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Research Article

Analysis of the Investment Factors for the Replacement of Coal-Fired Power Plants Using Fuzzy AHP

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Abstract: *Indonesia aims to reach net zero emissions by 2060 during the 2021 United Nations Climate Change Conference (COP26). This study investigated factors that might affect the decision-making process in the investment of coal-fired power plant replacement: Political, Economic, Social, Technological, Environmental, and Legal (PESTEL) factors. The fuzzy analytical hierarchy process (AHP) method was utilized, and 10 Indonesian and Japanese experts with prior experience in the investment of coal-fired power plant replacement projects in Indonesia participated in this study for a month. Economic and legal feasibility were found to be the most affluent factors in the decision-making process to mitigate from coal-fired power plants. Furthermore, gas-fired power plant was found to be the optimal alternative to mitigate from coal-fired power plants. Referring to the Levelized Cost of Electricity (LCOE), it was revealed that a geothermal power plant was also a possible alternative; however, private companies might face difficulties in accessing geothermal power sources as the Indonesian government manages it. This study provides insight and alternatives to consider replacing the current dependency on coal-fired power plants and reaching full potential in low carbonization, decarbonization, and net zero emissions in Indonesia.*

Keywords: *Investment Decision-Making, Net Zero Emission, Coal-Fired Power Plant, Fuzzy Analytical Hierarchy Process, PESTEL.*

I. INTRODUCTION

The Republic of Indonesia (hereafter called "Indonesia") aims to reach net zero emissions by 2060 during the 2021 COP26 in Glasglow, UK (Cabinet Secretariat of The Republic of Indonesia, 2021). In 2022, the International Energy Agency (IEA) and the Ministry of Energy and Mineral Resources of Indonesia published "An Energy Sector Roadmap to Net Zero Emissions in the Republic of Indonesia". According to the roadmap, Indonesia has enormously relied on fossil fuels such as unabated coal, oil, and gas for power generation. Fossil fuel was accountable for 80% of Indonesian electricity generation capacity in 2021, and it was particularly dependent on unabated coal. Therefore, Indonesia plans to replace and utilize fossil fuel power generation with zero emission power generation through multiple pathways and alternatives that would require efficient decision-making.

Indonesia is the world's fourth most populous country (World Bank, 2022), and its economy is expected to grow after the coronavirus (COVID-19) due to a significant shift from commodity exports to domestic demand (Asia Development Bank, 2023). As of 2021, Indonesia contributes to around 600 million tons of CO2 emissions 2021 (IEA, 2021), which makes Indonesia the world's ninth largest CO2 emitter (European Commission, 2022). Furthermore, A previous study in 2007 suggested an adverse implication for economic growth due to climate change.

Khan et al. (2016) reported that companies that display better responsibility in sustainability issues tend to demonstrate superior future performance. Meanwhile, Friede et al. (2015) found that the positive impact of Environmental, Social, and Governance (ESG) factors on Corporate Financial Performance remains consistent over time. Therefore, it is essential to shift from fossil fuel power generation, especially coal-fired power plants, to a lower carbonization or decarbonization power generation to stimulate economic growth and increase companies' performance.

Indonesia aims to mitigate coal-fired power plants due to lack of support in funding from international public and commercial banks as the practice contributes to further climate crisis (IEA, 2021). Furthermore, Indonesian coal-fired power plants also face various difficulties: political restrictions, economic concerns, social pressure, and technological, environmental, and legal issues. These factors might also be referred to as Yuksel's Political, Economic, Social, Technological, Environmental, and Legal factors (PESTEL) (2012).

The study explores corporate decision-making factors to identify the optimal alternative options to decrease unabated coal dependency as a major power generation source. This study attempts to answer the following research questions:

- What are the factors that influence corporate decision-making for the investment in coal-fired power plant replacement?

- What is the optimal alternative option, which is the replacement coal-fired power plant?

This study offers insight into optimal alternative options for power generation resources to replace coal-fired power plants. This study developed the potential investment factors and used the fuzzy Analytical Hierarchy Process (AHP) to assess the importance and priority of each factor.

II. LITERATURE REVIEW

This study used the applications of the extent analysis method on fuzzy AHP (Chan, 1996), which differs from the AHP method (Saaty, 1997). The AHP method analyses qualitative criteria to find alternatives without considering possible uncertainties; meanwhile, Chan's extension of the fuzzy AHP method employs a hierarchical structure to solve decision-making problems that consider the uncertainty in decision-making, such as human thoughts and perceptions.

Data was collected in a month, 2023, through interviews. Interviews ended when the information had reached saturation point (Monique Hennink et al., 2022). A sample of 10 participants was selected through the convenience sampling method (Stratton, S., 2021) to develop hypotheses and objectives for use in more rigorous business cases. The samples included people with investment experience in coal-fired power plants, such as project owners, project developers, and employees at consulting and Engineering, Procurement, and Construction (EPC) firms.

III. RESULTS AND DISCUSSION

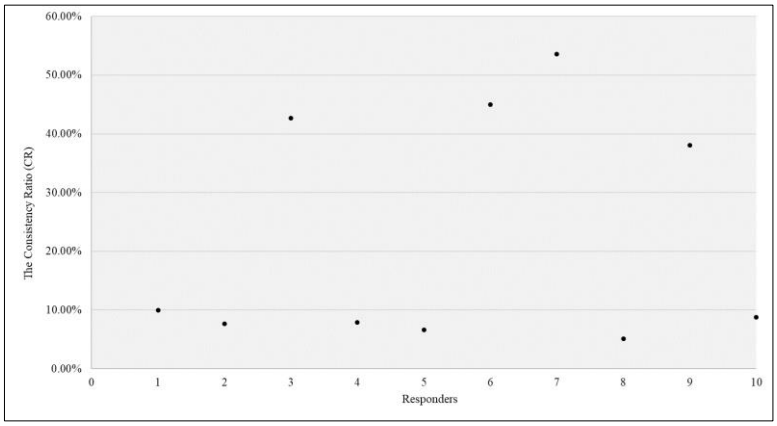

Figure 1: The Result of the Interviews with 10 Corporate Energy Experts

Figure 1 shows the data consistency of this study. 6 respondents were found to have a consistency ratio (CR) of less than or equal to 10%; thus, they were considered significant (Saaty, 1977). Thus, respondents with CR more than 10% were excluded from this study.

Table 1: The Result of Pairwise Comparison and Weights of Criteria Using Fuzzy AHP

Variable	Political	Economic	Social	Technological	Environmental	Legal
Political	-	.17	1,00	2.00	.33	.33
		.20	2.00	3.00	.50	.50
		.25	3.00	4.00	1.00	1.00
Economic	4.00	-	4.00	6.00	5.00	1,00
	5.00		5.00	7.00	6.00	2.00
	6.00		6.00	8.00	7.00	3.00
Social	.33	.17	-	1.00	1.00	1.00
	.50	.20		2.00	1.00	1.00
	1.00	.25		3.00	1.00	1.00
Technological	.25	.13	.33	-	.33	.20
	.33	.14	.50		.50	.25
	.50	.17	1.00		1.00	.33
Environmental	1.00	.14	1.00	2.00	-	.17
	2.00	.17	1.00	3.00		.20
	3.00	.20	1.00	4.00		.25
Legal	1.00	.33	2.00	3.00	4.00	-
	2.00	.50	3.00	4.00	5.00	
	3.00	1.00	4.00	5.00	6.00	

Si	.06	.26	.05	.03	.06	.14
(Fuzzy Synthetic	.11	.41	.08	.04	.11	.24
Extend)	.21	.64	.14	.08	.19	.42
W (Weights of Criteria)	.00	.67	.00	.00	.00	.33

Table 1 shows the pairwise comparison of each factor by fuzzy AHP. Economic feasibility was found to have the heaviest weight at .673, followed by legal feasibility. This study found that economic and legal feasibility were the most considered factors in deciding to invest in coal-fired power plant replacement. This finding might suggest that other factors, such as political, social, technological, and environmental factors, were overlooked in corporate decision-making.

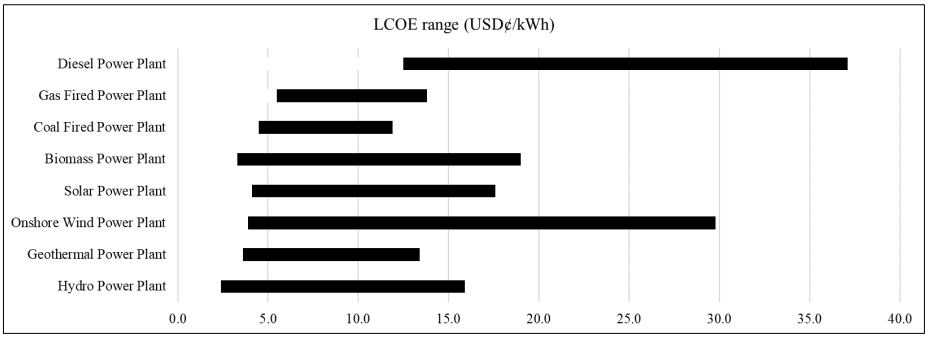

Figure 2: The Result of the Interviews with 10 Corporate Energy Experts

Figure 2 shows the LCOE in Indonesia by the Institute for Essential Services Reform (IESR) in 2023 (Muhammad et al., 2023). This study analyzed the economic feasibility of each type of power plant based on the LCOE. Figure 2 displays the LCOE's range in US$c/kWh for each type of power plant in Indonesia. It was found that coal-fired power plants had the lowest cost compared to other types of power plants. The result was followed by geothermal and gas-fired power plants.

Following this notion, this study then investigated the legal side of geothermal and gas power plants in Indonesia. However, in Indonesia, geothermal is considered a national asset that is controlled by the state and managed by the government in accordance with its authority (Law No. 21 of 2014, 2014). Therefore, private companies might face difficulties in accessing geothermal power sources. On the contrary, a gas-fired power plant might be a possible alternative to be implemented in Indonesia.

Several projects have started to generate electricity from gas-fired power plants in an effort to mitigate from coal-fired power plants all over the world, such as Japan (The Government of Japan, 2022) and the United States (US Energy Information Administration, 2020). This low carbonization effort was deemed realistic, with the goal of decarbonization and a net zero emission power plant in the near future utilizing hydrogen, ammonia, and carbon capture storage (CCS).

To further understand the economic impact, this study presents a business case for converting coal-fired to gas-fired power plants. Economic feasibility was found to be the most considered factor in corporate decision-making for the investment to mitigate from coal-fired power plants. Therefore, private companies may utilize coal-fired power plants up to their lifetime to maximize profitability without any incremental cost of electricity.

Table 2: The cost comparison between Super Critical Coal Fired Power Plant and Gas Turbine Combined Cycle Power Plant

Description	Super Critical Coal Fired Power Plant	Gas Turbine Combined Cycle Power Plant
Capacity Factor	100,000 kWh	100,000 kWh
Availability Ratio	70%	70%
AEP (Annual Energy Production)	95%	95%
Capital Expenditure (CAPEX)	0.0242 US$/kWh	0.0248 US$/kWh
Operational Expenditure (OPEX)	0.0068 US$/kWh	0.0100 US$/kWh
Fuel Cost	0.0258 US$/kWh	0.0427 US$/kWh
Total cost per kWh	0.0568 US$/kWh	0.0775 US$/kWh
Lifetime	40 Years	40 Years
Lifecycle Cost	1,323,530,880 US$	1,805,874,000 US$
Average Annual Cost	33,088,272 US$	45,146,850 US$

Table 2 shows the cost comparison between coal-fired (supercritical) power plants and gas (turbine combined cycle) fired power plants. The capital expenditure (CAPEX), operational expenditure (OPEX), and fuel cost were referred from the Recommended LCOE Institute for Essential Services Reform (2023). The average annual cost of a gas (turbine combined cycle) fired power plant was 36% higher than coal (supercritical) fired power plant.

The increased cost of electricity was found to have an impact on the price of final products with 1.1% on average (Agency of Natural Resources and Energy in Japan, 2020). To minimize the price impact, private companies may employ lean construction to gas-fired power plant conversion to be able to set the final product price within an acceptable price range.

In addition, Indonesia introduced a carbon tax of US$ 2.09/ton of CO2 from coal-fired power plants in April 2022 (OJK, 2022), with an average of 0.985/kWh CO2 emission (Ministry of Economy, Trade and Industry Japan, 2015). Therefore, a 100MW coal-fired power plant may expect to pay a carbon tax as high as US$ 205.865. Thus, it might encourage private companies to mitigate from coal-fired power plants after their lifetime.

There are three limitations to this study. First, the sample was relatively small and not representative of all energy experts, especially in Indonesia. Second, the sample was collected from energy experts whose nationalities are Japanese and Indonesian. Third, the study was conducted in a relatively short period and might not be able to cover all possible issues in this subject. Further studies may benefit from larger research with more diverse participants.

IV. CONCLUSION

This study aims to provide coal-fired power plant alternatives to support Indonesia in its efforts to reach net-zero emissions. This study employed fuzzy AHP analysis to compare the importance of each factor that influences the decision-making in the investment of coal-fired power plant replacement: politics, economics, social, technological, environmental, and legal feasibility. Economic and legal feasibility were found to have more influence on the decision-making process compared to other factors.

This study referred to LCOE and regulations in Indonesia for economic and legal feasibility. It was found that a gas-fired power plant is the most feasible alternative to mitigate from coal-fired power plants. Gas-fired power plants were also noted as a realistic alternative by utilizing hydrogen and ammonia of CCS (Matsumoto, et al., 2022) to support Indonesia in reaching net zero carbon emissions and decarbonization.

Interest Conflicts

The authors declare that there is no conflict of interest concerning the publishing of this paper.

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