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DETERMINING THE KEY CRITERIA DEVELOPMENT OF RENEWABLE ENERGY IN INDONESIA USING A COMBINATION ISM AND AHP METHODS

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Abstract: Carbon emissions from fossil fuel use are of concern throughout the countries. Therefore, efforts are made to reduce these emissions through the development of renewable energy technologies that support sustainable energy in the future. The development of renewable energy technology is also one of the Indonesian government's concerns to provide electricity for the community and industry. However, there are various criteria and alternative renewable energy that inhibits the development of renewable energy in Indonesia. This paper aims to determine key criteria and the alternative of renewable energy suitable for development in Indonesia. The Interpretive Structural Modelling (ISM) method used to determine the key criteria and the Analytical Hierarchy Process (AHP) method determined the priority of choosing alternative types of renewable energy. Several experts used in this study to determine the key criteria and judging in pairs of each alternative. The result of the study indicates ISM method obtained the key criteria is the type of renewable energy (A9). Furthermore, the result from the ISM method then assessed using the AHP method. The result of the pairwise comparison test shows that the micro-hydro energy with factor weight is about 0.263 and becomes the first priority. This article still has limitations and requires a more detailed review to get more accurate results.

Keywords: Analytical Hierarchy Process, emission, fossil fuel, Interpretive Structural Modelling, renewable energy

Introduction

Reducing carbon emissions is an issue which has become a trending topic related to global warming in recent decades. This is related to the excessive use of fossil fuels in the energy sector. Thus, the efforts are made by all countries to participate in the reduction of carbon emissions. One is to develop and enhance innovation in terms of renewable energy technologies to support sustainable energy in the future (Grassi *et al.*, 2012; Muneer *et al.*, 2005). However, there are several factors that inhibit the use of renewable energy such as globalization of economic recession, trade disputes, falling of gas and oil prices, reduced support for renewable energy development in several states and Europe (REN21, 2014; Noh *et al.*, 2015). Thus, it raises concerns that there is no increase in the competitiveness of renewable energy and the possibility of halting investment in renewable energy industries (REN21, 2014; Noh *et al.*, 2015). On the other hand, some countries remain consistent in developing renewable energy as a source of power to reduce the gap between the use of renewable energy and fossil fuel-based energy.

As one of the developing countries, Indonesia uses high energy in order to meet the needs of society and industry (Hasan *et al.*, 2012). The overall total installed electrical capacity in Indonesia in 2011 of approximately 28.6 GW (Webb, 2014). Furthermore, the report also states that coal use is around 44%, 23% oil, 21% natural gas, hydropower and geothermal respectively 21% and 5%. The report is very interesting because it reveals that Indonesia has not been able to supply sufficient energy despite having reserves of fossil fuels and renewable energy capacity in large numbers. Thus only about 65% of the total population of Indonesia that has access to electricity.

Generally, the main energy source in Indonesia is fossil fuel such as oil, natural gas, and coal about 96%, while renewable energy such as heat energy and water energy about 4% (Arianti, 2009). Furthermore, the use of fossil fuels to generate energy leads to significant reductions in oil and gas reserves. The study conducted by Hasan *et al.* (2012) explains that Indonesia's estimated crude oil reserves are only about 23 years old and natural gas 52 years. Therefore, efforts should be made to develop renewable energy in relation to supporting the sustainability of economic development (Salim, 2000). Thus, the Indonesian government formulates policies in the form of regulations related to energy management in the Energy Act.

Utilization of alternative energy should be improved in Indonesia if considering the number of resources that potentially become a source of electricity. For example, the sun is one of the main sources of energy on earth. Many other energy derived from solar energy directly or indirectly (George, 2007). Directly, solar energy can be converted into electrical energy by Photovoltaic technology. In addition, wind energy is the air that moves due to differences in temperature (due to solar heat) and air pressure. Some areas experience differences in temperature and pressure is quite extreme, causing the movement of air that has the potential to be a source of wind energy (Babu & Arulmozhivarman, 2013).

Several preliminary studies have been carried out by researchers in terms of renewable energies, such as Mardani et al. (2016) that evaluate energy-saving technologies, planning power supplies in remote areas (Rojas & Yusta, 2014; Mourmouris & Potolias, 2013; Mizanur *et al.*, 2013), use of micro-grid and renewable energy (Naveed *et al.*, 2017), solar energy use policy (Popiolek & Thais, 2016) and hydroelectric energy projects (Gul, 2014). On the other hand, renewable energy research in Indonesia has not been fully explored by researchers.

However, there are several studies on renewable energy in Indonesia such as the potential of solar energy in Indonesia (Handayani & Ariyanti, 2012), energy from biomass (Abdullah, 2003), renewable energy learning curve (Nugroho *et al.*, 2017), energy and sustainability scenarios in Indonesia (Hasan *et al.*, 2012), scenarios to secure energy demand (Mujiyanto & Tiess, 2013), challenges and renewable energy policies (Dutu, 2016). Thus, research to develop renewable energy is more challenging than fossil energy. One of the causes of this is the existence of problems and obstacles in determining the key factors and strategies in the process of choosing the types and technologies of renewable energy in accordance with the characteristics of Indonesia. Thus, this study will fill the previous research gap to explore the determination of key factors and the determination of the weight of renewable energy priority alternatives in Indonesia.

Materials and Methods

Primary data collection is conducted in various ways such as field observation, brainstorming and interviews with 3 experts such as, government, companies, and academics. Questionnaire method is conducted by giving a list of questions (questionnaire). In addition, secondary data were obtained from various literature sources and documents related to the study. Data analysis using Interpretative Structural Modeling (ISM) method developed by Saxena *et al.* (1992). Technical Data of Interpretative Structural Modeling is a collection of expert opinions as a panelist when answering the interrelationships between elements. ISM analyzes system elements and breaks them in graphical form of direct relationships between citeria and hierarchy levels. The criteria can be policy goals, organizational targets, assessment factors and others. Direct relationships can be in diverse contexts.

Generally, ISM techniques are divided into two parts, such as: element classification and hierarchical compilation. The first step that needs to be done in the ISM analysis is to determine the elements that match the problem. Sub-elements are then compiled on each selected element. The selection of elements and the preparation of sub-elements is done from the discussion with the expert. The results of the assessment are arranged in Structural Self Interaction Matrix

(SSIM) created in the form of Reachability Matrix (RM) table by replacing V, A, X, O into numbers 1 and 0. The element classification is based on Structural Self Interaction Matrix (SSIM) VAXO system:

V if e_{ij} = 1 and e_{ij} = 0;
A if e_{ij} = 0 and e_{ij} = 1;
X if e_{ij} = 1 and e_{ij} = 1;
O if e_{ij} = 0 and e_{ij} = 0

The matrix is then converted to a closed matrix. This is done to correct the matrix fulfilling the transitivity principle that if A affects B and B affects C, then A must affect C. Value 1 means there is a contextual relationship between the i element and the j element, whereas e_{ij} = 0 means there is no contextual relationship between the i element and the j element. Next, SSIM is converted to reachability matrix by converting VAXO to 1 and 0, then testing the transitivity rule, until a closed matrix occurs. Transivity matrix has fulfilled its processing continued to obtain reachability matrix, to obtain Driver Power (DP) and dependence (D). The last stage is to group sub-elements into 4 sectors (Mandal & Deshmukh, 1994):

a. Weak driver - weak Dependent variables (AUTONOMOUS), the variables in this sector are generally unrelated to the system, the relationship is minimal.
b. Weak driver strongly - Dependent variables (DEPENDENT), the variables that enter into this group are non-free variables,
c. Strong drivers - strongly dependent variables (LINKAGE), the variables in this sector should be studied carefully because their interactions can have an impact and feedback on the system
d. Strong driver - weak Dependent variables (INDEPENDENT) variables in this sector have a strong influence in the system and greatly determine the success of the program.

Once the key criteria are determined, the alternatives are made for the type of renewable energy. The results of the ISM method will use as the objective criteria to provide an assessment of alternative renewable energy. The selection of alternative renewable energy types is performed by using Analytic Hierarchy Process (AHP) method.

The AHP decision-making method developed by Saaty has helped solve problems effectively and efficiently (Saaty, 1980; Saaty, 1986). This method is capable of solving decision-making problems that have complex criteria consisting of multiple or multiple criteria (Rimantho *et al.*, 2017). In principle, the application of AHP method is a pairwise comparison of each criterion, sub-criteria, and alternatives based on hierarchical structure. Thus, the stages of AHP method implementation can be done as follows:

Stage 1: Define the problem and detail the desired solution.

Stage 2: Develop a hierarchical structure created based on goal setting, criteria, sub-criteria, and alternatives. Usually, the structural hierarchy arrangement will be done from the perspective of the largest to the smallest.

Stage 3: Making pairwise matrices matched after the hierarchy structure of the problem. The purpose of pairwise comparisons is to obtain relative importance values on each criterion and sub-criteria. This assessment is performed at the same level or level in the hierarchical structure. Assessment is done by experts by giving numerical value 1-9 as the table 1.

Stage 4: Synthesizing data in a pairwise matrix to obtain the priority of each hierarchical criteria and sub-criteria.

Stage 5: Perform consistency test of priority that has been obtained

Stage 6: Repeat the above steps for each level of the hierarchy

Stage 7: Use a hierarchical composition to weigh priority vectors with the criteria weights and add up all priority values that have been weighted with priority values from the next lower level and so on. The result is a comprehensive priority vector for the lowest hierarchy level.

Stage 8: Evaluate consistency for the entire hierarchy by multiplying each consistency index with the priority of the relevant criterion and summing the result. These results are then divided by similar statements using a random consistency index (random) that corresponds to the dimensions of each matrix. The hierarchy consistency ratio should not be more than 10% if more than 10% then the process should be fixed.

Table 1: Pairwise comparison preferences scales on AHP

Level of importance	Definition	Explanation
1	Equally	Two criteria have equal importance
3	Moderately	Experience and judgment slightly importance one criteria over the other
5	Strongly	Experience and judgment strongly importance one criteria over the other
7	Very strongly	Experience and judgment very strongly importance one over the other
9	Extremely	One criteria is absolutely more important than the other at the highest confidence level
2,4,6,8	Intermediately	Provided in order to represent a compromise if there is any doubt between two preference votes
Reciprocals	Opposites	Used for inverse comparison

Source: Saaty and Vargas (2012)

Results and Discussion

The results of discussions with experts, stakeholders, and researchers in the field obtained by various criteria associated with the development of renewable energy in Indonesia. The criteria such as power generated, environmental impacts, the availability of land, availability of resources and distribution locations. The five criteria are then developed and obtained information on sub criteria such as effectiveness (A1), efficiency (A2), sufficient power (A3), resource stability (A4), conformity standard (A5), pollution (A6), hazard level (A7), environmental regulation (A8), types of power plant (A9), development regulation (A10), Lay out generator (A11), generator area (A12), resource availability (A13), resource regulation (A14), distance distribution (A15), distribution area range (A16), and availability of equipment (A17).

Questionnaire results from the key respondents then composed in the Structural Self Interaction Matrix (SSIM) matrix as the Table 2.

Table 2: Structural Matrix Self Interaction Matrix (SSIM)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17
A1																	XXXXXXXXXAAAVVVO
A2																	VXXAOOXAXXVOAAO
A3																	XVVVXVXVOOXAOOO
A4																	OXXAXXOOXXVOA
A5																	VVXXXAOXXOOX
A6																	XXXXOOAXOOX
A7																	XXXXAOOXOX
A8									X	X	X	X	X	X	V	O	O
A9										X	O	X	X	X	V	V	V

	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**
A10											A	X	X	X	A	X	V
A11												X	A	O	O	O	V
A12													O	O	X	X	X
A13														X	V	V	X
A14															O	O	O
A15																X	A
A16																	X
A17																	

Based on Table 2 of the matrix SSIM then created in the form of Reachability Matrix (RM) table by replacing V, A, X, O into numbers 1 and 0. Thus, the results obtained as table 3

Table 3: *Reachability Matrix* (RM)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	DP*	R**
A1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	0	13	3
A2	1	1	1	1	1	0	0	0	1	0	1	1	1	0	1	1	0	9	6
A3	1	0	1	1	1	1	1	1	1	1	0	0	1	0	0	0	0	10	5
A4	1	1	1	1	0	1	1	0	1	1	0	0	1	1	1	0	0	11	4
A5	1	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0	1	11	4
A6	1	1	1	1	0	1	1	1	1	1	0	0	0	1	0	0	1	11	4
A7	1	0	1	1	0	1	1	1	1	1	1	0	0	0	1	0	1	11	4
A8	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	13	3
A9	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	16	1
A10	1	1	0	1	1	1	1	1	1	1	0	1	1	1	0	1	1	14	2
A11	1	1	0	0	1	0	1	1	0	1	1	1	0	0	0	0	1	9	6
A12	1	1	0	0	0	0	1	1	1	1	1	1	0	0	1	1	1	11	4
A13	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	14	2
A14	0	0	1	1	1	1	0	1	1	1	0	0	1	1	0	0	0	9	6
A15	0	1	0	0	0	0	1	0	0	1	0	1	0	0	1	1	0	6	7
A16	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1	1	1	6	7
A17	0	0	1	1	1	1	1	0	0	0	0	1	1	0	1	1	1	9	6
Dep***	13	11	9	12	11	12	13	12	13	15	6	9	10	9	10	8	10		
Hrc****	2	4	6	3	4	3	2	3	2	1	8	6	5	6	5	7	5		

DP*: Driven Power; R**: Ranking; Dep***: Dependence; Hrc****: Hierarch

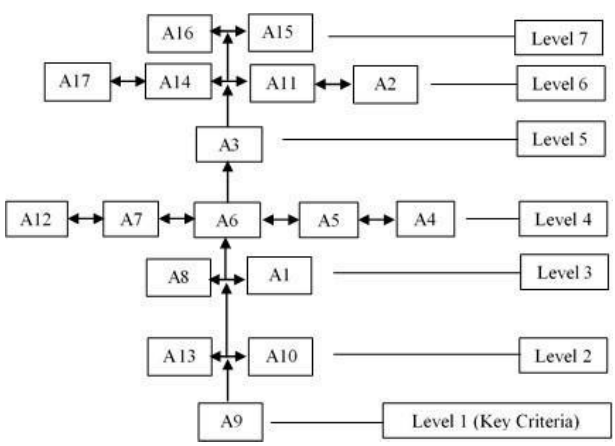

Figure 1: The hierarchical structure among the criteria of renewable energy development in Indonesia

Based on the interpretation of the final RM matrix above, it can be arranged a hierarchy of connectivity between factors determining the criteria of renewable energy development in Indonesia which can be explained in Figure 1.

Figure 1 shows that the type of power plant (A9) is the factor that has the highest driver power value. Thus, this criterion is the driving force that affects the success of other criteria such as resource availability (A13) and development regulation (A10). Furthermore, environmental regulation (A8) and Effectiveness (A1) will be the driving criteria for several criteria such as area generator (A12), hazard level (A7), pollution (A6), conformity standard (A5) and resource stability (A4). In addition, the distribution area range (A16) and distance distribution (A15) are criteria that have no effect on other criteria.

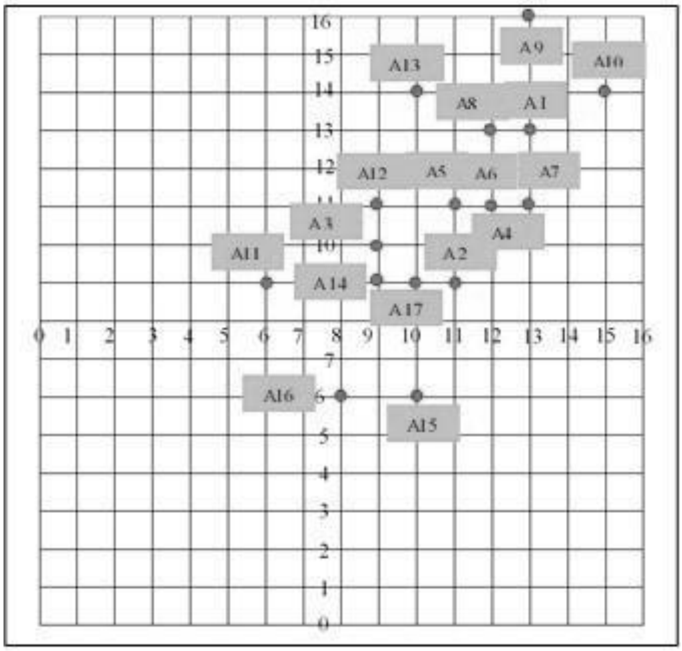

Figure 2: Driver-Power dependent matrix criteria

Figure 2 shows that the layout generator (A11) is the most independent criteria among other criteria. This means that this criterion is an independent of other criteria. Therefore, this criteria can be a trigger for other criteria such as distance distribution (A15) and Distribution area range (A16). The criteria included in the sector Linkage are needed to be examined carefully because of the relationship between these criteria are not stable. For instance, effectiveness (A1), Efficiency (A2), Sufficient power (A3), resource stability (A4), Conformity standard (A5), pollution (A6), hazard level (A7), environmental regulation (A8), type of power plant (A9), development regulation (A10), area generator (A12), resource availability (A13), and availability of equipment (A14)). In addition, according to low dependent value and high power driver value, it is known that the key criteria in developing renewable energy in Indonesia are the type of power plan (A9).

Furthermore, the criterion of the type of power plan (A9) is a goal that is expected to develop renewable energy types in Indonesia. Type of renewable energy alternative that can be implemented in Indonesia such as Geothermal Power Plant, Hydro Power Plant, Mini/Micro Hydro Power Plant, Solar Power Plant, Biomass Power Plant, Wind Power Generation, Marine Power Plant, waste to energy plant. Then created a hierarchical structure such as Figure 3.

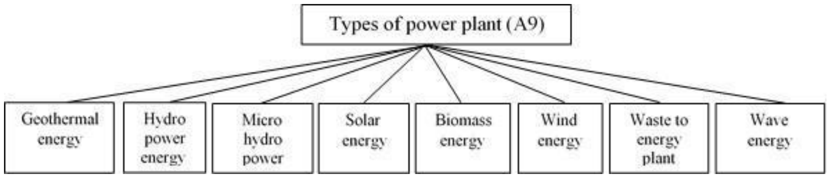

Figure 3: An alternative hierarchical structure in the development of renewable energy in Indonesia

The next step is to determine the alternative types of renewable energy that can potentially be developed in Indonesia. Based on the results of brainstorming with the experts obtained eight alternatives that can be an option such as geothermal energy, hydropower energy, micro hydropower, solar energy, biomass energy, wind energy, waste to energy, and wave to energy. In this step, each alternative is compared in pairs. Results of the assessment of the experts using AHP method stages indicate that alternative types of renewable energy have priority decisions as shown in Table 4.

Table 4 provides information related to the pairwise assessment by experts on several of alternative renewable energy that can be developed in Indonesia. Calculation of weights in the table refers to the eight stages of the AHP method as previously explained. Furthermore, the table also shows that hydro-micro energy has the highest weight of about 0.263 and the smallest weight is geothermal roughly 0.033. Thus, the first priority that can be an alternative development is micro-hydro energy. Furthermore, the next alternative priorities are biomass and wind energy. This is in accordance with the determination of key criteria that have been analyzed previously that this type of power plant will be affected by resource availability (A13) and development regulation (A10).

Table 4: The weight and priority of alternative types of renewable energy

Criteria	Weight	Ranking
Geothermal (GE)	0.033	8
Hydro power energy (HP)	0.046	7
Micro hydro (MH)	0.263	1
Solar energy (SE)	0.073	6
Biomass energy (BE)	0.168	2
Wind energy(WE)	0.159	3
Waste to energy (WTE)	0.123	5
Wave energy (WaE)	0.135	4

DP*: Driven Power; R**: Ranking; Dep***: Dependence; Hrc****: Hierarch

The Government of Indonesia has regulated the provision of electricity by developing regulations related to the business of providing electricity. Perusahaan Listrik Negara (PLN) as the Holder of Electricity Supply License (Minister of Energy and Mineral Resources No. 63412/20/600.3/2011 dated 30 September 2011) shall prepare the RUPTL Power Supply Plan (RUPTL). This planning must consider the provisions of the Decree of the Minister of Energy and Mineral Resources No. 2682.K /21/ MEM/2008 on the National Electricity General Plan 2008-2027 and the draft National Electricity General Plan 2015 to 2034 which has been prepared by the Ministry of Energy and Mineral Resources.

According to Indonesia's ministry of energy and mineral resources (2009) reported that there are around 88 hydropower plants with an installed capacity of 5 MW. In addition, the private sector also operates a smaller system. Hydroelectric energy options are supported by the availability of 8000 watersheds that are managed in 131 river basins (ADB, 2016). The total estimate of micro hydro in all regions of Indonesia is around 75 thousand MW (Erinofiardi *et al.,* 2017). However, the potential exploited is still approximately 9% in the form of micro hydro. Thus, the addition of cumulative capacity of approximately 20 MW in Eastern Indonesia, 21 MW in Java-Bali, 11 MW in Sumatera is one of the Indonesian government's strategies to use renewable energy. The study conducted by Erinofiardi *et al.* (2017) notes that the development of hydroelectric power in eastern Indonesia is roughly 13.9 MW.

Based on a report from Indonesia's national energy, it emphasizes that renewable energy sources contribute about 31% of the total energy mix in 2050 (Kencono *et al.,* 2015). Similar results were found in a study conducted by Erinofiardi *et al.* (2017) that hydropower is a renewable energy source and in accordance with the direction of Indonesia's national energy policy. This is because the type of micro-hydro energy source has a good efficiency between 60%-90%. Meanwhile, from the standpoint of economic analysis, several previous studies have suggested that it is highly dependent on two factors such as the location and capacity of a power plant (Erinofiardi *et al.,* 2017). The study of economic analysis related to micro-hydro cost about 400 thousand euros with a repayment time of about 6 years. Meanwhile, a total cost of approximately $ 700 per kilowatt is used for micro-hydro plants in Iran with an investment return of less than a year. Thus, it can be concluded that the micro-hydro potential has a better repayment period than other renewable energy types.

Compared to hydroelectric power, the use of wind energy in Indonesia is still low, with a total installed power plant of about 1.6 MW (Martosaputro & Murti, 2014). Wind power applications are generally used for isolated areas in remote areas. Most of the wind energy is used as the development of the research project. In addition, a wind turbine in Sukabumi-West Java and Selayar-South Sulawesi is installed with a capacity of about 100 kW. In addition, the total installed capacity in Nusa Penida-Bali is around 735 kW. Meanwhile in the area of Sangihe-North Sulawesi has an installed capacity of about 240 kW (Soeripno, 2009). The Government of Indonesia has regulated the provision of electricity by developing regulations related to the business of providing electricity. Perusahaan Listrik Negara (PLN) as the Holder of Electricity Supply License (Minister of Energy and Mineral Resources No. 63412/20/600.3/2011 dated 30 September 2011) shall prepare the RUPTL Power Supply Plan (R UPTL). This planning must consider the provisions of the Decree of the Minister of Energy and Mineral Resources No. 2682K/21/MEM/2008 on the National Electricity General Plan 2008-2027 and the draft National Electricity General Plan 2015-2034 which has been prepared by the Ministry of Energy and Mineral Resources.

RUPTL was developed to provide guidance in the development of vehicle electrification efforts PLN in the period of 2015-2024. In addition, it will be used in the preparation of long-term plans for PLN and the preparation of annual work plans and budgets. Furthermore, the business area of PLN covers the entire territory of the Republic of Indonesia except as stipulated by the Government as a business area for several stakeholders. The RUPTL will be periodically evaluated and amended as necessary. Thus, that the development plan of the electrical system is more appropriate to the current conditions. In addition, this RUPTL also outlines the development program of approximately 35,000 MW of electricity for the period 2015 to 2019 which has been amended to 10,000 MW. In order to succeed the development of electricity facilities, effective cooperation between PT PLN (Persero) and all stakeholders is required. This is because PLN itself will not be able to implement the whole program without the help of government, community and other stakeholders.

In this RUPTL role of private power is expected to increase significantly to encourage and accelerate the programs mentioned above.

The private sector's role will increase from 15% to 32% by 2019, and 41% by 2024. There are several issues that should also be of concern in the development of renewable energy by private parties, such as the increase in PLN's finances and timeliness of implementation. In addition, the role of the Government in shortening the licensing process will greatly help PLN and private power developers to realize the renewable energy development program in Indonesia.

Conclusion

The results of the key factor and selection of renewable energy alternative in Indonesia, using ISM and AHP method can be concluded that there are five main criteria and seventeen sub-criteria. Furthermore, the criteria includes power generated, environmental impacts, the availability of land, availability of resources and distribution locations. Additionally, the required criteria are seventeen such as effectiveness (A1), efficiency (A2), sufficient power (A3), resource stability (A4), conformity standard (A5), pollution (A6), hazard level (A7), environmental regulation (A8), types of power plant (A9), development regulation (A10), lay out generator (A11), generator area (A12), resource availability (A13), resource regulation (A14), distance distribution (A15), distribution area range (A16), and availability of equipment (A17). The determination of the key criteria of sub-criteria for the development of renewable energy in Indonesia using the Interpretive Structural Modeling method shows the sub-criteria of types of the power plant as the key sub-criteria. In addition, the analysis also shows that a micro-hydro energy has the greatest weight and become the first priority in the decision process of the selection of alternative types of energy that can be developed in Indonesia. The results of this research still have limitations and need to be examined in more detail to get a more accurate result to complement this study in relation to renewable energy development in Indonesia.

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