon would make coal-fired power plants more expensive to operate because coal power plant releases a significant amount of carbon dioxide. As a result, SMRs become more economically attractive.

As shown in Figures 3(a) and 3(b), implementing a carbon tax of 20$ and above will cause the NPV of CPP to decrease as well as the IRR of CPP.





(a) *(b)*

FIG.3. Sensitivity analysis of carbon tax on NPV (a) and IRR (b)

4.2.3 Discount rate

The discount rate has a significant impact on the Net Present Value (NPV) of a project or investment. Specifically, the higher the discount rate, the lower the NPV will be. This is because a higher discount rate reduces the present value of future cash flows more sharply. So when evaluating NPV, using a lower discount rate is typically more favourable as it results in a higher NPV.

In contrast, the Internal Rate of Return (IRR) does not depend on the discount rate. The IRR is defined as the discount rate that makes the NPV equal zero. It represents the expected rate of return of the investment. So while NPV varies based on the discount rate, IRR stays constant regardless of the discount rate used in the calculation. The IRR simply represents the breakeven return rate for an investment.

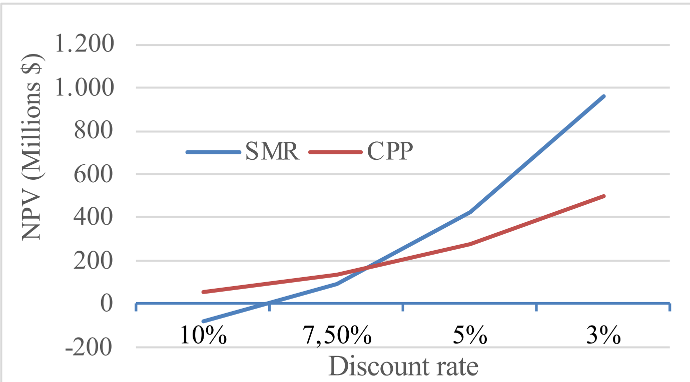


FIG.3. Sensitivity analysis of discount rate on NPV

The sensitivity analysis indicates that the economic competitiveness of SMR relative CPPs is quite sensitive to the discount rate used. Specifically, the net present value (NPV) analysis shows that at higher discount rates of 7,5-10%, CPP tend to have greater NPV due to their lower upfront capital costs as shown in Figure 3. However, as the discount rate decreases, the NPV of SMRs increases more rapidly surpassing that of CPPs. At a 5% discount rate, the SMR already demonstrates higher NPV, with this effect being even more pronounced at very low 3% discount rates.

5. CONCLUSION

Cost-benefit analysis is a systematic approach to evaluating the strengths and weaknesses of a decision or project. It is commonly used in economics and public policy to assess the economic efficiency of various projects or policies. Cost benefit analysis of nuclear power plants is a method of evaluating the potential advantages and disadvantages of building and operating a nuclear power plant. It involves comparing the costs of construction, operation, and maintenance against the benefits of the electricity produced, such as reduced greenhouse gas emissions and energy security.

In this study, a CBA has been carried out to compare a Nuclear Power Plant (NPP) project, specifically focused on deployment program of SMR in West Kalimantan, with a counterfactual project is an existing Coal Power Plant, which represents an alternative energy project or the current energy generation scenario.

The analysis points out that if the investment cost for SMR is reduced by 10% (5,595 $/kWe), SMR would have a higher NPV than CPP, indicating a more favourable financial outcome for the SMR project. Furthermore at a carbon tax rate of 20 USD/ton, the CPP would not be financially viable (negative Net Present Value - NPV), making the SMR a more attractive option under these conditions. At a discount rate of 5%, the NPV of SMR is higher than CPP (presumably another project or investment). This suggests that at a lower discount rate, the profitability or value of SMR is higher compared to CPP. This information can be crucial for decision-makers when considering the economic viability of investing in SMRs as part of their energy strategy.

ACKNOWLEDGEMENTS

This study is part of the IAEA Coordinated Research Project I12007, focusing on the economic appraisal of Small Modular Reactors (SMRs) projects. The author expresses gratitude to the IAEA and Saied Dardour for the opportunity to participate in this project.

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