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Research Paper

Analysis of Nuclear Energy for Future Power Plants in Indonesia

An Assessment for Sustainable Energy Development

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Abstract

Indonesia has been investing in expanding its power generation capacity to meet increasing needs. There is an ongoing demand for a new source of energy that is reliable, affordable, safe, and clean. This research has assessed the feasibility on implementing nuclear power plants in Indonesia using systematic literature review based on a comprehensive SWOT analysis, IFE/EFE matrix analysis, and TOWS analysis. The obtained result is that the impacts of internal and external factors are assessed as moderate-positive and positive, respectively. The research implies that strategies regarding investments, benefits, waste management, and collaborations with other alternative energy sources can significantly maximize the benefits and overcome challenges. This study contributes to the understanding of nuclear energy implementation in Indonesia and provides insights for policymakers, stakeholders, and researchers seeking to explore and promote sustainable energy solutions in an urgent need regarding increasing energy demand.

Keywords: SWOT analysis; IFE/EFE matrix; TOWS analysis; nuclear energy; sustainable energy

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1. Introduction

Electrical energy is vital for the world, playing a crucial role in advancing societies, economies, and technological progress. It is the backbone of modern economies, driving industrialization and the economy's growth (Nti et al., 2020). It improves the quality of life for people across the globe. Access to electricity enhances living conditions, particularly in rural and remote areas, by providing better healthcare, education, and communication services. It enables modern technologies, such as computers, internet connectivity, and mobile devices, facilitating information access, e-commerce, and social connectivity. Furthermore, electrical energy is a critical enabler of clean water supply and sanitation systems, contributing to public health and hygiene (Capodaglio & Olsson, 2020). Overall, electrical energy is instrumental in promoting human development social progress, and enhancing the well-being of individuals and communities worldwide.

Ensuring access to reliable, affordable, and clean electricity addresses global development challenges, including poverty alleviation, healthcare, education, and environmental sustainability (Moristanto & Setiandanu, 2020). It also applies in Indonesia, where the need for reliable and sustainable electrical energy is increasing yearly. Electricity demand is expected to grow at an annual average of 2.5% from 2021 to 2025 and then by 5% until 2029 (Kanugrahan et al., 2022). There are some reasons behind its continuous increase, which are explained as follows.

Electrical energy is essential for economic development in Indonesia. It powers various sectors, such as manufacturing, industry, commerce, and services. Reliable and affordable power enables businesses to operate efficiently, stimulates industrial growth, and attracts investment. Access to electricity boosts productivity, job creation, and overall economic prosperity (Saputra & Ali, 2021). Technological advancements and the proliferation of electrical appliances and devices contribute to the rising demand for electrical energy. The increasing use of electronic devices, household appliances, communication technologies, and industrial machinery requires an excellent electricity supply (Saudi et al., 2019). Various sectors' growing digitalization, automation, and electrification further amplify this trend.

As the population grows, electricity and energy consumption demand also increase. More households, businesses, and industries require access to reliable and affordable energy (Romadhoni, 2020). It places a tremendous strain on the existing power plant infrastructure and necessitates the development of new power generation facilities to meet the rising demand. Indonesia has also been experiencing rapid urbanization and infrastructure development. As more people migrate to cities and urban areas, expand, the demand for electrical energy increases. Urban areas require electricity to power residential buildings, commercial establishments, transportation systems, and essential infrastructure such as hospitals, schools, and public facilities (Bashir et al., 2021).

The Indonesian government has been actively promoting electrification efforts to increase access to electricity nationwide. It includes extending the electricity grid to remote areas, providing electricity to rural communities, and electrifying previously off-grid islands (Wibisono et al., 2023). These initiatives aim to improve the quality of life and support social development. As a result, expanding electricity access leads to an increase in overall electrical energy consumption.

Economic development will also lead to rising standards of living. As living standards improve, there is an increased demand for electrical energy to power modern amenities and comforts. People now rely on electricity for lighting, refrigeration, air conditioning, entertainment, and other daily activities. The desire for a higher quality of life and increased energy consumption contribute to the continuous growth in electrical energy demand (Hill, 2021).

To meet the growing demand for electrical energy, Indonesia has been investing in expanding its power generation capacity, upgrading transmission and distribution infrastructure, and diversifying its energy mix (Tambunan et al., 2020). These efforts aim to ensure a reliable and sustainable electricity supply to support economic growth, improve living standards, and drive socio-economic development. The significance of new power plants is based on factors such as strain on existing power plants, environmental impact, and energy security.

The increasing population can stress existing power plants more, leading to potential overloading and inefficiencies. Power plants may operate at maximum capacity for extended periods, increasing the risk of equipment failures and decreasing reliability (Behbahaninia et al., 2022). Adequate maintenance and upgrades become crucial to ensure existing power plants' continued performance and reliability.

Meeting the energy demands of a growing population can have significant environmental implications. Traditional power plants, especially those relying on fossil fuels, contribute to greenhouse gas emissions. The need for increased power generation can lead to higher carbon emissions, affecting air quality and contributing to climate change. As a result, a growing need exists to explore cleaner and more sustainable energy sources, such as renewable energy, to mitigate the environmental impact (Sasana & Aminata, 2019).

A larger population increases the importance of energy security. The stability and reliability of the power supply become critical to supporting economic growth, social development, and daily activities. Adequate power generation capacity, diversified energy sources, and robust energy infrastructure ensure an uninterrupted energy supply, reduce import dependency and enhance energy self-sufficiency (Sambodo & Novandra, 2019).

As a solution to overcome the electricity crisis, the construction of a nuclear-based power plant (Indonesian: *Pembangkit Listrik Tenaga Nuklir*) was proposed. However, public acceptance is shallow due to concerns about its safety, even though nuclear power development has made significant advancements in safety and technology, with its maturity continuously growing (Sugiawan & Managi, 2019). Moreover, from an environmental standpoint, nuclear power plants are considered the cleanest option (Pata & Kartal, 2023). From an economic perspective, they are more economical than other power plants (Jensen-Eriksen, 2022), especially when addressing electrical energy supply rather than nuclear weapons development.

However, adopting nuclear energy in Indonesia is a complex decision that requires careful consideration of various factors. A comprehensive assessment of nuclear energy, including a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, is necessary to understand the potential benefits, challenges, and risks associated with implementing nuclear power plants. This research aims to conduct a thorough SWOT analysis of nuclear power plants in Indonesia, evaluating the internal and external factors that influence the deployment and operation of such facilities.

By conducting a SWOT analysis, the study will analyze the internal and external factors that influence the adoption and development of nuclear power plants. It will evaluate the strengths and weaknesses of nuclear energy, such as its potential to provide a stable and reliable power supply and its associated environmental risks and concerns. Additionally, the study will identify the opportunities and threats of integrating nuclear energy into Indonesia's energy mix, considering factors such as policy frameworks, safety regulations, public acceptance, and international cooperation. This analysis will encompass various dimensions, including technological, economic, environmental, social, and political, ensuring a comprehensive assessment of the nuclear power plant's feasibility and compatibility with Indonesia's unique context.

Research on implementing nuclear plants in Indonesia is significant because it can address the country's increasing energy demand and contribute to sustainable development. Understanding the strengths, weaknesses, opportunities, and threats associated with nuclear power implementation enables policymakers and stakeholders to develop strategies that optimize benefits and mitigate risks. Such research can pave the way for the safe and efficient deployment of nuclear energy, ensuring long-term energy security, reduced carbon emissions, and economic growth while addressing environmental concerns and fostering public acceptance. The study will also contribute to the broader discourse on sustainable energy development and the transition to low-carbon energy sources in the global context.

2. Methods

The methodology employed in this study aims to comprehensively assess nuclear energy's potential for future power plants in Indonesia, considering its viability as a sustainable energy source. This assessment will involve a rigorous and systematic analysis of various technical, economic, environmental, social, and policy-related aspects. This research methodology is illustrated as a flowchart in Figure 1.

Figure 1. Research Flowchart

1.1 Data Collection and SWOT Aspects Determination

Data collection will include literature reviews from journals, policy analyses, investigations from previous surveys, and analyses of existing case studies from other countries that have implemented nuclear power plants. Table 1 presents the journal sources used in this literature study, identifying 20 aspects of strengths, weaknesses, opportunities, and threats in implementing nuclear power plants in Indonesia.

Table 1. SWOT Variables

Component	Aspect	Sources
Strength	Lower Operation and Maintenance Cost	Laleman, Balduccio, & Albrecht (2023) Roth & Jamarillo (2017) Reyseliani & Purwanto (2017)
	Skilled Workforce	Surya et al. (2021) Jafarinejad et al. (2021)
	High Suitability Area	Susiati et al. (2022) Abdullah et al. (2023)
	Attractiveness to Foreign Investors	Kim (2020) Terlikowski et al. (2019)
	Strong Government Support	Kim (2020) Narinda, Sudibyo, & Prakoso (2021)
Weakness	High Initial (Upfront) Investment	Kan, Hedenus, & Reichenberg (2020) Mari (2014)
	Lack of Sociopolitical Acceptance	Sugiawan & Managi (2019) Ho et al. (2022) Wang & Kim (2018)
	Limited Power Infrastructure	Maulidia et al. (2019) Bragg-Sitton et al. (2020)
	Nuclear Waste Management Challenges	Wisnubroto et al. (2021) Alwaeli & Mannheim (2022)
	Potential Safety Concerns	Jang & Park (2020) Xu & Zhang (2021)
Opportunity	Increasing Energy Demand	McNeil et al. (2019) Kanugrahan et al. (2023)
	Reduction in Carbon Emissions	Pata & Kartal (2023) Sun et al. (2023)
	Maximization of Energy Utilization	Bragg-Sitton et al. (2020)
	Technological Advancements	Locatelli, Mancini, Todeschini (2013) Terlikowski et al. (2019)
	Opening of New Jobs	Cho et al. (2021) Kenley et al. (2009)
Threat	Other Alternative Energy Sources	Timilsina (2021) Suman (2018)
	Geopolitical Risks	Palle (2021)
	Public Opposition to Nuclear Power	Ho et al. (2022) Karfopoulos et al. (2015)
	Natural Disasters	Susiati et al. (2022) Wu, Wu, & Gao (2020)
	Political Instability	Neumann et al. (2020) Ho et al. (2022)

While nuclear energy holds considerable potential, carefully considering strengths, weaknesses, opportunities, and threats is necessary to make informed decisions regarding its implementation. SWOT analysis will be the strategic planning methodology used to evaluate the internal strengths (S) and weaknesses (W) of a project, as well as the external opportunities (O) and threats (T) it faces (Alamanda et al., 2019). The determination of SWOT aspects requires the following steps.

a. Identify Strengths (S): Recognize the internal factors or capabilities that provide an advantage to the case. These can encompass resources, skills, competitive advantages, or other internal strengths.
b. Identify Weaknesses (W): Identify the internal factors or limitations that place the case at a disadvantage. These can involve deficiencies, gaps, constraints, or other internal weaknesses.
c. Identify Opportunities (O): Identify the external factors or favorable circumstances that benefit the case. These can include market trends, regulatory changes, or external opportunities.
d. Identify Threats (T): Identify the external factors or challenges that can negatively impact the case. These can involve competition, political risks, environmental factors, or other external threats.

The analysis helps identify critical factors that can influence the success or failure of the entity under consideration. The selected sources are based on relevant and credible academic journals offering a thorough analysis. Each analysis aspect must also be supported by at least one source published within the last five years.

1.2 IFE and EFE Matrix Analysis

In the context of utilizing an Internal Factor Evaluation (IFE) and External Factor Evaluation (EFE) matrix, SWOT analysis provides a structured approach to assess the strategic position of the entity (Alamanda et al., 2019). The IFE and EFE matrix focus on evaluating the internal strengths and weaknesses of the entity, as well as external opportunities and threats, considering factors such as resources, capabilities, and operations. Weighted ratings are assigned to each internal factor based on its importance and the entity's performance. The ratings typically range from 0 to 4, with higher numbers indicating better performance or greater importance. These weighted ratings are then multiplied by the assigned weights to calculate a score for each factor using Equation (1):

$$Total\ Score = \sum_{i=1}^{n} W_i I_i \quad (1)$$

Where Wi represents the weight of each SWOT aspect, I_i denotes the rating of each SWOT aspect, and n signifies the total number of aspects.

Once the IFE and EFE matrices are developed, they can be used with the SWOT analysis to understand the entity's strategic position comprehensively. The strengths and weaknesses identified in the IFE matrix are aligned with the opportunities and threats identified in the EFE matrix, creating a matrix that highlights the strategic implications of these factors.

1.3 TOWS Analysis

The TOWS Analysis is a strategic planning tool that integrates the external opportunities and threats identified in the SWOT analysis with the internal strengths and weaknesses of the research subject. It aids in recognizing strategic insights and formulating suitable strategies to leverage strengths, address weaknesses, capitalize on opportunities, and mitigate threats. The name TOWS was created by reversing the order of the SWOT acronym. The process of conducting a TOWS Analysis is as follows.

a. Combine Strengths and Opportunities (SO): Analyze how internal strengths can be leveraged to capitalize on external opportunities. Identify strategies to maximize the benefits of strengths in exploiting opportunities.
b. Combine Strengths and Threats (ST): Analyze how internal strengths can mitigate or overcome external threats. Identify strategies to minimize the impact of threats by leveraging existing strengths.
c. Combine Weaknesses and Opportunities (WO): Analyze how internal weaknesses can be addressed or overcome by taking advantage of external opportunities. Identify strategies to minimize weaknesses by capitalizing on available opportunities.
d. Combine Weaknesses and Threats (WT): Analyze how internal weaknesses can be minimized or mitigated in the face of external threats. Identify strategies to overcome weaknesses and reduce the impact of threats.
e. Develop Actionable Strategies: Based on the insights gained from the TOWS Analysis, develop specific, actionable strategies and action plans that align with the goals and objectives.

2. Results and Discussions

Nuclear energy is a form of energy generated through nuclear reactions, specifically nuclear fission. It involves splitting atomic nuclei, typically uranium or plutonium isotopes, releasing substantial energy in heat. This heat is then harnessed to produce steam, which drives turbines connected to generators, ultimately generating electricity. Nuclear power plants utilize this process to produce electricity on a large scale.

Nuclear reactions occur in a nuclear power plant in the reactor core, where fuel rods containing enriched uranium are arranged. These reactions generate intense heat, which is transferred to a coolant, usually water or a gas, circulating through the reactor. The heated coolant then flows through a heat exchanger, transferring its thermal energy to a secondary water loop, producing steam. The steam drives turbines, which rotate the alternator to generate electric power (Sun et al., 2023). The electricity generated is then fed into the power grid for distribution to consumers. This nuclear thermoelectric conversion process is illustrated in Figure 2, depicting the conversion from thermal energy to mechanical energy and then from mechanical energy to electrical energy.

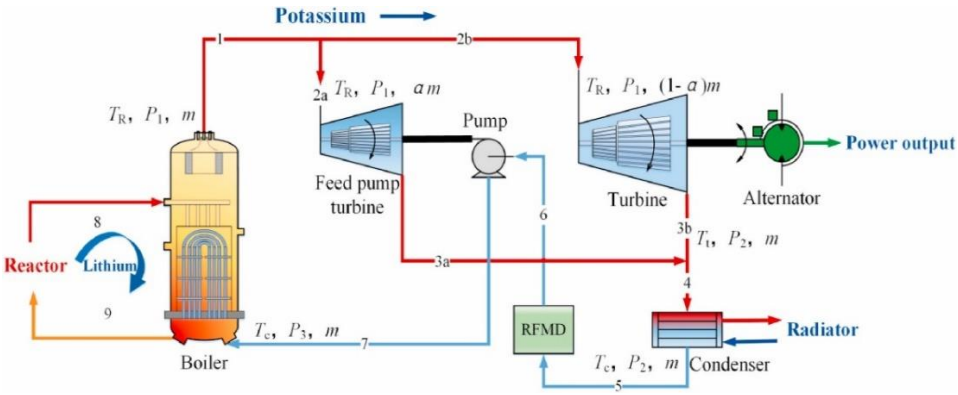

Figure 2. Nuclear Thermoelectric Conversion Scheme

Source: Sun et al. (2023)

One of the significant advantages of nuclear energy is its capability to generate electricity without emitting substantial amounts of greenhouse gases or air pollutants. Nuclear power plants do not produce carbon dioxide (CO2), sulfur dioxide (SO2), or nitrogen oxide (NOx), which are significant contributors to global warming and air pollution. As a result, nuclear energy has the potential to considerably reduce carbon emissions and alleviate the impacts of climate change.

However, nuclear energy does pose environmental challenges related to nuclear waste and the potential for accidents. The spent fuel rods and other radioactive waste generated by nuclear power plants are highly hazardous and demand careful management. Furthermore, the risk of accidents, such as meltdowns or radiation leaks, can lead to environmental consequences and threaten public health (Ohba et al., 2021).

Despite these challenges, there are reasons why nuclear power plants should be considered in Indonesia. As shown in Figure 3, Indonesia is experiencing a rapid increase in energy demand due to economic growth and population expansion, although the rise in electricity demand has slightly slowed due to the COVID-19 pandemic. Nuclear energy can offer a reliable and consistent electricity supply, aiding in meeting this escalating demand and supporting industrial and infrastructural development. The subsequent SWOT, IFE/EFE matrix and TOWS analyses will further explain these aspects.

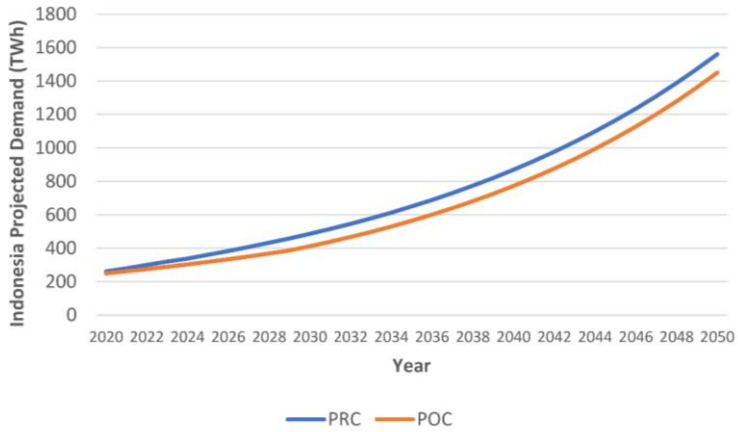

Figure 3. The pre-COVID-19 (PRC) and post-COVID-19 (POC) Electricity Demand Prediction

Source: Kanugrahan et al. (2023)

2.1 Strength Analysis

The strengths of nuclear energy in Indonesia underscore its potential benefits and advantages. One of the strengths of nuclear power plant implementation is the potential for lower operation and maintenance costs compared to other forms of power generation. Although the upfront capital costs of building a nuclear power plant can be high, nuclear plants can experience relatively low operational fuel costs, as stated in the research by the University of Gent, Belgium, shown in Figure 4 (Laleman, 2023).

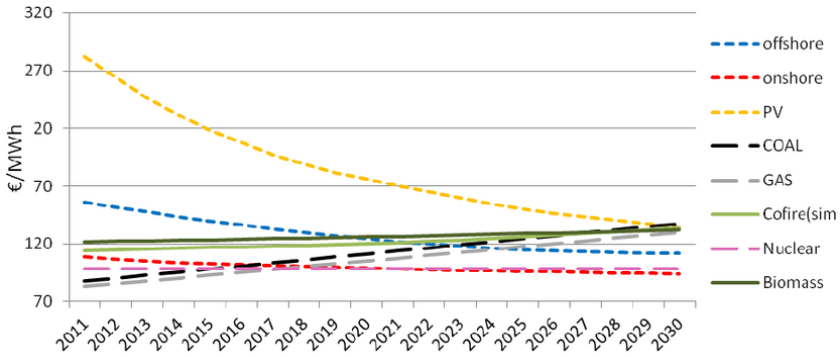

Figure 4. Levelized Cost of Electricity Comparison for Different Energy Sources

Source: Laleman et al. (2023)

The University of Indonesia has also conducted similar research to gain an Indonesian perspective. The cost of producing power using 100% renewable energy versus 100% renewable energy (without nuclear), focusing on the base case demand scenario, is depicted in Figure 5. The cost of power production does not show a significant change from 2020 to 2030. However, in the long run, the cost of producing 100% electricity without nuclear energy is predicted to exceed that of producing 100% with nuclear energy (Reyseliani & Purwanto, 2021).

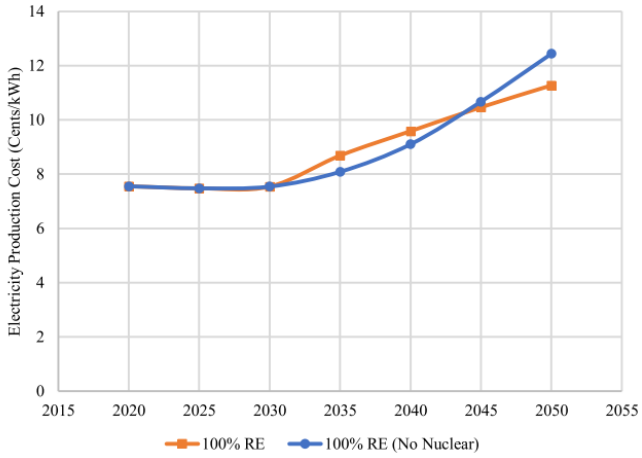

Figure 5. Electricity Production Cost for 100% Renewable Energy (With and Without Nuclear)

Source: Reyseliani & Purwanto (2021)

Nuclear fuel, such as uranium or thorium, is highly energy-dense (Layton, 2008), meaning a small amount can generate significant electricity. It leads to reduced fuel consumption and lower fuel costs over the operational lifetime of the plant. Moreover, advancements in nuclear technology, such as improved reactor designs and operational efficiencies, can further contribute to lower operating and maintenance costs.

The second strength of nuclear power plant implementation in Indonesia is its skilled workforce. The successful establishment of nuclear power plants demands a highly skilled workforce, encompassing engineers, technicians, nuclear physicists, and safety experts. Indonesia has the advantage of having a substantial and well-educated workforce that can be trained and employed in the nuclear industry. According to PII (Indonesian Engineers Association) calculations, by 2015, Indonesia had 211,124 engineers, predicted to rise to 546,075 engineers by 2025 (Handayani, 2015). The existing pool of skilled professionals can be further enhanced through specialized training programs and collaborations with countries possessing well-established nuclear energy initiatives. The growth of a skilled workforce will correlate positively with energy production and consumption (Surya et al., 2021).

Indonesia's geographical characteristics also render it highly suitable for implementing nuclear power plants. A geological analysis in Figure 6 demonstrates that West Kalimantan has a very high nuclear suitable area (Susiati et al., 2022), encompassing 25.81% of the unrestricted area in the province. This discovery is further substantiated by the Fuzzy Analytic Hierarchy Process (FAHP) method (Abdullah et al., 2023). The region features many coastal areas and large river valleys, positioning power plants near potential raw water sources for coolants, industrial zones, and a well-developed power grid. Additionally, the area is geologically stable, boasting a relatively low risk of severe seismic activities and natural disasters that could endanger nuclear facilities. This stability diminishes the likelihood of accidents or damage stemming from external factors.

Developing nuclear power plants in Indonesia is also highly appealing to foreign investors. Nuclear energy projects generally entail significant investments, and foreign investors can contribute financial resources, technical expertise, and experience in nuclear power plant construction and operation. Indonesia's stable economic growth further enhances this attractiveness (Kim, 2020). A robust regulatory framework, government support, and transparent policies can establish a favorable investment climate, encouraging foreign entities to engage in the development of nuclear energy projects.

Strong government support is a crucial advantage for implementing nuclear power plants. The Indonesian government's commitment to nuclear energy, as demonstrated through clear policy frameworks and regulations like Act No. 10/1997 on Nuclear Energy and Government Regulation No. 2/2014 on the Licensing of Nuclear Installation and the Utilization of Nuclear Materials, creates a stable and supportive environment for nuclear energy projects. Government support encompasses establishing regulatory bodies, formulating national energy plans involving nuclear power, and allocating resources and funding for research, development, and infrastructure. This support can expedite the development of nuclear power plants in Indonesia and serve as a means to achieve defense diplomacy (Narinda et al., 2021). It can simultaneously enhance energy security in the face of climate change and synergistically affect Indonesia's defense capabilities.

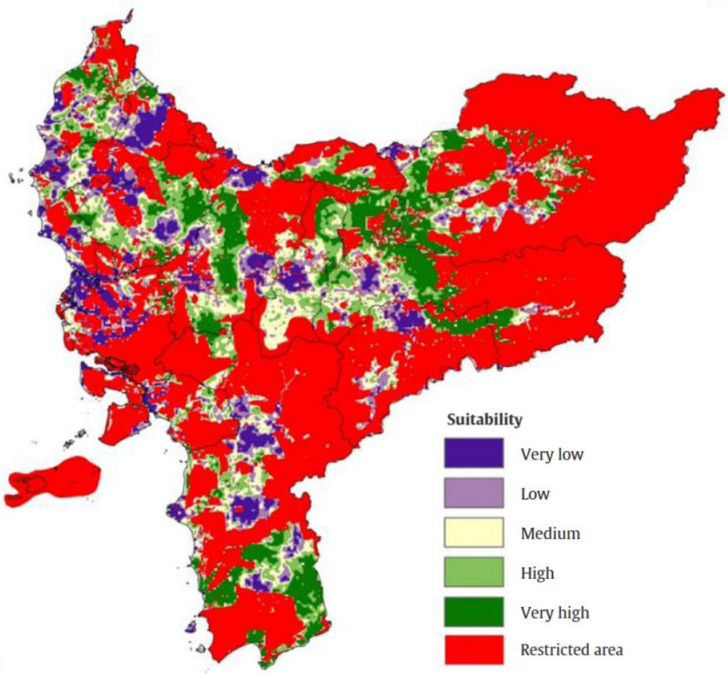

Figure 6. Geological Analysis of Suitable Locations for Nuclear Power Plants in West Kalimantan

Source: Susiati et al. (2022)

2.2 Weakness Analysis

The weaknesses associated with implementing nuclear energy in Indonesia emphasize the challenges and limitations that must be addressed. One of the significant weaknesses of nuclear power plants is the substantial initial (upfront) investment required for construction and commissioning, amounting to $7000/kW (Kan et al., 2022). It is corroborated by the data presented in Table 2.

Table 2. LCOE Decompositions by Percentage

LCOE	Nuclear	Coal	Gas
Initial Investment	61.24%	38.97%	14.40%
Taxes	17.37%	9.63%	2.55%
O&M	13.66%	16.32%	5.78%
Fuel	7.60%	35.08%	77.27%
Decommissioning	0.13%	0.00%	0.00%

Source: Mari (2014)

Building a nuclear power plant entails a substantial initial investment, as indicated in Table 2. The initial investments encompass engineering, procurement, and construction expenses. These costs can pose a barrier, especially for developing nations like Indonesia, where allocating significant amounts of money may present financial challenges. Adequate financial planning, access to funding sources, and meticulous cost-benefit analysis are essential to address this weakness.

Implementing nuclear power plants necessitates sociopolitical acceptance from the public, stakeholders, and policymakers. This acceptance is a pivotal element in successfully establishing nuclear power plants. The absence of acceptance can stem from safety concerns, fear of accidents, and misconceptions about the potential risks linked to nuclear energy (Sugiawan & Managi, 2019). Building public trust and awareness through transparent communication, education, and public engagement initiatives is crucial to addressing these apprehensions (Ho et al., 2022). Failing to secure public acceptance can result in opposition, regulatory obstacles, and even the abandonment of nuclear projects.

Implementing nuclear power plants necessitates a sturdy and comprehensive power infrastructure to distribute the generated electricity efficiently. Developing countries like Indonesia might lack power infrastructure or encounter difficulties incorporating nuclear power into the existing grid (Maulidia et al., 2019). Upgrading and expanding the power infrastructure, encompassing transmission lines, substations, and distribution networks, may be imperative to accommodate the supplementary power supply from nuclear facilities. This weakness underscores the requirement for thorough planning and coordination with other energy sectors to guarantee the seamless integration of nuclear power into the national grid.

Nuclear power generation produces radioactive waste that demands meticulous management and disposal. Effective waste management practices are crucial to mitigate environmental and health risks linked to radioactive materials. Establishing secure storage facilities, implementing efficient waste management strategies, and adhering to international safety standards are pivotal in addressing this weakness (Wisnubroto et al., 2021). Radioactive waste management involves several steps: collection, characterization, sorting, processing, storage, and disposal. These steps are further detailed in a flowchart illustrated in Figure 7.

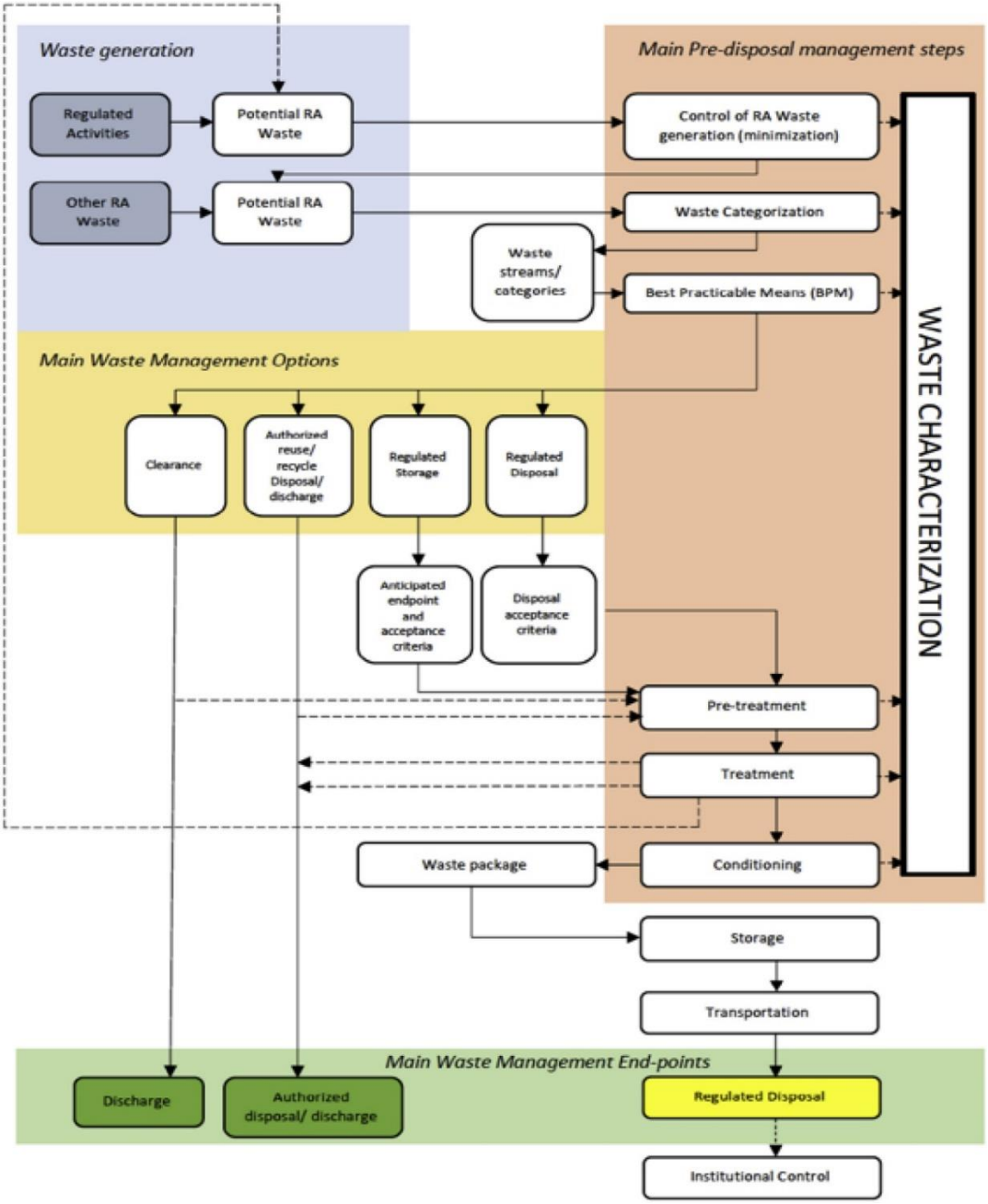

Figure 7. Radioactive Waste Management Steps

Source: Wisnubroto et al. (2021)

Safety concerns linked to nuclear power plants present the most substantial weakness. Despite modern reactor designs and stringent safety measures that mitigate risks, accidents and incidents can still transpire (Jang & Park, 2020). Nuclear power plants must adhere to rigorous safety protocols, maintain emergency preparedness, and provide ongoing training for personnel to ensure the secure operation of facilities. Regulatory frameworks must be in place to enforce safety standards and oversee compliance. Addressing safety concerns is pivotal for upholding public confidence and reducing potential risks of nuclear power generation.

2.3 Opportunity Analysis

The opportunities linked to nuclear energy in Indonesia underscore the potential benefits and positive outcomes that can be realized. One of the significant opportunities for nuclear power plant implementation is the capability to fulfill the escalating energy demand sustainably. As economies flourish and populations expand, the need for electricity rises, as depicted in Figure 8.

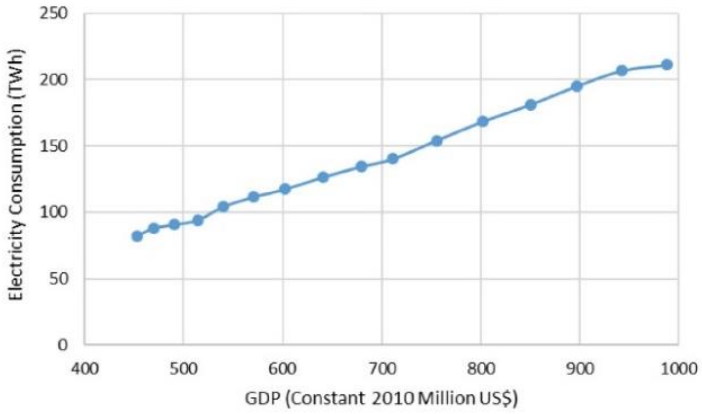

Figure 8. Indonesia's Electricity Consumption in Respect to GDP

Source: Susiati et al. (2022)

Nuclear power can offer a large-scale, continuous, and reliable electricity source, effectively addressing the escalating energy demands of a country like Indonesia. By diversifying the energy mix and integrating nuclear power into the generation capacity, Indonesia can ensure a stable and secure energy supply to bolster economic development. Nuclear power plants can also contribute to reducing carbon emissions, being regarded as a low-carbon energy source due to their lack of greenhouse gas emissions during electricity generation (Pata & Kartal, 2023). The implementation of nuclear power can aid Indonesia in reducing carbon emissions and combating climate change. By substituting fossil fuel-based power generation with nuclear energy, the nation can make substantial progress toward achieving emission reduction goals and aligning with international commitments such as the Paris Agreement. This transition would not only enhance the stability and sustainability of electricity but also reinforce environmental sustainability.

Nuclear power plants can offer high energy utilization efficiency. The energy density of nuclear fuel is significantly higher than conventional fossil fuels. Consequently, a small amount of nuclear fuel can generate substantial electricity over an extended period. This efficiency enables the optimal utilization of available resources, reduces fuel consumption, and minimizes waste generation. Nuclear energy plays a vital role in the global clean energy supply, functioning as a primary energy source and complementing and enabling other clean energy sources (Bragg-Sitton et al., 2020). There is an increasing necessity to approach energy resource utilization that maximizes effectiveness in meeting all energy needs.

The implementation of nuclear power plants presents opportunities for technological advancements and innovation. As the global nuclear industry continues to evolve, ongoing research and development efforts aim to enhance safety, efficiency, and sustainability in nuclear power generation. By embracing and adapting advanced reactor designs, such as Generation IV reactors (Locatelli et al., 2013), Indonesia can tap into the latest technological breakthroughs in the nuclear energy sector. It encompasses enhancements in reactor safety, waste management, energy utilization, and even the potential utilization of thorium-based reactors. Furthermore, this can facilitate technology transfer and knowledge-sharing among countries with well-established nuclear energy programs. This exchange of expertise holds the potential to contribute to the growth of Indonesia's nuclear industry and bolster local capabilities.

One of the significant opportunities for nuclear power plant implementation is the creation of new job opportunities across various sectors (Kenley et al., 2009). Development, construction, and operation

of nuclear power plants demand diverse skilled professionals, technicians, and support staff. Specific job opportunities from nuclear power plant implementation include engineering, construction, operation, maintenance, research, development, and safety positions.

2.4 Threats Analysis

The threats associated with nuclear energy in Indonesia identify the challenges and potential risks that must be mitigated. One of the primary threats to nuclear power plant implementation is competition from other alternative energy sources. The rapidly evolving renewable energy sector, such as solar and wind power, poses a challenge to expanding nuclear power. As different renewable energy resources advance in technology, there may be a shift in focus towards these alternatives, potentially reducing the demand for nuclear energy.

Secondly, nuclear power plant implementation is subject to geopolitical risks that can impact the availability of resources, technology, and expertise. The global nuclear industry heavily relies on international collaborations and transferring knowledge, materials, and equipment across borders (Palle, 2021). Geopolitical tensions, conflicts, trade restrictions, or changes in international agreements can disrupt the smooth flow of these resources and affect the progress of nuclear projects.

Public opposition and concerns about the safety, environmental impact, and nuclear waste management associated with nuclear power can pose significant threats to its implementation. Misinformation, lack of awareness, and fear of accidents or radiation leaks can lead to strong public opposition and protests against nuclear energy projects. This opposition can hinder the development of new plants, delay regulatory approvals, and create significant challenges in gaining social acceptance for nuclear power.

The potential impact of natural disasters on nuclear power plants is a significant threat that must be carefully considered. Indonesia is prone to earthquakes, tsunamis, and volcanic eruptions. While modern nuclear power plants incorporate stringent safety measures, including robust design features and multiple safety systems, extreme natural events can still pose risks to plant safety (Susiati et al., 2022). Ensuring that nuclear facilities are located in appropriate areas to mitigate the effects of potential natural disasters is crucial to addressing this threat.

Political instability and changing government priorities can threaten the implementation nuclear power plants. Nuclear energy projects require long-term planning, consistent policy support, and regulatory stability. Changes in government, shifts in energy policies, or the lack of a clear long-term commitment to nuclear energy can create uncertainties and deter investment in the sector (Neumann et al., 2020). Political stability and continuity in energy policies are essential to ensure nuclear power plants' successful implementation and operation.

2.5 IFE and EFE Matrix Analysis

To analyze the Internal Factor Evaluation (IFE) of the SWOT aspects related to internal strengths and weaknesses of nuclear power plants, ratings and weights will be assigned to each factor. The evaluation of the internal matrix pertains to how strong or weak each aspect is. The numbers range from 4 to 1, where 4 indicates a significant strength, 3 indicates a moderate strength, 2 indicates a minor weakness, and 1 indicates a significant weakness. Strengths are only given ratings of 3 and 4, while weaknesses are only given ratings of 2 and 1. Each key factor should also be assigned a weight from 0.0 (low importance) to 1.0 (high importance). This number signifies how crucial that factor is for ensuring the successful implementation of nuclear power plants in Indonesia. The assignment of weights and ratings, along with the calculations, is presented in Table 3.

Table 3. IFE Matrix

Component	Aspect	Weight	Rating	Score
Strength	Lower Operation and Maintenance Cost	0.1	4	0.4
	Skilled Workforce	0.05	3	0.15
	High Suitability Area	0.2	3	0.6
	Attractiveness to Foreign Investors	0.1	4	0.4
	Strong Government Support	0.15	3	0.45
Weakness	High Initial (Upfront) Investment	0.05	1	0.05
	Lack of Sociopolitical Acceptance	0.05	2	0.1
	Limited Power Infrastructure	0.1	1	0.1
	Nuclear Waste Management Challenges	0.1	2	0.2
	Potential Safety Concerns	0.1	2	0.2
Total		1.0		2.65

Similar to the Internal Factor Evaluation (IFE), the External Factor Evaluation (EFE) also involves analyzing ratings that range from 4 to 1. However, the assessment focuses more on the positive or negative impact of opportunities and threats the country may encounter while implementing nuclear power plants. In this context, a rating of 4 indicates an excellent effect, 3 signifies an above-average effect, 2 represents an average effect, and 1 indicates a poor effect. Opportunities are only assigned ratings of 3 and 4, while threats are exclusively given ratings of 2 and 1. Each key factor should also be assigned a weight ranging from 0.0 to 1.0. The assignment of weights and ratings, along with the subsequent calculations, is presented in Table 4.

Table 4. EFE Matrix

Component	Aspects	Weight	Rating	Score
Opportunities	Increasing Energy Demand	0.2	4	0.8
	Reduction in Carbon Emissions	0.15	4	0.6
	Maximization of Energy Utilization	0.2	4	0.2
	Technological Advancements	0.15	4	0.6
	Opening of New Jobs	0.1	3	0.3
Threats	Other Alternative Energy Sources	0.05	2	0.1
	Geopolitical Risks	0.05	1	0.05
	Public Opposition to Nuclear Power	0.05	2	0.1
	Natural Disasters	0.15	1	0.15
	Political Instability	0.05	2	0.1
Total		1.0		3.00

An IE matrix can be constructed to visualize the evaluated IFE and EFE better. On the x-axis of the IE matrix, the value of the IFE is 2.65, and on the y-axis, the value of the EFE is 3.00. The results of the IE matrix indicate that the implementation of nuclear power plants in Indonesia falls within quadrant II of the final IE matrix, as shown in Figure 9.

IE MATRIX		IFE		
		Strong	Average	Weak
		(4.0 - 3.0)	(3.0 - 2.0)	(2.0 - 1.0)
EFE	Strong (4.0 - 3.0)	I	II	III
	Average (3.0 - 2.0)	IV	V	VI
	Weak (2.0 - 1.0)	VII	VIII	IX

Figure 9. Final IE Matrix

The IFE score of 2.65 suggests that the impact of internal strengths and weaknesses on implementing nuclear power in Indonesia is moderately positive. It indicates the presence of notable strengths alongside areas of weakness that require attention. The score signifies room for improvement and further enhancement of internal factors. The EFE score of 3.0 implies that the external opportunities and threats related to nuclear power implementation in Indonesia have a positive influence. It suggests the availability of opportunities and potential threats demanding management and resolution. The score underscores external factors supporting nuclear power implementation alongside challenges that need thorough consideration. In ideal scenarios, these threats could potentially be surpassed by the benefits of opportunities. It underscores the need for strategic planning, investment, and stakeholder involvement to capitalize on strengths, address weaknesses, leverage opportunities, and mitigate threats to nuclear power implementation in Indonesia.

The initial steps to enhance the obtained IFE and EFE scores involve refining aspects with lower ratings. Regarding internal factors, the IFE score can be boosted by securing additional government support, such as enacting laws that favor nuclear power plant construction. Moreover, establishing electricity infrastructure before implementing nuclear power plants can ensure grid reliability and stability. Concerning external factors, elevating the EFE score can be achieved by collaborating with alternative energy sources and transforming threats into new opportunities. Additionally, public education is crucial to counter opposition towards nuclear energy usage.

2.6 TOWS Analysis

To create a more streamlined approach, one can undertake a TOWS analysis. Engaging in a TOWS analysis offers a holistic grasp of the internal and external factors linked to the introduction of nuclear power plants in Indonesia. It facilitates the identification of strategic alternatives for policymakers, stakeholders, and industry participants, encompassing weakness rectification, strength utilization, opportunity exploitation, and threat alleviation. The analysis is a foundation for devising impactful strategies and policies to foster Indonesia's prosperous and sustainable integration of nuclear energy. The TOWS analysis for implementing nuclear power plants in Indonesia follows.

Table 5. TOWS Matrix

Strengths-Opportunities (SO) Strategies: • Leverage the advantage of lower operation and maintenance costs and a skilled workforce to optimize energy utilization and meet the growing demand. • Capitalize in the high suitability area and foreign investment potential to drive advancements in nuclear technology, thereby reducing carbon emissions. • Exploit strong government support and the creation of new jobs to promote nuclear energy as a solution to energy demand while fostering economic growth.	**Weaknesses-Opportunities (WO) Strategies:** • Address the high initial investment by seeking foreign investments and partnerships to alleviate financial burdens and facilitate technological progress. • Overcome challenges related to sociopolitical acceptance and limited power infrastructure by emphasizing nuclear energy's benefits in reducing carbon emissions and maximizing energy efficiency.
Strengths-Threats (ST) Strategies: • Mitigate potential safety concerns through rigorous safety measures, research, and development, highlighting nuclear energy's safety advantages over alternatives. • Utilize strong government support and a skilled workforce to manage geopolitical risks, public opposition, and concerns related to natural disasters through stringent regulations and safety protocols.	**Weaknesses-Threats (WT) Strategies:** • Develop comprehensive plans for nuclear waste management, incorporating technological innovations and international best practices to minimize environmental and safety risks. • Collaborate with alternative energy sources to explore hybrid solutions, mitigating geopolitical risks, public opposition, and political instability.

Table 5 presents the comprehensive TOWS matrix, serving as the foundational framework for devising strategies to implement nuclear power plants in Indonesia. This matrix encompasses the alignment of strengths and opportunities, weaknesses and opportunities, strengths and threats, and weaknesses and threats. It ensures the optimization of positive attributes and the mitigation of negative factors. Succinct elaborations of the provided solutions are detailed below.

Strengths-Opportunities (SO) Strategies:

a. Leveraging the lower operation and maintenance cost and skilled workforce to maximize energy utilization and meet the increasing energy demand:

b. By capitalizing on the cost efficiency of nuclear power plants' operations and maintenance, Indonesia can achieve cost-effective energy production, as demonstrated in the practices of the United States (Roth & Jamarillo, 2017). The country can harness its skilled workforce within the energy sector to optimize nuclear power plant operations, thus enhancing energy utilization. A pathway to achieving this is by enhancing the development of distinct professional standards recognized through national qualification frameworks to validate the acquired qualifications formally (Jafarinejad et al., 2021). This strategy empowers Indonesia to address escalating energy demands driven by economic expansion and population growth, thus ensuring a sustainable energy supply.

c. Capitalizing on the high suitability area and attractive foreign investment to drive technological advancements in nuclear energy and reduce carbon emissions:

d. Indonesia's highly-suited regions, such as coastal zones like West Kalimantan, can serve as ideal locations for constructing and operating nuclear power plants (Susiati et al., 2022), benefiting from favorable conditions for safety and efficiency. Foreign investments can be appealed through incentivizing policies and favorable investment environments, thereby nurturing progress in nuclear energy technology (Terlikowski et al., 2019). This strategy positions Indonesia to curtail carbon emissions by substituting fossil fuel-based power generation with nuclear power, aligning with its environmental sustainability commitments.

e. Utilizing strong government support and the opening of new jobs to promote nuclear energy as a solution to energy demand and create economic opportunities:

f. Strong government backing is pivotal in providing regulatory frameworks, policies, incentives, and long-term visions for advancing nuclear power while cultivating new employment avenues. Research indicates that adopting nuclear energy can foster job creation within the construction, operation, and maintenance of nuclear power plants, ultimately invigorating economic growth (Cho et al., 2021). This strategy positions nuclear energy as a pragmatic solution for meeting energy demands and concurrently generating socio-economic advantages.

Strengths-Threats (ST) Strategies:

a. Mitigating potential safety concerns through robust safety measures, research, and development, demonstrating the safety advantages of nuclear energy over alternative sources:

b. To effectively alleviate potential safety apprehensions tied to nuclear power, rigorous safety protocols, thorough risk assessments, and ongoing monitoring must be implemented. Concurrently, investment in research and development is crucial to enhance safety technologies, thereby bolstering the safety benefits of nuclear energy compared to other energy alternatives (Xu & Zhang, 2021). Facilitating transparent communication with the public and stakeholders is vital to amplify comprehension and confidence in nuclear power plants' safety measures and risk management.

c. Using strong government support and a skilled workforce to address geopolitical risks, public opposition, and concerns related to natural disasters by implementing stringent regulations and safety protocols:

d. Collaborative initiatives involving the government and international partners can effectively address geopolitical risks linked to importing nuclear technology and materials (Terlikowski et al., 2019). This collaborative effort can be supplemented by comprehensive communication campaigns and inclusive public consultations, facilitated through education and training, aimed at countering public opposition and cultivating trust in the safety and merits of nuclear power (Karfopoulos et al., 2015). Concurrently, stringent regulatory frameworks and safety protocols, guided by expert input, must be established to tackle concerns about natural disasters and ensure the resilience of nuclear power plants against such adversities.

Weaknesses-Opportunities (WO) Strategies:

a. Addressing the high initial investment by seeking foreign investments and partnerships to reduce the financial burden and promote technological advancements:

b. Indonesia can attract foreign investments and foster collaborations with international organizations or corporations to alleviate the challenges posed by the high initial investment. These partnerships can secure the requisite funding for constructing and operating nuclear power plants. Engaging with foreign entities brings expertise and technology transfer and alleviates financial strain on Indonesia's budget. This approach mirrors the successful case of South Korea, which, despite being a developing nation, effectively harnessed nuclear energy for power generation by engaging in strategic partnerships (Sung & Hong, 1999). Through such collaborations, Indonesia can surmount the financial hurdle of the substantial upfront investment required for nuclear power plants.

c. Overcoming the lack of sociopolitical acceptance and limited power infrastructure by emphasizing the benefits of nuclear energy in reducing carbon emissions and maximizing energy utilization:

d. Comprehensive public awareness campaigns and educational initiatives are essential to address the challenges stemming from societal acceptance and inadequate power infrastructure. Underlining nuclear energy's pivotal role in curbing carbon emissions and combating climate change can garner more comprehensive public support. A study across 27 nuclear energy-utilizing nations revealed that increased nuclear energy acceptance correlated with heightened perceived benefits and knowledge, lowering perceived risks (Wang & Kim, 2018). Concurrently, prioritizing investment in power infrastructure development can fortify the grid, ensuring seamless integration of nuclear power and consistent electricity supply. By effectively highlighting nuclear energy's advantages—such as its potential to optimize energy utilization and foster sustainable development—Indonesia can effectively surmount challenges related to public acceptance and infrastructure limitations.

Weaknesses-Threats (WT) Strategies:

a. Developing comprehensive plans for nuclear waste management, incorporating technological advancements and international best practices to minimize environmental and safety risks:

b. To effectively address nuclear waste management, Indonesia can invest in research and development to advance technologies for handling nuclear waste. Prioritizing recycling and reprocessing methods can minimize waste volume and enhance safety. Collaborating with experienced international organizations and countries in the realm of nuclear waste management is essential to adopting global best practices and ensuring adherence to international standards and regulations (Alwaeli & Mannheim, 2022). Through such concerted efforts, Indonesia can proactively mitigate potential environmental and safety risks linked to implementing nuclear power plants.

c. Collaborating with other alternative energy sources to explore hybrid energy solutions and mitigate geopolitical risks, public opposition, and political instability:

d. Indonesia can facilitate collaboration between nuclear power and other renewable sources like solar and wind energy to foster a resilient energy landscape. This approach aligns with the positive outcomes of the United States' comparable initiatives (Bragg-Sitton et al., 2020). Indonesia can diversify its energy portfolio by cultivating hybrid solutions, mitigating the vulnerabilities of relying solely on one energy source. Engaging stakeholders vested in alternative energy resources can help alleviate geopolitical risks and promote stability amid political fluctuations. Embracing hybrid nuclear-renewable systems bolsters energy security and enhances public acceptance (Suman, 2018).

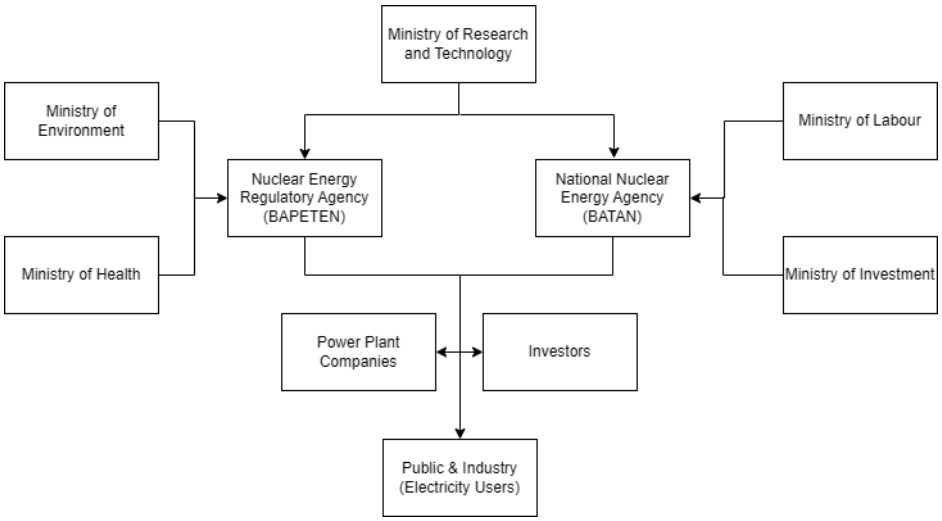

Figure 10. Proposed Stakeholders Structure

Collaboration among diverse stakeholders is paramount to ensure the successful implementation of nuclear power plants in Indonesia. An illustrative stakeholder structure is presented in Figure 10. By engaging and coordinating the efforts of government bodies, industry representatives, academic experts, investors, and the public, the challenges can be effectively addressed, risks mitigated, and the advantages of nuclear power plants maximized.

Conclusions

This research has assessed the feasibility of implementing nuclear power plants in Indonesia through a systematic literature review and comprehensive analysis. Based on the analysis, it is evident that the internal strengths and weaknesses of nuclear power implementation in Indonesia have a moderate positive impact. It suggests the presence of notable strengths alongside weaknesses that require attention. Additionally, the external opportunities and threats related to nuclear power implementation in Indonesia exhibit a positive impact. It implies that the opportunities available in implementing nuclear power plants can outweigh the associated threats.

By capitalizing on opportunities and addressing challenges, Indonesia can effectively realize the implementation of nuclear power, meeting energy demands, reducing carbon emissions, enhancing safety, and creating economic prospects. Strategies such as seeking foreign investments, accentuating the advantages of nuclear energy, formulating comprehensive waste management plans, and collaborating with alternative energy sources can ensure success and maximize the advantages of nuclear power implementation in Indonesia.

One limitation of this study stems from potential constraints in the availability and accuracy of data, particularly given that nuclear power plants have not yet been fully implemented in Indonesia. Additionally, restricted access to proprietary or classified information could be hampered by research accuracy and depth, leading to an incomplete understanding of complex factors. In addition, due to the rapidly changing nature of technology and geopolitical dynamics, the results may have a limited lifespan, requiring continual updating to remain relevant and applicable to the development context nuclear energy adoption in the country.

These limitations underscore the urgency for Indonesia to expedite research on the implementation of nuclear power plants. Future research topics concerning nuclear energy for power plants in Indonesia may encompass safety and risk assessment, human resource development, socio-economic impacts, energy planning, policy frameworks, environmental impact assessment, and perception assessment.

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