Using multi-criteria decision analysis for sustainability of combined cycle power generation indicators in Indonesia: An industrial perspective

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Abstract. Combined Cycle Gas Turbine Plant is one of the fossil fuel power generations that has become the priority of the fuel-switching program by the Indonesian government to reduce greenhouse gas emissions. Various indicators can be used to assess the sustainability of the power plant. However, the solution for each indicator is challenging to implement at once by the power industry. This paper presents the determination of important indicators from the industry stakeholder by using a multi-criteria decision analysis approach, which affects the sustainability of power plants. The result of this research shows that the environmental dimension has the most important scale value 0.6 of 1 compared to the social and economic dimension, and the primary elements that must be managed on environmental aspects are emissions related to the quality of the ecosystem. Our results can be used in assessing the sustainability of Combined Cycle (CC) Gas Turbines, especially in Indonesia.

1. Introduction
Sustainability is an issue that is currently considered essential in many countries [1]. Even in the energy sector, the concept of sustainable development is an indicator that is highly recognized by policymakers [2]. The idea of sustainable development is mostly taken from the definition of the Brundtland report in a publication entitled Our Common Future, which is “the development that meets current needs without reducing the ability of future generations to meet their own needs” [1,3]. Energy is needed for survival, a reliable and inexpensive electricity supply is crucial for the economic development of any country, and the welfare of its population [3,4]. Energy demand continues to increase due to the increasing population and industrial development that occurs in the world [5]. However, most of the energy needs in the world are still met through fossil energy, even though renewable energy has been developed because the cost of renewable energy production is relatively more expensive compared to fossil energy [4]. Indonesia’s fossil energy use in 2015 for the power generation sector shows 93.8% using fossil energy. The use of fossil energy in Indonesia consists of coal 28.7%, petroleum 43.0%, and natural gas 22.0%, and the remaining 6.2% use renewable energy [6]. The government is targeting the final energy mix with a share of renewable energy by 23%, meaning that the other 77% is fossil energy [7]. The high use of fuel will harm the environment [5]. So it is essential to develop greenhouse gas (GHG) mitigation and the other environmental impact strategies for the energy sector [8]. The key to sustainability and knowing the usefulness of using electricity is to consider economic, ecological, and social aspects [1,2,4].
Combined Cycle Power Generation is a generator that is considered to have the best efficiency among other thermal plants and has the smallest emissions from other fossil plants. However, CC power plants have higher production costs. Especially when compared to coal, this is undoubtedly a consideration for policyholders in determining which plants will be operated [9]. There are risks both economically, socially, and environmentally that will affect the sustainability of the plant. So that sustainability studies need to be carried out to evaluate and determine policy strategies that can encourage and improve the sustainability of generators, one of which is by implementing life cycle assessments combined with decision-making tools such as Multi-Criteria Decision Analysis. The life cycle approach has been recognized and used globally to know the cycle of a product or service more comprehensively so that policyholders can determine how policies can be taken to maintain the sustainability of products or services [10,11].

However, for developing countries, the use of the life cycle approach is still rarely used [12]. Besides, there has not been much integrated and multidisciplinary research from economic, environmental, and social aspects for sustainability assessment, which can be used as a standard foundation with a life cycle approach [2,12]. At present, various indicators can be used to assess sustainability. Nevertheless, the solution for each indicator is challenging to implement at once. Moreover, these indicators cause additional costs in handling. So we need weighting for each indicator so that policyholders can be taken by prioritizing the primary indicators that are considered the most important.

This study aims to determine the priority indicators and critical aspects that are considered the most influential in sustainability according to stakeholder views. Then by using the multi-criteria decision analysis method, the level of importance of the indicator is determined, which is the most influential in the sustainability of the power plant life cycle. Thus, policyholders can assess management priorities in the life cycle of a power plant.

2. Materials and Method

The method used in this research is the multi-criteria decision analysis (MCDA) method. The MCDA method used in this study is the Analytic Hierarchy Process (AHP) because AHP has more literature than the other methods and is considered the most powerful among the other MCDA methods [13]. MCDA is a method that can be combined with the Life Cycle Assessment method to determine and evaluate the level of sustainability. MCDA itself consists of several ways that can be used, including Simple Additive Weighting Method (SAW), ARAS, COPRAS, MAUT, PROMETHEE, VIKOR, Delphi, Weighted Product Model (WPM); Electre; Technique for Order Preference by Similarity to Ideal Solution (TOPSIS); Analytic Hierarchy Process (AHP) [13–15].

In this study, the sub-method used is AHP, where AHP is a participatory method. Then the researcher determines the aspects that will be assessed for their importance obtained through a deepening of the literature, then summarized into three main elements and downgraded to 10 derived issues. Then the stakeholders are asked to rate from that aspect the most important criteria. In this study, the stakeholders chosen represent the owner of the company, which consists of 4 executive officers with the positions of one General Manager, and three managers, respectively. Each of these executive officials has experience in the field of power generation 15 years or more. These executive officers are considered to know the business process of power generation more thoroughly and are considered experts in the field of power generation. Then the researcher discusses the aspects referred to by these experts and asks them to provide an assessment of each criterion on a Linkert scale and then transformed into a comparison matrix between criteria. The stages carried out in this study are illustrated in a flow chart, as shown in Figure 1. The Linkert scale definition is shown in Table 1.
Table 1. Numerical Rating for Verbal Judgement and Preference.

| Importance degree | Description                                      |
|-------------------|--------------------------------------------------|
| 1                 | As important as the others                      |
| 3                 | Little more important than the others           |
| 5                 | Obviously more important                        |
| 7                 | Very clearly more important                     |
| 9                 | Absolutely more importance                      |
| 2,4,6,8           | A grey area, when in doubt about the two areas  |

In Figure 1, the concept flow chart method will be carried out, namely determining the indicators that can be used to assess the sustainability of the production process. Then define in what areas these indicators will be applied. In this study, the determined indicators will be used to assess the electricity production process at the plant. Then sort out the signs that have been identified in each aspect, namely economic, social, and environmental. Then discover the primary indicators that will be used to assess sustainability using the AHP method. The first AHP assessment flow is to make a pair-wise comparison matrix that is comparing criteria at each level. Next is calculating the level of consistency. The value of persistence at all levels should not be less than 0.1; this low level of consistency shows a reasonable degree of homogeneity in the comparison estimates [16]. Main weights and sub-criteria are found, and then these weights are multiplied to see the final weights. Then the sub-criteria are compared with alternative programs such as business as usual, and sustainable development. However, in this study, alternative assessments were not carried out, only up to weighting criteria because the purpose of this study was to develop sustainability assessment criteria.

Figure 1. Decision support framework for energy system sustainability indicators [2].

3. Result and Discussion
3.1. Criteria Set
Based on the results of the literature study, researchers found many indicators used to evaluate the sustainability of the plant. Then adapted to obtain the indicators from previous studies shown in Figure 2. Environmental elements defined as indicators that cause environmental quality degradation or other impacts on environmental quality such as climate change, resource depletion, and emission. Social issues described as indicators that cause potential problems in the human and social system. The
economic element defined as indicators that cause potential problems in the financial system or corporate finance.

![Hierarchy criteria that can be used to assess the sustainability.](image)

**Figure 2.** Hierarchy criteria that can be used to assess the sustainability.

### 3.2. AHP Result

Table 1 shows the results of weighting and the consistency value of the ratios of each aspect. We validate our model by checking the consistency ratio (CR). The value of CR cannot be more than 0.1. If the CR value is more than 0.1, then the data is invalid, so a review needs to be done on the pair-wise comparison assessment. The CR value shows for criteria of environment, social, and economic are 0.02 and 0.01, respectively. Therefore, we accept the results of our model.

| Criteria      | Weight | CR    | Sub-Criteria                                      | Weight | Percentage (%) |
|---------------|--------|-------|--------------------------------------------------|--------|----------------|
| Environment   | 0.6    | 0     | Ecosystem Quality (Emissions)                    | 0.40   | 40             |
|               |        |       | Resource Depletion                               | 0.10   | 10             |
| Social        | 0.2    | 0.02  | Climate Change                                   | 0.10   | 10             |
|               |        |       | Health and Safety                                | 0.10   | 10             |
|               |        |       | Public Acceptability                             | 0.03   | 3              |
|               |        |       | Provision of employment                          | 0.04   | 4              |
|               |        |       | Employee welfare                                 | 0.03   | 3              |
| Economic      | 0.2    | 0.01  | Capital Cost                                     | 0.11   | 11             |
|               |        |       | Operation and Maintenance Cost                   | 0.05   | 5              |
|               |        |       | Fuel Cost                                        | 0.04   | 4              |

CR: Consistency Ratio

Based on the results of calculations using the AHP method obtained in Figure 3 that the environmental dimensions are the top priority affecting the sustainability of the plant with a scale 0.60 of 1. This result shows that the main focus of sustainability, according to the owner of the company, is the environmental aspect. Besides, environmental elements are very crucial because if it does not match to the regulation, it can result in the termination of the production process. Then the social and economic aspects show the same result, which is 0.20. This result indicates that the economic and social elements have the same scale of importance. This study shows different results from the case
study in Lithuania that the economic dimension has a higher importance weight than the environment [15]. Similar research has also been carried out in Pakistan, which shows that economic indicators have greater importance than the environment [14]. However, the results of the AHP are judgments from experts who may have different views and understandings from one region to another. This AHP result depends on the conditions in an area that can be influenced by existing policies and economic terms of a country [17].

Each aspect of sustainability is broken down into more detailed criteria that represent economic, social, and environmental aspects. In Figure 4, this study shows that the Ecosystem Quality (Emissions) criteria have the highest value, with a value of 0.40 of 1. Then followed by a capital cost of 0.11, then health and safety, resource depletion, climate change 0.10 each, while others have a value of less than 0.05. Table 2 shows the aspects of social criteria that are considered the most important are health and safety with a value of 0.10, then provision of employment 0.04, finally employee welfare and public acceptability with the same amount of 0.03. The environmental aspects that show the highest priority value is the quality of the ecosystem (emissions) 0.40, then resource depletion and climate change have the same priority value of 0.10. In the economic element, capital cost becomes the aspect with the highest priority value with a value of 0.11, then followed by operation and maintenance cost 0.05, and fuel cost 0.04.

Our result shows a simple but reliable and scientifically based MCDA approach to address the problem of managing electricity production. So that results are obtained that generally describe the industry's view of the sustainability of its business. Thus the industry can think of appropriate strategies to overcome the problem of sustainability.
The limitation of this research is that it does not involve all stakeholders in assessing indicators of the sustainability of the electricity production process in Combined Cycle Power Generation. However, the result can be interpreted to see how the viewpoint of industry stakeholders in the sustainability of power plants. Their viewpoint is fundamental to the debate about the indicators of the sustainability power plant. These results support the previous works, that expert criteria do not mean that the person must be a genius, smart, holding a doctorate, and so on, but rather referring to someone who understands the problem at hand, feels the effects of a problem, or has an interest in the problem [18]. In further analysis can be developed by involving other stakeholders such as employees, the local community, the government, and consumers so that the assessment of sustainability indicators can better accommodate the wishes of each stakeholder. In addition, the selected indicators are impact indicators that can be translated into more specific indicators.

4. Conclusion
Based on the results of this study, it can be concluded that the main components that affect sustainability, according to stakeholders from the power industry, are environmental aspects 0.60 and then social and economic that have an equal value 0.20. Then the primary elements that must be managed on environmental aspects are emissions related to the quality of the ecosystem. The main components in the social issues that must be managed are health and safety. The economic element that must be accomplished is the capital cost. Our results could be used for understanding the industrial perspective of the sustainability of the power plant. The next research should include other stakeholders to assess sustainability indicators.

Acknowledgment
This research is funded by the Grant of Indexed International Publication for Master Student (PUTI Q4) Universitas Indonesia 2020 with contract number: NKB-2575/UN2.RST/HKP.05.00/2020

References
[1] Atilgan B and Azapagic A 2016 An integrated life cycle sustainability assessment of electricity generation in Turkey Energy Policy 93 168–86
[2] Santoyo-Castelazo E and Azapagic A 2014 Sustainability assessment of energy systems: Integrating environmental, economic and social aspects J. Clean. Prod. 80 119–38
[3] WCED 1987 Report of the World Commission on Environment and Development: “Our Common Future”
[4] May J R and Brennan D J 2006 Sustainability assessment of Australian electricity generation Process Saf. Environ. Prot. 84 131–42
[5] Karapekmez A and Dincer I 2020 Comparative e fficiency and environmental impact assessments of a solar- assisted combined cycle with various fuels Appl. Therm. Eng. 164 114409
[6] ESDM 2016 Directorate General of New, Renewable Energy and Energy Conservation : “Statistik ebtke 2016”
[7] ESDM 2019 Ministry of Energy and Mineral Resources : Statistics Of Electricity In 2018 vol 32
[8] Turconi R, Boldrin A and Astrup T 2013 Life cycle assessment (LCA) of electricity generation technologies: Overview, comparability and limitations Renew. Sustain. Energy Rev. 28 555–65
[9] Chatzimouratidis A I and Pilavachi P A 2009 Technological, economic and sustainability evaluation of power plants using the Analytic Hierarchy Process Energy Policy 37 778–87
[10] Keller H, Rettenmaier N and Reinhardt G A 2015 Integrated life cycle sustainability assessment - A practical approach applied to biorefineries Appl. Energy 154 1072–81
[11] Guinee J B, Heijungs R, Huppes G, Zamagni A, Masoni P, Buonamici R, Ekvall T and Rydberg T 2011 Life Cycle Assessment: Past, Present, and Future Environ. Sci. Technol. 45 90–6
[12] Wiloso E I, Nazir N, Hanafi J, Siregar K, Harsono S S, Setiawan A A R, Muryanto, Romli M,
Utama N A, Shantiko B, Utomo J J H A, Sari A A, Saputra S Y and Fang K 2019 Life cycle assessment research and application in Indonesia *Int. J. Life Cycle Assess.* 24 386–96

[13] Sabaei D, Erkoyuncu J and Roy R 2015 A review of multi-criteria decision making methods for enhanced maintenance delivery *Procedia CIRP* 37 30–5

[14] Mirjat N H, Uqaili M A, Harijan K, Mustafa M W, Rahman M M and Khan M W A 2018 Multi-criteria analysis of electricity generation scenarios for sustainable energy planning in Pakistan *Energies* 11 1–33

[15] Sliogeriene J, Turskis Z and Streimikiene D 2013 Analysis and choice of energy generation technologies: The multiple criteria assessment on the case study of Lithuania *Energy Procedia* 32 11–20

[16] Saaty T L 1990 How to make a decision: The Analytic Hierarchy Process *Int. Ser. Oper. Res. Manag. Sci.* 48 9–26

[17] Ribeiro F, Ferreira P and Araújo M 2013 Evaluating future scenarios for the power generation sector using a Multi-Criteria Decision Analysis (MCDA) tool: The Portuguese case *Energy* 52 126–36

[18] Brojonegoro B and Permadi B 1992 “AHP” *Pusat Antar Universitas, Studi Ekonomi* (Jakarta: UI)