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Analysis of Renewable Energy Sources and Technologies for Rural Electrification in Indonesia using AHP

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Analysis of Renewable Energy Sources and Technologies for Rural Electrification in Indonesia using AHP

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Abstract

Indonesia as an archipelago country faces many difficulties in providing electricity to all needs and all areas. A significant number of villages in rural areas, remote areas and the isolated islands of Indonesia do not have electricity access. However, as Indonesia has abundant renewable energy sources, one of the solutions proposed by the Indonesian government to provide electricity in rural areas is by generating electricity using the renewable energy sources nearby. In order to find suitable renewable energy sources and technologies for rural electrification, some criteria to select the best or the most suitable are needed to be proposed and examined. This research aims to investigate the most important criteria and sub-criteria in selecting renewable energy sources and technologies for rural electrification in Indonesia as well as to analyze the most suitable ones.

Using Analysis Hierarchy Process (AHP), this research performed surveys to Indonesian government officials, the decision makers, to identify the most important ones among five criteria and eighteen sub-criteria suggested by literatures. AHP results suggested that energy source is the most important criterion in selecting renewable energy sources and technologies for rural electrification in Indonesia, followed by environmental, socio-political, technical and economic criteria. Also the availability of energy source was found to be the most important sub-criterion while profitability is the least important sub-criterion in global ranking.

This study also performed a survey to score the best renewable energy source for the North Maluku region. Among five renewable energy alternatives suggested by the government plans, results of the survey suggested that micro hydro is the most suitable renewable energy source and technology for rural electrification in Indonesia, followed by biomass, solar, geothermal and wind energy. Results of this study can be used as a basis for decision making processes of rural electrification of Indonesian government.

Keywords: rural electrification, electricity generation, renewable energy, Analysis Hierarchy Process (AHP)

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Chapter 1. Introduction

1.1 Research Motivation

As of the end of 2017, the electrification ratio in Indonesia is 95.35%, which is higher than the expectation targeted by the government at 92.75%. Those numbers are quite high, but the electrification ratio is not evenly distributed throughout the regions in Indonesia. There are still many regional areas that have low electrification ratio, such as Papua region and East Nusa Tenggara region with ratios of 61.42% and 59.85%, respectively.[1] The geographical nature of Indonesia, which has more than 17,000 islands, causes not only inequality of electrification ratios, but also difficulties in providing electricity to the entire nation. There are many villages in rural areas, remote areas, and border areas that are not covered by electricity access. Statistic Indonesia[2] reported that there were 12,659 villages lacking electricity access and 2,519 villages totally dark without any electricity access.

The Government of Indonesia (GOI) identified that one of the solutions for increasing electricity access in remote areas as yet with no electricity grid is renewable energy. This solution is being applied for rural electrification to maintain the sustainability of electricity by maximizing the utility of the nearest renewable energy source. By choosing renewable energy for rural

[1] Electrification ratio, data from Ministry of Energy and Mineral Resources 2018, https://www.esdm.go.id/assets/media/content/content-rasio-elektrifikasi.pdf
[2] Village Potential Survey 2014 (PODES 2014), Statistics Indonesia (BPS)

electrification, there will be an increase in the contribution of the renewable energy target of the total energy mix in Indonesia, which is targeted to be as high as 23% contribution by 2025.[3]

Renewable energy technology can be the right choice for rural electrification if it is well-planned. However, it can be the wrong choice if it is not well-planned, because it is expensive. Several criteria and sub-criteria need to be considered by policy makers or energy planners, as the final decision-makers in the renewable energy development for rural electrification, to ensure the successful project and plan.

A thorough qualitative and quantitative evaluation is, therefore, needed in order to find the most important criterion and sub-criterion in determining renewable energy source and technology for rural electrification. Once the evaluation is done, the most suitable renewable energy source and technology for rural electrification in Indonesia can be obtained.

1.2 Research Objectives and Focus

The objective of this study is to find the most important criteria and sub-criteria in developing renewable energy for rural electrification in Indonesia that should be considered by the decision-makers in the policy-making process and the renewable energy development plan. This study also aims to find suitable renewable energy for rural electrification based on renewable energy

[3] The contribution of renewable energy target in 2025 is 23%, as targeted in Government regulation no 79 of 2014 on the national energy policy

experts' perspectives.

The ranking and weight of the criteria and sub-criteria of renewable energy development will help the decision-makers in designing future renewable energy development plans. This study is important since Indonesia has a strong intention in building renewable energy power plants for rural electrification. Since renewable energy is expensive, much more investment is needed for developing in rural areas compared to developing in an urban area and building a fossil power plant. By using a renewable energy source in the nearest residential area, the fuel cost and the fuel transportation costs are not required. This shows that renewable energy has more economic value. Besides the economic aspect, sustainability of electricity is also a crucial aspect for rural electrification. The process of generating electricity from a renewable energy source is more sustainable since it does not use limited energy source, such as fossil fuel. In this research, other criteria will also be accounted in weighting and ranking the criteria and sub-criteria of renewable energy sources and technologies.

Indonesia has abundant renewable energy sources for electricity generation, such as geothermal energy, solar energy, hydro energy, wind energy, bioenergy, wave energy, and other renewable energy. Among these sources of energy, this research will select five types of renewable energy in a small-scale power plant for rural electrification.

Thus, this research aims to answer the following research questions:

1. What are the important criteria for selecting renewable energy sources and technologies for generating electricity in rural areas of Indonesia using the Analytic Hierarchy Process?
2. Which renewable energy source is the most suitable for generating electricity in rural areas of Indonesia? (Small-scale geothermal energy, solar photovoltaic, micro hydro power, wind power, or biomass?)

To answer the research questions, this study conducted extensive literature reviews and survey with energy and renewable energy experts in Indonesia as respondents. For the first question, Analytic Hierarchy Process (AHP) was implemented to calculate the weight and ranking of each criterion and sub-criterion. For the second question, the scoring of renewable energy options given by renewable energy experts will be used in deciding the most suitable energy source and technology for rural electrification in Indonesia.

1.3 Research Structure

This study is divided into six chapters with their own subchapters, as explained in Figure 1. Chapter One is the introduction of this study, which describes the research motivation, research objectives and focus as well as research structure. Chapter Two includes a long description of the research background, which describes electricity development, renewable energy potential, the rural electrification program in Indonesia and the renewable energy development plan. The next chapter, Chapter Three, explains the literature review, which covers multi-criteria decision analysis (MDMA), multi-criteria decision-making for the energy sector, analytic hierarchy process (AHP), previous studies and important criteria and sub-criteria in selecting suitable renewable energy for rural electrification in Indonesia. Chapter Four explains the methodology used in this study, including the methodological framework, AHP, and the survey. Chapter Five explains the empirical result of the study and discussion based on the result. The last chapter, Chapter Six, concludes the result of this study and evaluates its limitation for improvements in future works.

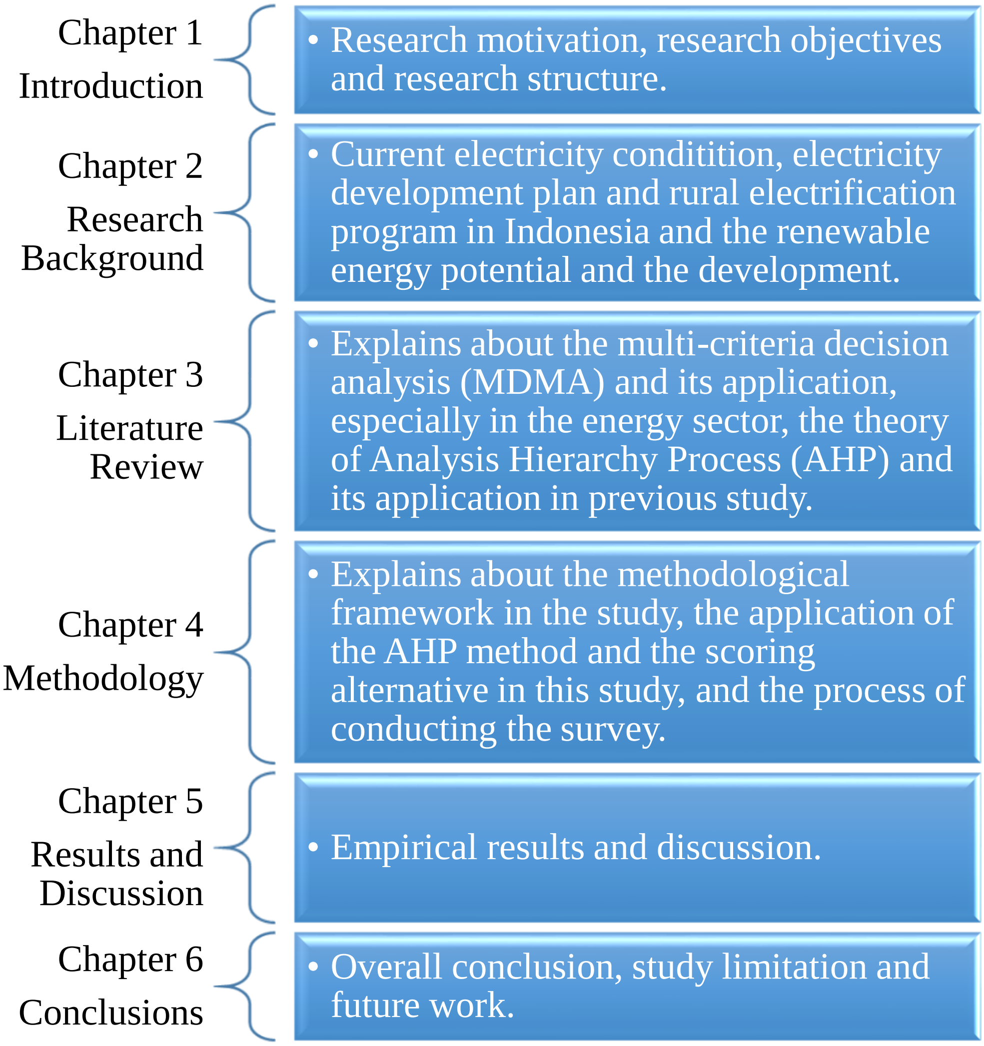

Figure 1. Structure of the thesis

Chapter 2. Research Background

2.1 Electricity Development in Indonesia

Indonesia is an archipelagos country with over 17,000 islands and with more than 250 million population. That makes Indonesia the fourth most populous country in the world. In economic condition, Indonesia is the largest economy in South East Asia and the world's 10th largest economy (Indonesia Overview, n.d.). Nowadays, electricity, as one of basic requirements that people need to perform their daily activities, has become an important factor to support economic growth. It means that, by providing electricity access to all the nation, it can have an effect on stimulating economic activity and will increase the economic level. Many previous researches have been done on finding the correlation of economic growth and electricity consumption in Indonesia and found that electricity and energy consumption and economic growth have a positive correlation (Maqin & Sidharta, 2017; Yoo & Kim, 2006). With that spirit, the Government of Indonesia (GOI) targeted to increase 7-8% of economic growth in 2019 by fulfilling electricity demand by around 6.86% by building more power plants and increasing the electrification ratio in following the electricity supply business plan (RUPTL) 2018-2027 scenario (RUPTL PT PLN (PERSERO) 2018-2027 Kebijakan Ketenagalistrikan, 2018).

2.1.1 Electricity Development Plan

The electricity development plan in Indonesia is mainly focused on supplying electricity demands, increasing ratio of electrification, and providing electricity access to the rural areas. In order to increase electrification ratio and fulfill electricity demand, the government has several plans. **The first government plan** is to increase power generation capacity. There are three major programs for increasing power generation in Indonesia, Fast Track Program (FTP) I, Fast Track Program (FTP) II and 35,000 MW program. In 2006, the government launched the first fast-track program, an initiative program aimed to accelerate electricity generation capacity with all power generations using coal-fired power plants. This program was supposed to build a 10GW power plant and be completed in five years. Before the first stage was completed, in 2010, the government launched the second stage of acceleration program, which is fast-track program II. In this program, power generations are dominated by renewable energy power plants. As with the previous program, FTP II was supposed to be finished in five years and build a 10GW power plant. As time passed, those two programs still had many projects left and could not be completed in the time given. In 2014, Indonesia launched the ambitious target to build a 35,000MW power plant. This program consists of a new power generation project and also the previous power generation projects, FTP I and FTP II, and is intended to be completed in 2019 *(Power in Indonesia: Investment and Taxation Guide*, 2017).

The second government plan is to increase the power transmission line, power distribution, and power substations. In the package of the 35,000MW program, the government targeted not only to build power generation but also build a 41,000KMS transmission line, 82,000MVA of power substations and 221,000KMS distribution lines by 2019. Based on the electricity supply business plan (RUPTL) 2018-2027, the government targeted to build more power transmission and distribution lines by 2027. The total target for power transmission increased to 63,855KMS, and target for distribution lines increased to 526,390KMS. Those numbers were increased to support in building Indonesia's national grid. To date, Indonesia only has one integrated electricity grid, Java-Bali, and is targeted to have other integrated electricity grids, namely, Sumatera electricity grid and the Kalimantan electricity grid, and to expand the Java-Bali grid into the Java-Bali-Nusa Tenggara electricity grid, Sulawesi electricity grid, Maluku electricity grid, and Papua electricity grid.

The third government plan is rural electrification. As mentioned in the first chapter, rural electrification has become one of the main focuses of electricity development plans in Indonesia. Indonesia is targeted to have 100% of villages in Indonesia having access to electricity bt the end of 2019. Several programs were launched to achieve the target. Further explanation for the rural electrification program in Indonesia will be explained in the next subchapter.

2.1.2 Indonesia's Energy Mix

Energy mix in electricity generation in Indonesia is still dominated by fossil energy, that is coal and gas, renewable energy only contributes a small percentage but is increasing year by year. The current renewable energy portion for generating electricity in Indonesia is 12.52% and consists of geothermal power plant, bioenergy power plant, solar power plant, micro hydro power plant and also wind turbine. The percentages of electricity generation with other fuels are 6% of diesel, 58.3% of coal and gas 23.2%. Based on National Energy Policy of Indonesia, the targeted renewable energy in the total energy mix for generating electricity in 2025 will be increased to coal 54.4%, gas 22.2% diesel 0.4% and renewable energy 23.0%, with the details of renewable energy targets being geothermal 8%, hydro, micro hydro, and pump storage 15%, and other renewable energy 4% (wind, biomass, solar) (RUPTL PT PLN (PERSERO) 2018-2027 Kebijakan Ketenagalistrikan, 2018).

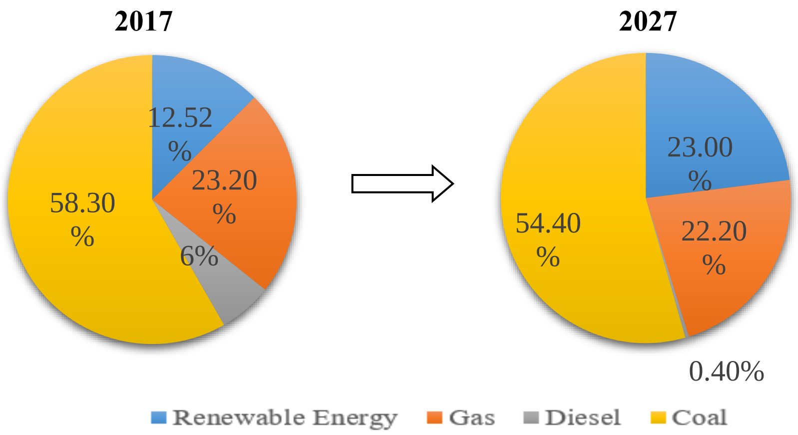

Figure 2. Energy mix for electricity generation in 2017 and target in 2027

The total installed capacity of power generation as of November 2017 is 54.5GW, more than half of which is generated by fossil-fuel power plants using coal and gas. Fossil fuel still dominates electricity generation because electricity prices generated using coal-fired power plants and gas power plants are still cheaper compared to electricity from renewable energy. Moreover, Indonesia still has large coal, oil, and gas reserves, although these are is declining. Data from British Petroleum Statistical Review in 2017 explained that oil reserves in Indonesia were 3,200 million barrels, accounted for 0.2% of the world's total reserves. Oil refining capacity is 1111 thousand barrels daily with total oil production of 949 thousand barrels per day. With minimum oil refinery capacity, oil production in Indonesia cannot meet the balance with oil consumption, which has reached 46,909 thousand barrels per day. In other fossil fuel types, the natural gas reserve is about 2.9 trillion cubic meters and contributes to the world's natural gas reserves with a total share of 1.5%. Natural gas production in 2017 was around 68 billion cubic meters with total natural gas consumption around 39,2 billion cubic meters. Moreover, for coal, the proven reserves are around 22,598 million tonnes and contribute to total proved world reserves with a total share of about 2.2%. Total coal production in 2017 was around 271.6 million tonnes oil equivalent with total consumption around 57.2 million tonnes oil equivalent, (British Petroleum, n.d.). Fossil fuel production is being used as domestic consumption and also for the export commodity; as mentioned before, oil consumption in Indonesia still higher than its consumption, some of the raw material, which is crude petroleum, is being exported and refined petroleum imported for domestic consumption. Production of coal and natural gas is still higher than its consumption, making those two items as the primary export commodity in Indonesia. (OEC - Indonesia (IDN) Exports, Imports, and Trade Partners, n.d.).

Based on Figure 2, the strategy of the Indonesian government is reducing fossil fuel energy for electricity generation and increasing renewable energy to change the portion of the energy mix in 2025. Indonesia has launched several programs relevant to the strategy, such as a new tariff policy for renewable energy's electricity prices, changing the composition of power generation in the Electricity Supply Business Plan and another program that supports in reducing fossil energy and increasing renewable energy.

2.2 Renewable Energy Potential and Technologies

Renewable energy has become one of the alternative energy sources which can replace fossil energy for generating electricity and heating. High dependence on fossil energy causes fossil energy resources to deplete year by year; consuming fossil energy also produces carbon emissions to the atmosphere that can lead to climate change. Renewable energy is a promising technology for generating electricity or heating and which is cleaner than fossil energy. Several campaigns have been designed to address reducing fossil energy and increasing renewable energy consumption to prevent the effect of climate change, one of them is the Paris Climate Agreement. Indonesia, as one of the countries which participated in the Paris Climate Agreement, pledged on the Intended Nationally Determined Contribution (INDC). Based on Indonesia's INDC (Republic of Indonesia, 2015), by 2030, Indonesia needs to reduce emissions by 29% through Indonesia's own efforts as business as usual and up to 41% with other countries' support. To fulfill the pledge, the GOI targeted on increasing renewable energy for generating electricity since Indonesia has abundant renewable energy sources. The total renewable energy resource in Indonesia is 441.7GW, which consists of hydro, micro/mini hydro potential 75GW, solar energy potential 207.8GWp, bioenergy potential including biomass and biofuel 32.6GW, wind energy potential 60.6GW, marine energy potential 17.9GW, and geothermal energy potential 28.5GW. From the total 441.7GW, only 9.07GW is being utilized for electricity generation. The next section will explain about the renewable energy potential and technology in that already developed in Indonesia, excluding marine energy, because this technology is counted as new technology in Indonesia and still under-studied.

2.2.1 Geothermal Energy

Indonesia is located in the "Pacific Ring of Fire" of volcano line, which means Indonesia has huge geothermal energy potential which can be used for electricity generation. According to the Ministry of Energy and Mineral Resources (MEMR), total geothermal energy potential in Indonesia is

28,508MW, 23.22% of the world's geothermal energy potential. From the total geothermal energy potential, 11GW is counted as a geothermal energy source, and the rest is geothermal energy reserves, with 17GW. All of the geothermal energy is spreads across 342 locations in 34 provinces of Indonesia, as explained in Table 1.

The first traditional exploration of geothermal energy began in the Dutch colonial era, in 1920, but modern geothermal exploration started in 1972 with exploration in Kamojang, West Java. The development of geothermal technology and utilization of geothermal energy potential in Indonesia has processed very slowly and faced many challenges and uncertainties. In building a geothermal energy power plant, it ideally needs need six years, starting from permission until forming a geothermal power plan to produce electricity and delivering to the customer. However, in reality, geothermal power plant construction needs more time because of permission problems and also the exploration stage. As of the end of 2017, Indonesia has built 12 geothermal energy projects with total installed capacity of 1808.5MW. In 2018, Indonesia targeted additional power capacity of 250MW, thus, at the end of 2018 total installed capacity for the geothermal energy power plant is 2058.5MW. If that is realized, Indonesia will become the country with the largest installed geothermal power plant in the world after the United States. Based on RUPTL, the government target of 8% of the total energy mix is from a geothermal power plant by 2027.

In producing electricity, geothermal power plants use four conversion techniques: direct steam plant, high-temperature system with vapor-dominated reservoir; flashed steam plants lower temperature system with water-dominated reservoir; binary system with low-temperature system; and a hybrid, combined system with more than two systems arranged in series or parallel combination. The technique of heat conversion best suitable for a geothermal power plants in the rural area of Indonesia is the binary system because it can produce electricity on a small-scale power generation. A completed project using the binary system in Indonesia is the Lahendong geothermal power plant with capacity of 550kW (National Energy Council, 2017).

2.2.2 Solar Energy

Indonesia is located in the center and crossed by the equator line, which means Indonesia has two seasons, dry and rainy, and gets maximum sunlight all year long. The geographic situation also means Indonesia has constant solar radiation, even though every place has a different amount. The average of annual solar energy received on the horizontal surface is approximately between 1500kWh per m2 and 2200kWh per m2. The best areas for solar radiation in Indonesia are Java, Bali, East, and West Nusa Tenggara and Maluku. Based on MEMR data, solar energy potential in Indonesia is the largest renewable energy potential compared with other renewable energy sources.

Total solar energy potential in Indonesia is 207.8GWp, with different potentials in every province in Indonesia, as explained in Table 2.

Table 1. Geothermal energy potential in Indonesia

No.	Island	Total Location	Potential of Geothermal Energy (MWe)					Installed
			Energy Source		Reserve			
			Speculative	Hypothetical	Possible	Probable	Proven	
1.	Sumatera	98	2817	1917	5065	930	917	452
2.	Java	73	1410	1689	3949	1373	1865	1,224
3.	Bali	6	70	22	122	110	30	-
4.	Nusa Tenggara	28	225	395	901	-	15	12.5
5.	Kalimantan	14	152	17	13	-	-	-
6.	Sulawesi	87	1308	325	1248	80	140	120
7.	Maluku	33	560	91	677	-	-	-
8.	Papua	3	75	-	-	-	-	-
Total		342	6617	4456	11.975	2.493	2.967	1.808,5
			11.073		17.435			

(Source: MEMR, Pengembangan Panas Bumi Indonesia, 2018)

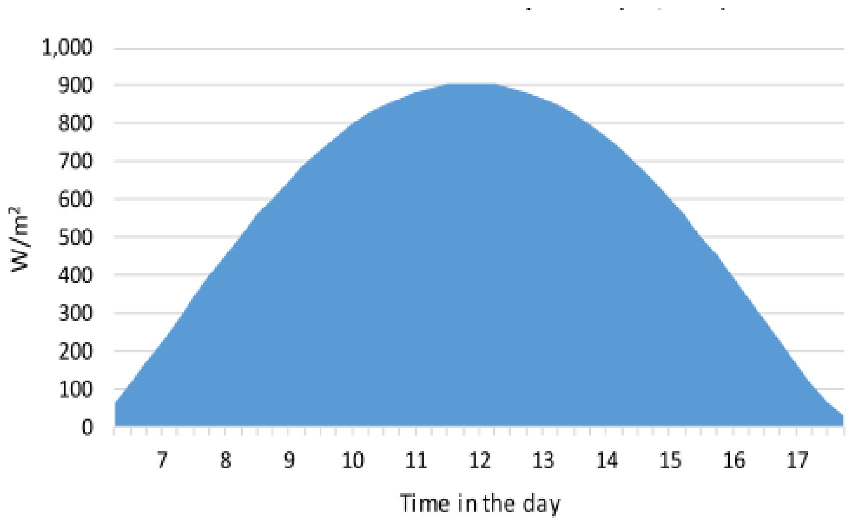

Figure 3. Characteristic of solar radiation in Indonesia

A solar energy power plant will produce electricity when the semiconductor is illuminated by sunlight and, through chemical reaction, sunlight will be converted into electrical current. Therefore, the important factor in that reaction is solar radiation; without it, a solar power plant cannot produce electricity. In Indonesia, solar radiation will be effective to produce electricity from 7 A.M to 5 P.M on a sunny day (see Figure 3) (National Energy Council, 2017). Other than those hours, to be able to supply electricity continuously it requires a solar power plant to be connected to an electricity grid or connected with energy storage, or connected with another power plant (hybrid), for example, with a diesel power plant. In Indonesia, to support electricity in a rural area with no grid nearby, the solar power plant is usually connected with an additional component, which is a battery, and in some areas, the solar power plant is connected in the hybrid system combined with diesel power plant to supply electricity at night.

Table 2. Solar Energy Potential in Indonesia

No.	Province	Potential (in Mw)
1.	West Kalimantan	20,113
2.	South Sumatera	17,233
3.	East Kalimantan	13,479
4.	North Sumatera	11,851
5.	East Java	10,335
6.	West Nusa Tenggara	9,931
7.	West Java	9,099
8.	Jambi	8,847
9.	Central Java	8,753
10.	Central Kalimantan	8,459
11.	Aceh	7,881
12.	Riau islands	7,763
13.	South Sulawesi	7,588
14.	East Nusa Tenggara	7,272
15.	West Papua	6,307
16.	Central Sulawesi	6,187
17.	South Kalimantan	6,031

No.	Province	Potential (in Mw)
18.	West Sumatera	5,898
19.	North Kalimantan	4,643
20.	Southeast Sulawesi	3,917
21.	Bengkulu	3,475
22.	North Maluku	3,036
23.	Bangka Belitung	2,810
24.	Banten	2,461
25.	Lampung	2,238
26.	North Sulawesi	2,113
27.	Papua	2,035
28.	Maluku	2,020
29.	West Sulawesi	1,677
30.	Bali	1,254
31.	Gorontalo	1,218
32.	Yogyakarta	996
33.	Riau	753
34.	Jakarta	225
Total		207,898

(Source: Buku Statistik, Ministry of Energy and Mineral Resources, 2016)

Based on MEMR data, as of the end of 2015, the installed capacity of a solar power plant in Indonesia built by an Independent Power Producer (IPP) is around 13MWp in six different locations. MEMR also built small solar power plants spread across areas of Indonesia with total capacity of around 21.5MWp in 494 different locations. In total, the installed capacity of solar power plants in Indonesia is 34.5MWp located in 500 different locations and different types of solar power plant, rooftop solar photovoltaic and concentrated photovoltaic with the majority being small solar photovoltaics (Statistik EBTKE 2016, 2016). One of the biggest concentrate solar power (CSP) connected to the electricity grid is Kupang solar power plant with total installed capacity of 5MWp. This power plant is the first IPP solar power plant in Indonesia.

The solar power plant has an advantage in construction time compared to other power plants because solar power plants can be built in a short time. In an ideal situation, a solar power plant can be used for 20 years without changing the photovoltaic panels, only changing the inverter every 10 years and changing the battery every 3-5 years if the system uses battery as an energy storage system (National Energy Council, 2017).

2.2.3 Wind Energy

Wind turbine is a technology that can convert kinetic energy to electrical energy. Starting with the wind hitting the blade, the rotor blade then transfers the energy to the drive shaft which can speed up or speed down the gearbox that is coupled with a generator to produce electricity. The wind turbine will operate in a cut in wind speed of around 3-4m/s until a high cut out of around 22-25m/s in onshore or around 23-30m/s in off-shore, with rated power of around 10-12m/s. Electricity production in wind turbine depends on wind speed: if wind speed increases, electricity production will be increased, and if the wind speed is decreased, electricity production will decrease. Since wind speed is a natural process, wind speed cannot be controlled; what can be controlled is blade pitch, the rotor of the wind turbine. By controlling blade pitch, constant electricity output will be produced (National Energy Council, 2017).

A wind turbine can be installed either onshore or offshore, the two types having different design construction and also specification. For example, offshore wind turbines are usually built with large turbines and in considerable large numbers, while onshore wind turbines are built in smaller turbines and fewer numbers than off-shore. In Indonesia, the total potential of wind energy in both onshore and offshore is around 60GW with the biggest potential being in East Nusa Tenggara.

Wind turbine development in Indonesia is increasingly advanced, in mid-2018, the President of the Republic Indonesia launched the first large wind turbine in Indonesia, located in Sidrap, South Sulawesi. Installed capacity of the Sidrap wind turbine is 75MW, consisting of 30 Gamesa turbines, with each turbine capacity of 2.5MW. At the end of 2018, a further big wind turbine was launched, namely the Tolo wind turbine, located in Jeneponto, South Sulawesi. The total installed capacity of the Tolo wind turbine is 72MW, consisting of 20 turbines with each turbine able to generate electricity as much as 3.6MW. Those two wind turbines are located in South Sulawesi and will connect to the South Sulawesi electricity grid (Kementerian ESDM Republik Indonesia, n.d.).

Table 3. Wind energy potential in Indonesia

No.	Province	Potential (in Mw)
1.	East Nusa Tenggara	10,188
2.	East Java	7,907
3.	West Java	7,036
4.	Central Java	5,213
5.	South Sulawesi	4,193
6.	Maluku	3,188
7.	West Nusa Tenggara	2,605
8.	Bangka Belitung	1,787
9.	Banten	1,753
10.	Bengkulu	1,513
11.	Southeast Sulawesi	1,414
12.	Papua	1,411
13.	North Sulawesi	1,214
14.	Lampung	1,137
15.	Yogyakarta	1,079
16.	Bali	1,019
17.	South Kalimantan	1,006

No.	Province	Potential (in Mw)
18.	Riau islands	922
19.	Central Sulawesi	908
20.	Aceh	894
21.	Central Kalimantan	681
22.	West Kalimantan	554
23.	West Sulawesi	514
24.	North Maluku	504
25.	West Papua	437
26.	West Sumatera	428
27.	North Sumatera	356
28.	South Sumatera	301
29.	East Kalimantan	212
30.	Gorontalo	137
31.	North Kalimantan	73
32.	Jambi	37
33.	Riau	22
34.	Jakarta	4
Total		60,647

(Source: Buku Statistik, Ministry of Energy and Mineral Resources, 2016)

2.2.4 Micro Hydro

Located in tropical forest, Indonesia has many rivers and small lake located in most areas of Indonesia. Moreover, Indonesia also has high rainfall potential, which can afford the rivers and small lakes a water supply. The rivers with enough water reserves which can be used for generating electricity with a hydro power plant. Total hydro energy potential Indonesia is around 75,000MW and is divided into large-scale hydro power plant potential, and small-scale hydro potential. The small-scale hydro power plant can be derived as a mini-hydro power plant with an installed capacity below 2MW, a micro hydro power plant with an installed capacity below 500KW, and pico hydro power plant with a capacity less than 10KW. The potential of a small-scale hydro power plant, either mini-hydro, micro hydro or pico hydro, is 19,385 GW; all of the small-scale hydro power plants can be used for rural electrification (Gokhale, Date, & Akbarzadeh, 2017).

Table 4. shows the total micro hydro power plant potential in Indonesia. From the start of 2014 until the end of 2015, Independent Power Producer (IPP) constructed micro hydro power plants in 41 different locations with total installed capacity of 134.21MW. From 2011 until the end of 2015, the Directorate General of New Renewable Energy and Energy Conservation (DGNREEC), as a government department, constructed 47 small-scale hydro power plants with installed capacity 3.36MW (Statistik EBTKE 2016, 2016).

Table 4. Mini/micro hydro energy potential in Indonesia

No.	Province	Potential (in Mw)	No.	Province	Potential (in Mw)
1.	East Kalimantan	3,562	17.	Riau	284
2.	Central Kalimantan	3,313	18.	Maluku	190
3.	Aceh	1,538	19.	South Kalimantan	158
4.	West Sumatera	1,353	20.	West Kalimantan	124
5.	North Sumatera	1,204	21.	Gorontalo	117
6.	East Java	1,142	22.	North Sulawesi	111
7.	Central Java	1,044	23.	Bengkulu	108
8.	North Kalimantan	943	24.	East Nusa Tenggara	95
9.	South Sulawesi	762	25.	Banten	72
10.	West Java	647	26.	West Nusa Tenggara	31
11.	Papua	315	27.	North Maluku	24
12.	South Sumatera	448	28.	Bali	15
13.	Jambi	447	29.	West Sulawesi	7
14.	Central Sulawesi	370	30.	Yogyakarta	5
15.	Lampung	352	31.	West Papua	3
16.	Southeast Sulawesi	301	Total		19,385

(Source: Buku Statistik, Ministry of Energy and Mineral Resources, 2016)

2.2.5 Bioenergy

Bioenergy is a renewable energy created from natural and biological sources, such as animal manure, food waste, palm oil mill effluent (POME), wood chips, sugar cane, coconut, paddy, and other crop products, and some modern technology uses municipal waste, solid and liquid waste from industry (Orloff, n.d.). Bioenergy technology can be categorized into biomass, biofuel, biogas, and municipal waste, and all of that can be used for generating electricity. In

Indonesia, biomass/biofuel energy potential is around 30GW, biogas potential is around 2.6GW, and accumulation of two bioenergy type is 32.6GW. Both IPP and the government have developed and build biomass, biogas, and municipal waste power plants in several areas of Indonesia with a total installed capacity of on-grid biomass, biogas, and municipal power plant of 119.6MW, which consists of 20 unit power plants in different locations. The installed capacity of the off-grid bioenergy power plant is 1,626MW. DGNREEC, as a government department, also participate in the built of bioenergy power plants with total installed capacity of 4.5MW (Statistik EBTKE 2016, 2016). Detailed information about biomass/biofuel and biogas potential in Indonesia is shown in Table 5 (Kuvarakul, Devi, Schweinfurth, Winarno, & Sikumbang, 2014).

Table 5. Bioenergy potential in Indonesia

No.	Province	Biomass/Biofuel	Biogas	Total
1.	Riau	4,157.4	37.7	4,195.1
2.	East Java	2,851.3	569.6	3,420.9
3.	North Sumatera	2,796.1	115.5	2,911.6
4.	West Java	1,979.8	574.3	2,554,1
5.	Central Java	1,884.1	348.4	2,232.5
6.	South Sumatera and Jambi	3,882.4	90.1	3,972.5
7	Central Kalimantan	1,486.7	12.2	1,498.9
8.	Lampung	1,407.6	84.5	1,492.1
9.	West/ South Kalimantan	2,524.6	52.5	2,598.1
10.	Aceh	1,136.6	37.7	1,174.3
11	East/North Kalimantan	946.6	17.7	964.3
12.	South/West Sulawesi	1088.1	77.2	1,165.3
13.	West Sumatera/Bengkulu	1,556.1	46.5	1,602.6
14.	Banten and Jakarta	347	244.7	591.7
15	West/East Nusa Tenggara	533.8	100.8	634.6
16.	Central Sulawesi	307.4	19.5	326.9
17	Yogyakarta	183.1	41.1	224.2
18.	Bangka Belitung	217.7	5.4	223.1
19.	Bali	146.9	44.7	191.6
20.	North/ Southeast Sulawesi	283	31.5	314.5
21.	Gorontalo	119.1	11.5	130.6
22.	Papua/West Papua	102.2	19.2	151.4
23	North Maluku	27.5	7.0	34.5
24.	Maluku	23.6	9.0	32.6
25.	Riau Islands	11.6	4.3	15.9
Total		30,051.2	2,602.6	32,653.8

(Source: Buku Statistik, Ministry of Energy and Mineral Resources, 2016)

2.3 Rural Electrification Program

One of the problems in electricity development in Indonesia is rural electrification. Many villages are located in the remote and outer area. This means those villages are still in the dark and it is difficult to provide electricity. Generating electricity to a rural area has two different approaches (Rahman, Paatero, & Lahdelma, 2013; The World Bank & The Energy and Mining Sector Board, 2008), establishing a grid extension from the main grid and building an off-grid electricity system separated from the main grid. For providing electricity in a rural area, Indonesia has created and implemented several programs, such as: “Listrik Perdesaan” (electricity for villages), “Listrik Murah Hemat”, “Program Indonesia Terang (Bright Indonesia), a regular program from DGNREEC, and the Lampu Tenaga Surya Hemat Energi (LTHSE)/energy efficient solar lamp.

“Listrik Perdesaan” (electricity for villages) is a program to enlarge electricity access to villages which are not covered by electricity by building a distribution line and using local energy potentials such as wind power, solar power or hydro power. “Listrik Murah Hemat” is a program for giving electricity access to people who live in a village in poor economic condition by installing simple electricity installation for the households with three lamps and one electricity socket. Those two programs were planned and budgeted by the Directorate General of Electricity (DGE) and built and installed by the State-owned electricity company (PLN). Started in 2013, the program contributed to provide electricity in villages and increase the electrification ratio in Indonesia. At the end of 2015, this program was discontinued due to the limitation of government budget (Direktorat Jenderal Ketenagalistrikan, 2013).

"Program Indonesia Terang" (Bright Indonesia) is a program designed for providing electricity to all villages in Indonesia. This program was launched in six provinces in the eastern part of Indonesia, Maluku, North Maluku, Papua, West Papua, East Nusa Tenggara, and West Nusa Tenggara, as a pilot project. The central government cooperates with local government and PLN are planning on providing electricity with three ways, expanding the electricity grid connection, building an off-grid electricity system using renewable energy and providing a solar home system for the scattered households. This program only existed in 2016 and the government canceled it when the Ministry changed (Program Indonesia Terang Dicanangkan - Kementerian ESDM Republik Indonesia, n.d.)

The regular program from DGNREEC purposes in building small-scale renewable energy power plants with government budget for a rural area. To date, this program has been carried out based on MEMR regulation number 39 for the year 2017 and mainly focuses on building small-scale renewable energy power plants to villages with no PLN grid access and villages without electricity. Running from 2011 until 2018, DGNREEC successfully built 50MW renewable energy power plants, such as solar power plant, micro hydro power plant, biogas power plant, biomass power plant and hybrid power plant, with a government budget (Kementerian ESDM Republik Indonesia, n.d.).

"Lampu Tenaga Surya Hemat Energi" (LTSHE)/energy efficient solar lamp program is a program from DGNREEC for providing electricity access to people who do not yet get electricity. DGNREEC targeted 293,532 households who live in the isolated area, outer area, and small islands. In this program, each household will have one set of LTSHE, consisting of a solar panel, Sehen lamp with battery, hub, and remote control (Kementerian ESDM Republik Indonesia, n.d.).

2.4 Renewable Energy Development

2.4.1 Challenges in Renewable Energy Development

Renewable energy development in Indonesia started a long time ago, but the percentage in energy mix is still small compared to fossil energy in the total energy mix. There are many difficulties and barriers to renewable energy development in Indonesia, and several reports and also research that have identified the barriers are described below:

- Grid connection barrier: Indonesia is not connected to one electricity grid connection, only Java and Bali Island are connected and there is the imitative grid connection of Sumatera island, Sulawesi island, Kalimantan island, and some small grid connections (International Renewable Energy Agency (IRENA), 2017).

- Off-grid electricity runs very slowly: the government mainly focuses on large-scale renewable energy project (International Renewable Energy Agency (IRENA), 2017; Kirari, Adel, Andria, & Lakaseru, 2018).
- Cost recovery for PLN: as the state-owned company responsible for providing electricity it began by building the power plants, electricity transmission, substation, and distribution. PLN also needs to buy electricity from the Independent Power Producer (IPP). If the price is higher than the electricity tariff, it means PLN needs to cover the price. Mostly, renewable energy is higher than the electricity tariff, so PLN needs to cover that price (International Renewable Energy Agency (IRENA), 2017).
- Project finance: renewable energy for generating electricity needs high financing cost, both for initial cost and also for operation and maintenance costs (Bridle et al., 2018).
- Land acquisition and community involvement: many renewable energy projects were delayed, and some canceled because of the land acquisition problem. Mostly, the problem happens to power plants which need large land area, such as Solar PV (Bridle et al., 2018; International Renewable Energy Agency (IRENA), 2017).
- Policy and regulation barrier: the regulation and policy in electricity development and renewable energy development changes very quickly; it

has an impact in a complicated process in power purchase agreement (PPA) or permission and permits (Bridle et al., 2018).

- Price and tariff: this becomes a problem of renewable energy deployment since renewable energy is an expensive technology; the electricity generated from renewable energy technology is still high (Bridle et al., 2018).
- Limited trusted data from the relevant authorities that provide information about rural population or rural development plan (Kirari et al., 2018)
- Lack of a specific rural electrification financing scheme that is attractive to a private investor. Based on the paper, the specific financing scheme needed should consider the long-term renewable energy project and also the risk investment guarantee (Kirari et al., 2018).

2.4.2 Renewable Energy Development Plan in Indonesia

The government of Indonesia targeted on increasing the percentage of renewable energy in the total energy mix and also the percentage of total power generation. To achieve that, the government targeted, in the electricity supply business plan (RUPTL) 2018-2027, to build a 4,583MW geothermal power plant, 7,472MW hydro power plant, 811MW micro hydro power plant, 1.045MW solar power plant, 589MW of wind turbine power plant, 411MW of biomass power plant and 2,745MW of biofuel power plant. The total target until the end of 2027 is to build 14,911MW of renewable energy power plants.

2.4.2.1 Renewable Energy Development Plan in North Maluku

This research chooses North Maluku as an example for the renewable energy development program, because North Maluku is a province located in Eastern part Indonesia. Moreover, North Maluku was one among six provinces selected for “Program Indonesia Terang” (Bright Indonesia), the program for rural electrification acceleration. The North Maluku province still has 51 villages without electricity, mostly located in the southern part of North Maluku.[4] The composition of North Maluku consists of 1,474 islands, but only 89 are populated. One of the biggest and populated islands is Halmahera Island, while medium-populated islands are Tidore Island, Morotai Island, Obi Island and Bacan Island along with other small-populated islands. The total population of North Maluku is 1,141,561 with total area 31,982.50km^2.

For electricity condition in North Maluku, the electricity system in North Maluku consisted of six small grid systems, with electricity load of more than 1.5MW in each system. The six systems are Ternate-Soa-Siu (Tidore), Tobelo-Malifut, Jailolo-Sofoifi-Payahe, Bacan, Sanana, and Daruba. In the Ternate-Tidore system, it is supported with coal-fired power plant 14MW and diesel mobile power plant 30MW; supporting other systems there are 23 small power plants (diesel power plant and solar power plants).

North Maluku has five different renewable energy potentials, geothermal, hydro, solar, wind, and also biomass. As volcanic origin, with the volcanos

[4] Presented in a coordination meeting on Program Indonesia Terang (Bright Indonesia) in North Maluku, March 15th, 2016

Dukono in Halmahera, Gamalama in Ternate Island and a large stratovolcano on Tidore, it gives North Maluku a geothermal potential of around 580MW. Solar energy is the biggest renewable energy source in North Maluku with the potential of 3,036MW. Other renewable energy sources are small-scale hydro power plant potential of around 24MW, wind energy potential around 504MW and bioenergy potential around 34.5MW. The total renewable energy potential in North Maluku is 4,178.5MW.

The Governor of North Maluku planned to build more micro hydro, solar and geothermal power plants in North Maluku, build a diesel power plant and also build a hybrid power plant. For 2019, they also planned to build medium voltage electricity network Bicoli-Sowoli, Mabapura and low voltage electricity network Sil-Sowoli (Direktorat Pemanfaatan Tata Ruang, 2017).

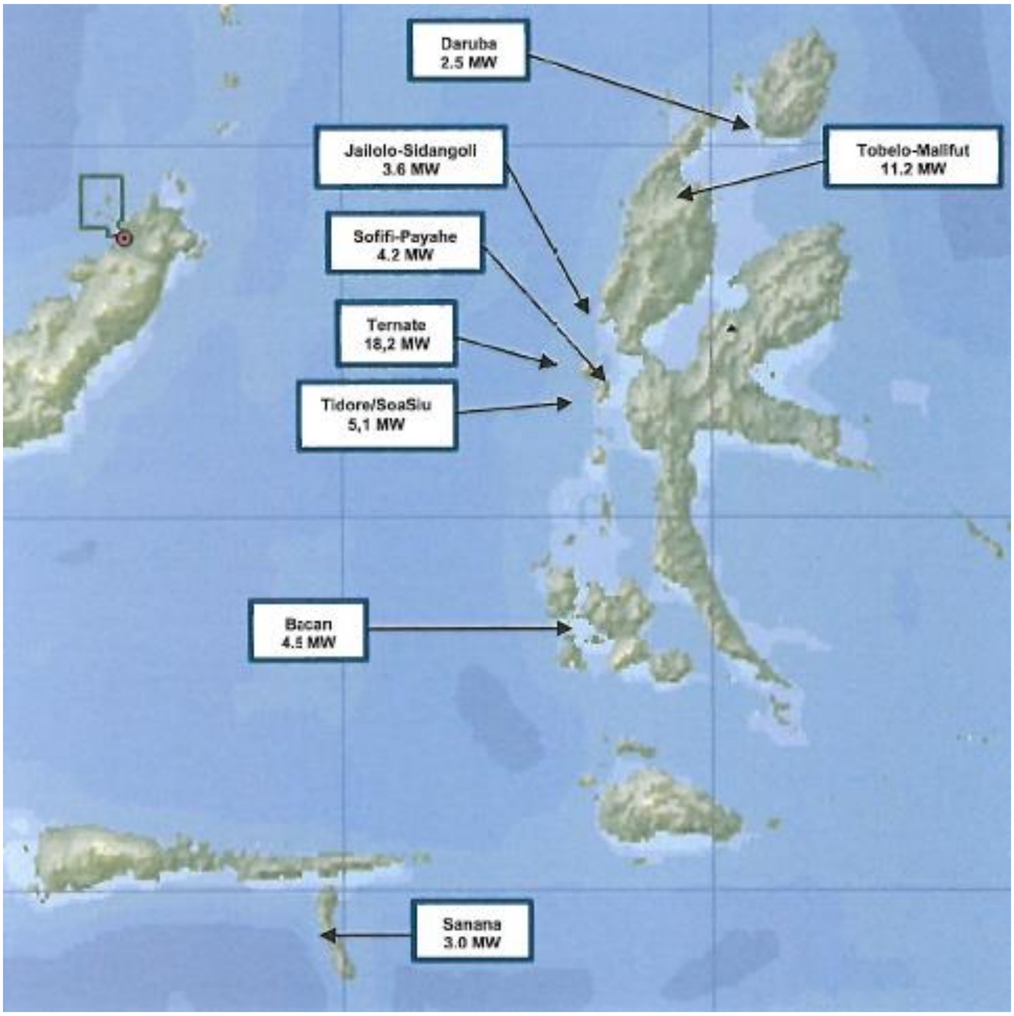

Figure 4. North Maluku Power Plant Map

Chapter 3. Literature Review

3.1 Multi-criteria decision analysis (MDMA)

Multi-criteria decision analysis (MDMA) has been used for several decades to solve problems involving several options or several items from which to choose. MDMA can be applied in several sectors, such as transportation, public sector, agriculture, health, energy, and other sectors. In our daily life, application decision analysis is usually used before we choose one item among many options. For example, before we decide to buy something we usually consider the benefit of the item, the price, the quality and other factors. A simple example application of multi-criteria decision analysis is in how to select a suitable automobile for the family. There are several options of an automobile for the family, for example, sports car, SUV, or sedan. In every option, there is a different classification, such as the mechanical factor has different brake systems, quality of the shift, and horsepower. In the aesthetic factor, there is different color, shape, and wheels, in the comfort criteria there are different seat types, and air conditioning system. All those factors usually become a consideration before buying a car and the evaluation of those factors/ criteria should match with our minimum requirement to obtain the maximum satisfaction and the maximum benefit.

In an academic discussion, the function of multi-criteria decision analysis is to solve the decision process problem. There are four basic types of problem formulation in the decision process, as explained by Roy (1981), **First is** choice problem formulation for choosing the best solution or action and also to decompose the selection procedure. **Second is** sorting problem formulation for shorting the action based on the peculiar value and also for formulating a segmentation procedure. **Third is** ordering the problem formulation with the purpose to help organize the actions, according to descending preference order or in outlining ranking procedures. **Fourth is** description problem formulation to help describe the action and/or its consequences in a systematic way, and describe the analytical procedure.

Many previous research papers explained about the application of the MCDM method: Ma, Diaby, and Xiao (2014) reviewed the MCDM method used in healthcare areas; Guarini (2018) explained the several methods of solving real estate and land management process; and Barfod and Leleur, (2014), Boujelbene and Derbel (2015), and Schmale, Schneidemesser, and Dörrie (2015) explained the application of MCDM method in the transportation sector. In the energy sector, Mardani et al. (2017) reviewed the MCDM application in solving the energy management process and Kumar et al. (2017) reviewed the MCDM for sustainable energy development as well as many other sectors that use MCMA in their study. Table 6 explains the MCDM method that is mostly used to solve the problem in the decision process.

Table 6. Type of MCDA method (Marttunen, Lienert, & Belton, 2017)

Acronym	Method	Description
AHP	Analytic Hierarchy Process ANP	Pairwise comparison procedure based on a linguistic scale to compare the importance of criteria and desirability of alternatives against criteria.
ANP	Analytic Network Process ELECTRE	More general form of AHP. ANP structures the decision problem as a network.
ELECTRE	Elimination Et Choix Traduisant la REalité, (Elimination and Choice Expressing Reality)	Family of MCDA methods based on outranking relations between alternatives.
MAVT, MAVA	Multi-Attribute Value Theory/Analysis (including, e.g. MACBETH, Simple Added Weighting)	Overall priority values of alternatives are calculated based on the objectives' weights, value-functions and performance scores of alternatives
MAUT, MAUA	Multi-Attribute Utility Theory/Analysis	Extension of MAVT, includes probabilities and risk attitudes to form utility functions
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation	Calculates positive and negative preference flows for each alternative based on the pairwise comparisons of the alternatives
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution	Ranks alternatives using the geometric distance from the positive and negative ideal solution

3.2 Multi-Criteria Decision-Making for Energy Sector

MCDA has become popular in the energy sector and is a very useful method as a tool supporting the decision and policy makers or energy planners for their decision analysis. By using MCDA, it will help decision-makers to be more consistent with the "general" objectives, make transparent assessment procedures, and increase the efficiency of the decision-making process. In the energy sector, MCDA is used for sustainable energy planning (Pohekar & Ramachandran, 2004), to solve energy management problems (Mardani et al., 2017), and in planning in order to create sustainable renewable energy development (Kumar et al., 2017).

Many studies have used the MCDM method in their study for a specific purpose on the energy sector. For examples, Ghimire Prasad (2016) used AHP to find the barrier in renewable energy development in Nepal; Hong and Abe, (2012) used MCA to analyze the impact of rural electrification projects in the Philipines; Al Garni, Kassem, Awasthi, Komljenovic, and Al-Haddad (2016) used AHP to evaluate renewable power generation for Saudi Arabia energy planning; and Tasri and Susilawati (2014) used AHP to select a suitable renewable energy source, and there are many other researches using MDMA methods.

3.3 Analysis Hierarchy Process

In many previous studies on the decision analysis process, researchers use Analysis Hierarchy Process (AHP). It has become the most used and trusted method to solve the problem of multi-criteria decision-making and complexity management problem. The AHP method was developed by Saaty in the1970s, and year-on-year many researchers have made further developments to the AHP method, thus, the AHP method is used for problem solving in the decision-making problem in several sectors, such as health, education, economy, energy, and many others. The AHP method evaluates the respondent's preference to determine the relative importance of elements. The AHP input could be quantitative data as the respondent's preference, or quantitative data which scale the data using RNA (rank number alternative) and are interpreted into a matrix (Al Garni et al., 2016).

In the application, many researchers have criticized the AHP method and pointed out the disadvantages. The following are some researchers' opinions about the disadvantages of AHP:

- The reliance of goal and the alternative create an unpredictable result, because the correlation of goal until the alternative is interconnected by a hierarchy of three; if the preference of one element changes, it will change the other elements (Kumar et al., 2017; Shahroodi et al., 2012).
- Inconsistency due to the 1 to 9 scale. In the AHP scale, it uses 1-9 to evaluate the pairwise comparison and this was criticized because this

scale is not fair to evaluate elements. In effect, if the pairwise is evaluated with 1-9 scale it will create inconsistency in the calculation (Barfod & Leleur, 2014; Ishizaka & Labib, 2009)

- More decision-maker involvement creates more complications in assigning the weights. Basically, the AHP method is evaluated by an individual, and, for obtaining group opinion, the individual response is aggregated into one. This will create difficulties because AHP only uses the consistent answer from the individual response, which means that if many decision-makers are involved in the survey, it will require more calculations in weight and consistency (Ishizaka & Labib, 2009; Kumar et al., 2017; Shahroodi et al., 2012).
- The meaningfulness of response to questions: to obtain the weight, in AHP you are asked to give a score for the pairwise comparison of elements without providing the detailed information about the elements, such as the price of the apple, pineapple or orange, if they need to compare the preference of the fruit (Barfod & Leleur, 2014).
- The number of pairwise comparisons which are required in the study may be too many and this will create complexity and inconvenience in the AHP application. In comparing of the AHP, each element should be compared; if the study only has a few elements it will create the advantage of AHP because it will have a consistent answer, but if the study has many elements and alternatives, such as if there are eight

elements and eight alternatives, it will create 224 pairwise comparisons and also will create inconsistency of the answer (Barfod & Leleur, 2014; Ishizaka & Labib, 2009).

Even though there are many critics, the AHP method has many advantages for solving decision-making problems, and the strengths of the AHP method means many people use it as their method. Those advantages are explained as follows:

- ✓ Structuring the problems on hierarchical structure makes it better focused and transparent. It also allows the complex problem to be decomposed into sets of simpler judgments and provides a documented rationale for the choice of a particular option (Barfod & Leleur, 2014; Ishizaka & Labib, 2009).
- ✓ The simplicity of pairwise comparison: by using pairwise comparison it means that the decision-maker can focus on each particular part of the problem. Only two attributes need to be compared in each pairwise, which simplifies the judgment of the decision-maker option (Barfod & Leleur, 2014; Ishizaka & Labib, 2009).
- ✓ Adaptability and easy to use option (Barfod & Leleur, 2014; Ishizaka & Labib, 2009).
- ✓ AHP does not require complex mathematics in calculation option (Barfod & Leleur, 2014; Ishizaka & Labib, 2009).

- ✓ Repetition allows consistency to be checked, in order to get the weight of each element/ AHP needs more judgment from the decision-maker. In AHP, the decision-maker is asked to compare in each element. For example, in comparing A, B, and C, the pairwise is comparing A and B, B and C and A and C, in that way, the judgment will allow setting which is the biggest value, which element has medium value and which elements have the smallest value. The decision-maker can crosscheck their judgment, which reflects the consistency or inconsistency option (Barfod & Leleur, 2014; Ishizaka & Labib, 2009).

In the application of AHP, to make a decision-making process in an organized way, it is necessary to describe the decision into the following steps (Saaty, 1987; Saaty, 2008; Wind & Saaty, 1980):

1. Define the problem and specify the solution or the goal and also select the factor that might become the consideration in the decision-making processes, such as the criterion, sub-criterion, and alternatives.
2. Make the decision hierarchy from the top with the goal of the decision, then followed by the objectives from a broad perspective, then go to the intermediate levels (usually the criteria, and continue to the following elements) and the lowest level (which usually is a set of the alternatives).
3. Construct a set of pairwise comparison matrices from interpreting the answer of pairwise comparison.

4. Calculate all obtained pairwise comparison matrices to find the weight and priority in each level and also find the global priorities. And also find the weight of alternative if the last level is the set alternative.

3.4 Previous Studies

The analytical hierarchy process is used by scholars in weighting and ranking the important factors or finding the best option among several options based on the preferences of the respondents. This section will explain the previous study which was used as the role model or the example of the research. All of the researches that will be explained below are about renewable energy development and renewable energy technology.

"Selection among renewable energy alternatives based on a fuzzy analytic hierarchy process in Indonesia" (Tasri & Susilawati, 2014) investigated the suitable renewable energy sources in Indonesia using Fuzzy AHP with consideration on five criteria: quality of the energy source, socio-political, economic, technological and environmental, and also considered 15 sub-criteria. The five alternatives renewable energy that were compared are hydropower, geothermal, biomass, wind, and solar energy. The paper found that hydropower is the most suitable renewable energy for Indonesia, and energy source criterion becomes the most important factor in selecting the most important criteria and economics become the second most important criterion, with slight differences. Energy experts with four different backgrounds were the respondents of this research to compare their different perspectives on selecting renewable energy alternatives in Indonesia.

"Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP" (Heo, Kim, & Boo, 2010) investigated the important factors in renewable energy development in South Korea using Fuzzy AHP. Factors were a consideration in the paper are technological, market, economic, environmental and policy and seventeen factors were considered more deeply. The result found that market criterion is the most important factor and economic feasibility the most important factor among all factors for the dissemination of renewable energy programs in the case of South Korea. This research has two different categories of respondents, first is policymakers and second is energy experts. That result indicated there were significant differences in the most important criteria of renewable energy dissemination and indicated that there is existence of a significant gap in the way of approaching renewable energy dissemination.

"Selection of renewable energy sources for the sustainable development of electricity generation system using analytic hierarchy process: a case of Malaysia" (Ahmad & Tahar, 2014) explained that solar is the most favorable resource based on the study, followed by biomass resources. In the study, the researchers used the Analytic Hierarchy Process (AHP) comparing five different energy alternatives, hydropower, solar, wind, and biomass. In comparing energy alternatives, the study used four criteria, technical, economic, social and environmental criteria and also considered 13 sub-criteria to determine the best energy alternative in Malaysia. Another result of the study is that the economic criterion has the highest weight, and, for sub-criteria, the highest weight is resource potential.

"Alternative Energy Options for India – A Multi-criteria Decision Analysis to Rank Energy Alternatives using Analytic Hierarchy Process and Fuzzy Logic with and Emphasis to Distributed Generation" (Kulkarni, Jirage, & Anil, 2017) investigated the best operation energy alternative for the rural area of India using AHP and fuzzy logic. The paper compared three operation energy alternatives, the central grid/grid extension, the solar home system (SHS) and micro-grid within two scenarios, cost scenario, and environment scenario. In comparing technology and scenario, respondents of research considered nine criteria, generation cost, reliability, constrain, the price for consumers, capacity, operation and maintenance, losses and availability. The result found that micro-grid is the ideal choice among the technology alternatives in decentralizing in India for generating energy.

"A multi-criteria decision-making approach for evaluating renewable power generation sources in Saudi Arabia" (Al Garni et al., 2016) used AHP for finding the most promising renewable energy technology in Saudi Arabia. This paper considered four criteria, technical, environmental, socio-political and economic criteria with 14 sub-criteria to compare five renewable energy technologies, solar PV, solar thermal, wind, waste-to-energy and geothermal technology, to produce electricity. The result found that solar photovoltaic is the most promising technology in Saudi Arabia followed by solar thermal. Technological and economic criteria have the same percentage as the most important criteria needed to be considered.

3.5 Important Criteria and Factors in Selecting Suitable Renewable Energy for Rural Electrification

In order to analyze the important criteria and factors in selecting renewable energy sources and technologies for rural electrification, comprehensive literature reviews were conducted to find the correct and proper criteria and factors to be compared. Draft of criteria and sub-criteria were established with references from previous research, the current condition of rural electrification in Indonesia, rural electricity development plan and also renewable energy potential in Indonesia. The first draft consisted of five criteria, and 26 (twenty-six) sub-criteria were used as the pairwise comparison in the preliminary survey for this study. The preliminary survey was reviewed by energy experts and AHP experts to get feedback and comment for making the final draft of the survey. The criteria and sub-criteria that were selected for the preliminary survey, as shown in Table 7, were reviewed and evaluated, and the result and the explanation of the criteria and sub-criteria for the final survey will be discussed in the next chapter.

Table 7. Criteria and sub-criteria for the preliminary survey

Criteria	Sub-criteria	References
Technical	Maturity of technology	(Ahmad & Tahar, 2014), (Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005) (Demirtas, 2013), (Diputra, 2018)
	Technology performance	(Akash, Mamlook, & Mohsen, 1999), (Demirtas, 2013), (Diputra, 2018)
	Availability of equipment and parts	(Ahmad & Tahar, 2014), (Diputra, 2018), (Kabir & Shihan, 2003)
	Energy production capacity	(Cavallaro & Ciraolo, 2005), (Demirtas, 2013), (Talinli, Topuz, & Uygar Akbay, 2010)
	Energy system safety	(Akash et al., 1999), (Al Garni et al., 2016), (Demirtas, 2013), (Kabir & Shihan, 2003), (Singh & Nachtnebel, 2016),
	Maintainability/ less Training requirement, easy to maintain	(Barry, Steyn, & Brent, 2011), (Diputra, 2018), (Kabir & Shihan, 2003)
	Ease of decentralization	(Al Garni et al., 2016), (Singh & Nachtnebel, 2016)
Economical	Capital Cost	(Ahmad & Tahar, 2014), (Akash et al., 1999), (Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005), (Demirtas, 2013), (Diputra, 2018), (Ghimire Prasad, 2016), (Kablan, 1997), (Talinli et al., 2010)

	Operation and Maintenance Cost	(Ahmad & Tahar, 2014), (Akash et al., 1999), (Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005), (Diputra, 2018), (Talinli et al., 2010)
	Profitability	(Diputra, 2018), (Tasri & Susilawati, 2014)
	Volatility of Energy Prices/stable price	(Diputra, 2018)
	Affordability Price	(Ghimire Prasad, 2016), (Tasri & Susilawati, 2014)
	Payback period	(Demirtas, 2013)
Socio-Political	Population	(Diputra, 2018)
	Job Creation	(Ahmad & Tahar, 2014), (Al Garni et al., 2016), (Diputra, 2018), (Kablan, 1997), (Singh & Nachtnebel, 2016), (Tasri & Susilawati, 2014),
	Public acceptance	(Ahmad & Tahar, 2014), (Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005), (Demirtas, 2013), (Diputra, 2018), (Ghimire Prasad, 2016), (Kabir & Shihan, 2003), (Tasri & Susilawati, 2014),
	Government policy	(Ghimire Prasad, 2016), (Tasri & Susilawati, 2014)
Environmental	CO2 emission	(Ahmad & Tahar, 2014), (Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005), (Demirtas, 2013), (Diputra, 2018), (Kablan, 1997), (Talinli et al., 2010), (Tasri & Susilawati, 2014)

	Noise pollution	(Cavallaro & Ciraolo, 2005), (Diputra, 2018), (Kabir & Shihan, 2003), (Tasri & Susilawati, 2014)
	Impact on ecosystem	(Ahmad & Tahar, 2014), (Cavallaro & Ciraolo, 2005), (Demirtas, 2013), (Kabir & Shihan, 2003), (Kablan, 1997), (Singh & Nachtnebel, 2016), (Talinli et al., 2010),
	Flexibility of location	(Kabir & Shihan, 2003),
	Requirement for waste disposal	(Singh & Nachtnebel, 2016), (Talinli et al., 2010), (Tasri & Susilawati, 2014)
	Land requirement	(Ahmad & Tahar, 2014), (Al Garni et al., 2016), (Diputra, 2018), (Kabir & Shihan, 2003), (Tasri & Susilawati, 2014),
Energy source	Resource availability	(Ahmad & Tahar, 2014), (Akash et al., 1999), (Al Garni et al., 2016), (Diputra, 2018), (Kablan, 1997), (Tasri & Susilawati, 2014)
	Resource durability	(Diputra, 2018), (Tasri & Susilawati, 2014)
	Distance to user	(Diputra, 2018), (Tasri & Susilawati, 2014)

Chapter 4. Methodology

4.1 Methodological Framework

The purpose of this study is to analyze renewable energy sources and technologies for rural electrification in Indonesia through finding the important criteria and sub-criteria and finding the most suitable renewable energy. This study uses the two main stages method. First, this study uses the AHP method for finding the important criteria and sub-criteria in selecting renewable energy. Second, this study conducts scoring of renewable energies and technologies alternatives. As presented in Figure 5, this survey conducted several steps to obtain the result and conclusion. Starting with literature review, it selected criteria and sub-criteria, conducted a preliminary survey, first survey, and second survey, analyzing the results until composing the conclusion.

In accordance with AHP methodology, before starting this study with the survey, the first thing established in this survey was a hierarchy tree. Basically, the hierarchy tree of AHP consists of minimum three levels of hierarchy, the first element is the goal of the decision, in the second level is the criteria and the third, lowest, level is alternatives; for a more complex hierarchy, another level can be added. In the four levels hierarchy, the additional level represents the sub-criteria. An example of four-level hierarchy is shown in Figure 6, the first level is the goal, the second level is criteria, the third level is sub-criteria and the fourth level is the alternative. The next chapter will discuss the AHP method used in this study and also the scoring of alternatives according to the methodology framework.

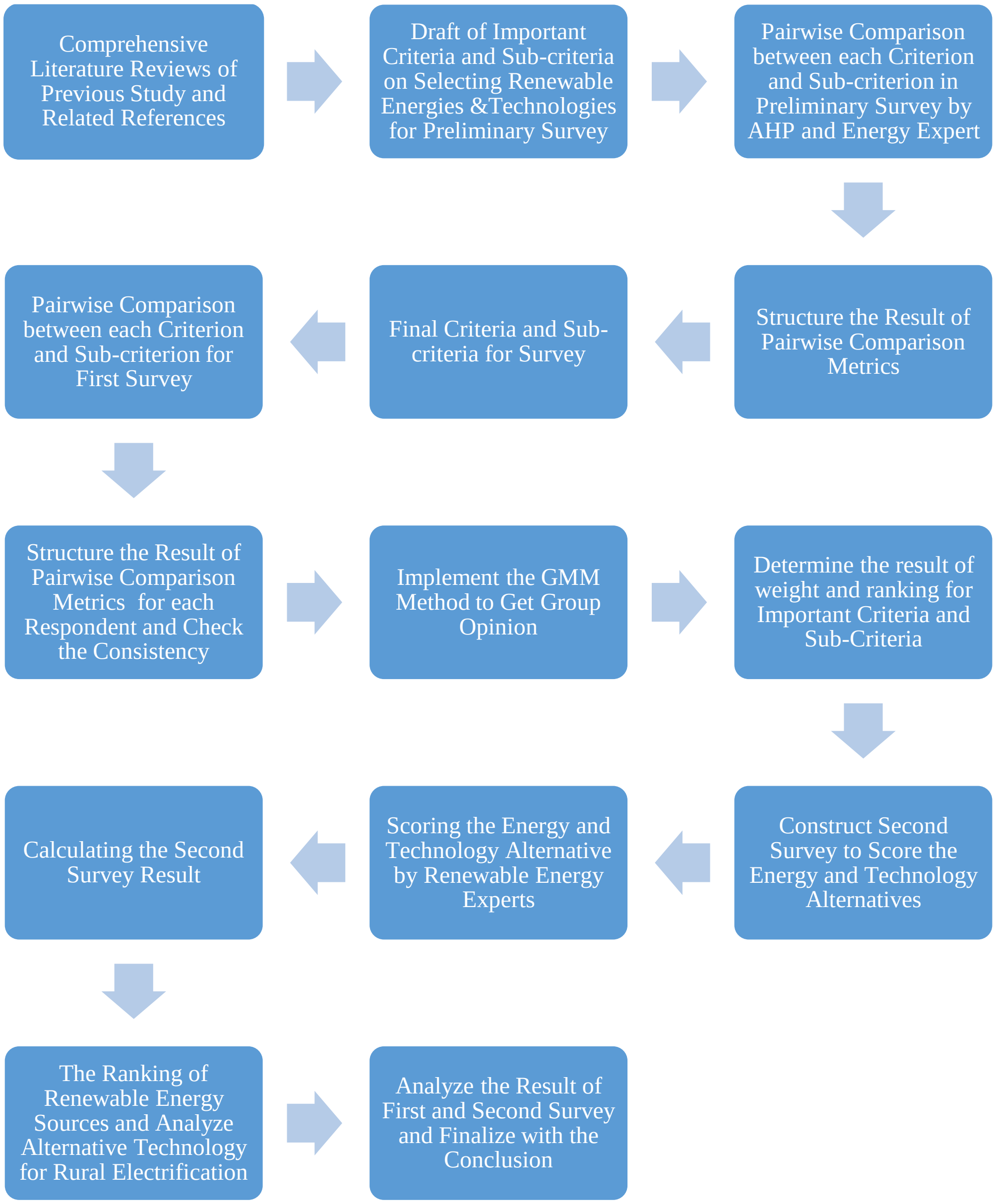

Figure 5. Research methodology of this study

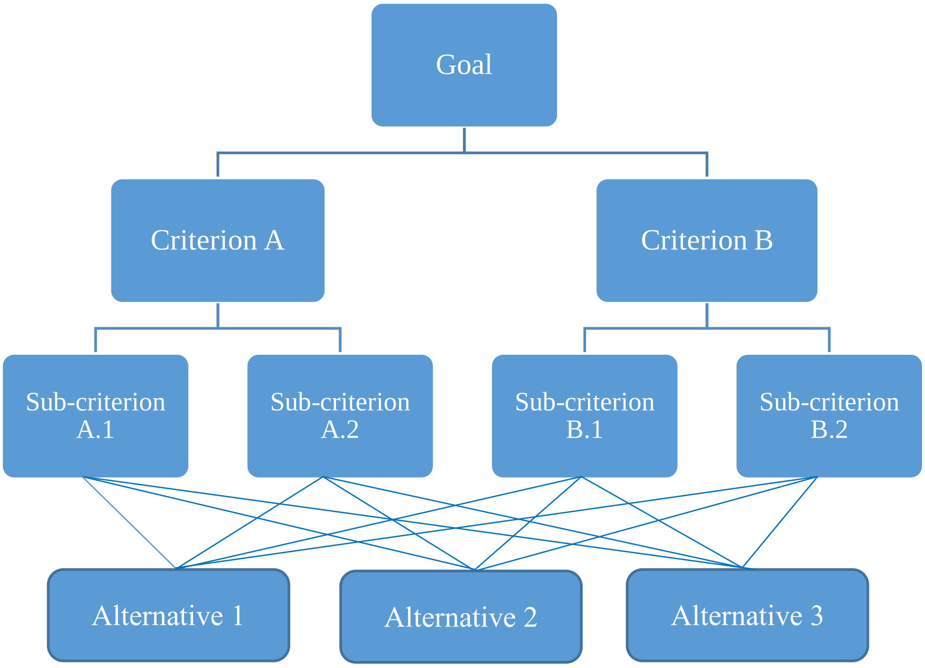

Figure 6. Example of a four-level hierarchy structure

4.2 AHP Method for the Study

Analytic Hierarchy Process (AHP) is used by many researchers to solve the problem in the multi-criteria decision-making process. Even though the AHP method is a popular method, it is not perfect and there are many negative points and disadvantage, as explained in the previous chapter. To minimize the negative points in using AHP, implementation needs to follow the AHP method guidelines, as explained previously. Regarding the existing guidelines from Saaty, after defining the problem, the next step is structuring the decision hierarchy tree, from the top, or first, level to the bottom level. As explained before, this study uses a four-level hierarchy tree, with one goal, five criteria, eighteen sub-criteria, and five alternatives. As shown in Figure 10, the goal of this study is finding a renewable energy source and technology for rural electrification. The second level has five criteria, economic, technological, socio-political, environmental, and energy source. In the third level, there are eighteen sub-criteria, as described below:

a. Capital cost

This factor is used to measure the initial investment/cost needed to invest until the electricity can be delivered to the consumer. For example, the initial cost to build a small geothermal power plant is higher than building a micro hydro power plant, because, in a geothermal power plant, it requires several steps to build power generation, which is longer than other power generation.

b. Operation and maintenance cost

This factor is used to evaluate the cost to maintain and operate the specific renewable energy power plant. For example, a solar power plant with battery requires higher cost in operation and maintenance than micro hydro because the battery component needs to be changed every 3-5 years.

c. Profitability

This factor indicates the different profitability of renewable energy power plants.

d. Affordability price

Affordability price is the ability of local people to purchase the energy that is generated from a renewable energy source

e. Job creation (Labor impact)

This factor is used to measure the ability of renewable energy power plants in creating jobs for local people.

f. Public acceptance

This factor is used to measure the acceptance and support of the local people towards renewable energy power generation.

g. Government policy

This factor is used to measure whether utilization of a specific renewable energy source for rural electrification can support current government policy on sustainable development or not.

h. Maturity of technology

This factor is used to determine the maturity of technology in the renewable energy power plant. The maturity of technology can be explained as the technology that has been used for long enough, at less risk and has been commercialized.

i. Technology performance

This factor is used to evaluate the performance of a renewable energy power plant technology as to whether the technologies can be well-operated and has good performance or not.

j. Availability of equipment and parts

This factor is used to consider the equipment and parts availability of each different renewable energy technology.

k. Training requirement

This factor is used to consider the requirement of personal training or skill training for operating and maintaining the renewable energy power plant.

l. Ease of decentralization

This factor is used to consider the ability of a renewable energy power plant to connect to the grid.

m. CO2 emission

This factor is used to consider the amount of CO2 emission that is produced from generating a renewable energy power plant.

n. Noise pollution

This factor is used to consider the noise produced from generating a renewable energy power plant.

o. Land requirement

This factor is used to consider the required area to build the renewable energy power plant.

p. Resource availability

This factor is used to measure the availability of renewable energy sources which can supply the electricity generation in that area. For example, in North Maluku five different renewable energy sources can be used for generating electricity, solar energy, wind energy, biomass energy, geothermal energy, and micro hydro energy

q. Resource durability

This factor is used to measure the duration of the renewable energy source for generating electricity. For example, biomass tends to have a shorter duration in supplying energy sources because it will depend on the biological process and climate.

r. Distance to user

This factor is used to explain the important level of the distance of the energy sources to the power plant, and the consumer; the greater the distance from the energy sources may increase the losses of electricity in the transmission process and also will cost in terms of the construction.

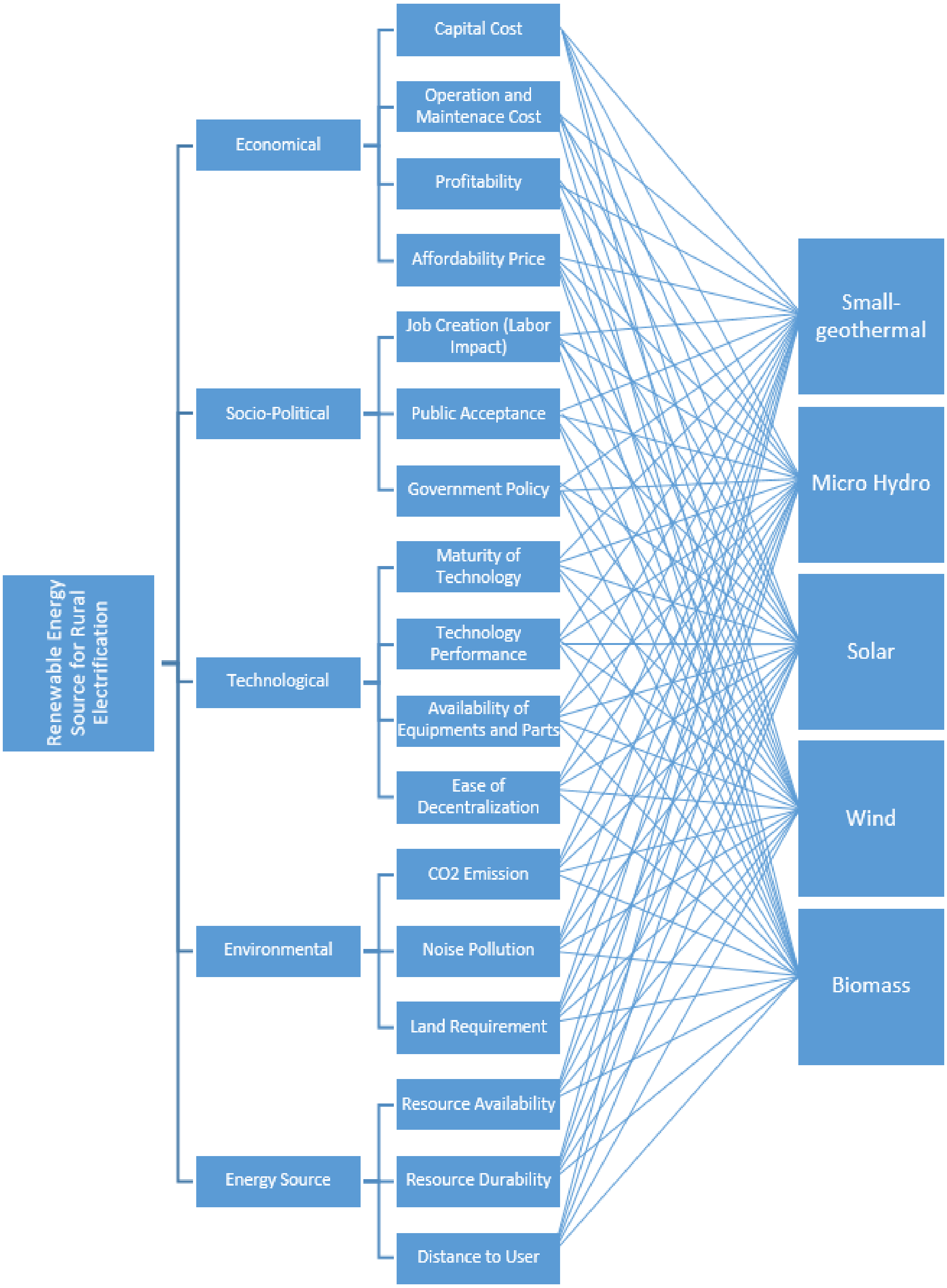

Figure 7. Analytic hierarchy tree of this research

The next stage after structuring the hierarchy tree is constructing pairwise comparison in each level. Respondents or experts will judge the pairwise comparison based on their relative importance, then establish a pairwise comparison matrix. The number of pairwise comparisons is obtained based on total criteria n, with the formula $n(n-1)/2$ (Saaty, 1987). There are five criteria in this survey and, as such, the total pairwise comparison of criteria has ten pairwise comparisons. Furthermore, there are twenty-five pairwise comparisons in the sub-criteria, six pairwise comparisons in the economic sub-criteria, ten pairwise comparisons in the technological sub-criteria, three pairwise comparisons in the socio-political sub-criteria, three pairwise comparisons in the environmental sub-criteria and three pairwise comparisons in the energy source sub- criteria.

In evaluating the pairwise comparison, respondents or experts need to compare the degree of one item in the pairwise; either one item is dominant or has the same value. To facilitate the respondent in evaluating (Saaty, 1987; Wind & Saaty, 1980), there is need to establish a fundamental scale in the AHP method, as shown in Table 8. By using this fundamental scale, the AHP method can translate the qualitative information into qualitative measurement in number scale. For comparison using AHP scale, Cabala (2010) suggested to use odd numbers from 1 to 9 and use the even numbers if there is a better way to describe them other than using an even number. The result of evaluating the pairwise is a number which can be calculated in matrix form. Aij indicates the criteria i and criteria j which will be compared with the AHP scale. $[A_{ij}]$, where i,j=1,2,…,n,

$$A_{ij} = 1 \text{ for } i{=}j, \text{ and } i \text{ more than } j$$

$$A_{ij} = \frac{1}{A_{ij}} \text{ for } i \neq j,\ i \text{ less than } j$$

Table 8. Fundamental scale in AHP (Wind & Saaty, 1980)

Scale	Definition	Explanation
1	Ai and Aj are equally important	Two activities contribute equally to the objective
3	Ai is moderately more important than Aj	Experience and judgment strongly favor one activity over another
5	Ai is strongly more important than Aj	Experience and judgment strongly favor one activity over another
7	Ai is very strongly more important than Aj	An activity is strongly favored and its dominance demonstrated in practice
9	Ai is extremely more important than Aj	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

Following past studies (Barfod & Leleur, 2014; Brunelli, 2015; Saaty, 1987; Saaty, 2008; Wind & Saaty, 1980) the pairwise comparison result which is the result of the survey is translated to matrix form A in equation (1). The pairwise comparison, which consists of comparison of element i and element j with total *n* elements (2), substitutes to equation (1) and become the matrix structured as equation (3). Before calculating in the next step, matrix A first needs to be transformed. Then, the next step is calculating the weight of the element in a matrix with the following equation (4). By substituting equation (4) with equation (3), it will create equation (5) where A indicates the matrix of the pairwise comparison result, *w* indicates the eigenvector or the weight and λ_{max} indicates the maximum eigenvalue of matrix.

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{23} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

$$({}^{w_i}/{}_{w_j})_{n\times n} = A \quad (2)$$

$$A=\begin{bmatrix} {}^{w_1}/{}_{w_1} & {}^{w_1}/{}_{w_2} & \cdots & {}^{w_1}/{}_{w_n} \\ {}^{w_2}/{}_{w_1} & {}^{w_2}/{}_{w_2} & \cdots & {}^{w_2}/{}_{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ {}^{w_n}/{}_{w_1} & {}^{w_n}/{}_{w_2} & \cdots & {}^{w_n}/{}_{w_n} \end{bmatrix} \quad (3)$$

$$Aw = \lambda_{max}w \quad (4)$$

$$Aw=\begin{bmatrix} {}^{w_1}/{}_{w_1} & {}^{w_1}/{}_{w_2} & \cdots & {}^{w_1}/{}_{w_n} \\ {}^{w_2}/{}_{w_1} & {}^{w_2}/{}_{w_2} & \cdots & {}^{w_2}/{}_{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ {}^{w_n}/{}_{w_1} & {}^{w_n}/{}_{w_2} & \cdots & {}^{w_n}/{}_{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} \lambda_{max}w_1 \\ \vdots \\ \lambda_{max}w_n \end{bmatrix} = \lambda_{max}w \quad (5)$$

After finding the weight of the element, the next step is testing the consistency with equation (5) and (6). First find the consistency index (CI) following equation (5) and then find the consistency ratio (CR) by comparing the CI with the random consistency index (RI). The acceptable value of consistency is 10% or less (CR≤0.1). Otherwise, the quality of data/judgment should be improved, or the data cannot be used.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

$$CR = \frac{CI}{RI} < 0.1 \tag{6}$$

Table 9. Consistency Random Index (Wind & Saaty, 1980)

m	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

All the weight calculated in the previous step can be used to rank the elements in each level (local priorities) or can be used to rank the weight in global priorities by multiplying the weight in the upper level by the weight in the lower level.

For aggregating the individual respondent to the group, this research is following previous research by Brunelli (2015) who derived weights from multiplicative pairwise comparison using the Geometric Mean Method (GMM) in equation (7). That study also explains that, by calculating the respondent into the group, it will satisfy the fundamental consistency requirements.

$$w_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{\frac{1}{n}} \tag{7}$$

One of the functions of the AHP method is for ranking the alternative, to find the rank following the AHP step, the first thing being to make the pairwise comparisons of energy alternatives for each sub-criterion or criterion. For example, to find an alternative based on the weight of the sub-criteria, the pairwise comparison of the alternative differs in each sub-criterion. Then, find the weight based on the matrix pairwise comparison result. After that, the weight of the alternative in each sub-criterion is multiplied with the result of the weight of the sub-criterion in respect to the criterion. Then, the final weight of the alternative can be ranked as the best alternative to the last option of an alternative.

4.3 Scoring the Renewable Energy Technology

This section discusses one of the steps in the research framework, which is how to rank the renewable energy sources and technologies for rural electrification in Indonesia. In previous researches, the way to evaluate the alternative was by using a series of AHP methods with pairwise comparison of the alternative in respect to the criteria or sub-criteria, then multiply with the weight of the criteria or sub-criteria as the result of the pairwise comparison of them (Cabala, 2010; Saaty, 2008). Using the theory from Saaty to rank the energy alternatives, Ahmad and Tahar (2014) and Al Garni et al. (2016) calculate the weight of pairwise comparison of alternative technology in respect to the criteria, and then multiply with the weight of the criteria concerning the goal. Using different ways in ranking energy source and technology alternatives, this study will use scoring the energy alternatives in respect to the sub-criteria. The step in scoring energy alternatives involves renewable energy experts giving the score in the sub-criteria in each renewable energy alternative, then, averaging all the responses to analyze each criterion and each renewable energy technology. Finally, accumulate all the sub-criteria scores and average them for each energy alternative to identify the score of each renewable energy alternative.

This study also adopts the AHP method to rank the renewable energy alternatives, but changes the weight of pairwise comparison of energy alternatives with the average score of the sub-criteria in each energy alternative. It then multiplies with the weight of the sub-criteria obtained from the AHP method process. The result of this process will identify the rank of renewable energy sources and technology which are suitable to use for rural electrification in Indonesia.

4.4 Survey

4.4.1 Survey on AHP Pairwise Comparison

In this research, analytic hierarchy process is designed to compare the preference of energy experts about criteria and sub-criteria in selecting renewable energy sources for rural electrification and also its alternative. Before determining the criteria and sub-criteria for the final survey, research was done using a preliminary survey with five criteria and twenty-seven sub-criteria, as presented in Table 7. This criteria and sub-criteria were changed into pairwise comparison, ten pairwise comparisons for criteria, and sixty (60) pairwise comparisons for sub-criteria. In a preliminary survey, the researcher asked five energy experts in the AHP method to answer the pairwise, and review the sub-criteria and sub-criteria. The result explains that too many sub-criteria were used, and resulted to an inconsistent answer. The respondents suggested reducing the sub-criteria for maximizing the consistency level for the final survey. Folllowing the preliminary survey, this study undertook a further literature review based on the survey results.

After completing the preliminary survey and a deeper literature review, this research decided on reducing the number of sub-criteria from 27 sub-criteria to 18 sub-criteria. The sub-criteria are divided into five different criteria, there are five sub-criteria in technological, four sub-criteria in economic, and three sub-criteria each in the environmental, socio-political and energy source criteria, as shown in Table 10. In the final survey to find the important criteria and sub-criteria in selecting renewable energy sources and technologies for rural electrification, this survey established ten pairwise comparisons of the main criteria and 25 pairwise comparisons of sub-criteria.

Table 10. Criteria and sub-criteria for the final survey

Criteria	Sub-criteria	References
Technical	Maturity of technology	(Ahmad & Tahar, 2014), (Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005), (Demirtas, 2013), (Diputra, 2018)
	Technology performance	(Akash et al., 1999), (Demirtas, 2013), (Diputra, 2018)
	Availability of equipment and parts	(Ahmad & Tahar, 2014), (Diputra, 2018), (Kabir & Shihan, 2003)
	Maintainability/ less training requirement, easy to maintain	(Barry et al., 2011), (Diputra, 2018), (Kabir & Shihan, 2003),
	Ease of decentralization	(Al Garni et al., 2016), (Singh & Nachtnebel, 2016)
Economical	Capital cost	(Ahmad & Tahar, 2014), (Akash et al., 1999), (Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005), (Demirtas, 2013), (Diputra, 2018), (Ghimire Prasad, 2016), (Kablan, 1997), (Talinli et al., 2010),
	Operation and maintenance cost	(Ahmad & Tahar, 2014), (Akash et al., 1999), (Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005), (Diputra, 2018), (Talinli et al., 2010)
	Profitability	(Diputra, 2018), (Tasri & Susilawati, 2014)
	Affordability price	(Ghimire Prasad, 2016), (Tasri & Susilawati, 2014)

Socio-Political	Job creation	(Ahmad & Tahar, 2014), (Al Garni et al., 2016), (Diputra, 2018), (Kablan, 1997), (Singh & Nachtnebel, 2016), (Tasri & Susilawati, 2014)
	Public acceptance	(Ahmad & Tahar, 2014), Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005), (Demirtas, 2013), (Diputra, 2018), (Ghimire Prasad, 2016), (Kabir & Shihan, 2003), (Tasri & Susilawati, 2014)
	Government policy support	(Ghimire Prasad, 2016), (Tasri & Susilawati, 2014)
Environmental	CO2 emission	(Ahmad & Tahar, 2014), (Al Garni et al., 2016), (Cavallaro & Ciraolo, 2005), (Demirtas, 2013), (Diputra, 2018), (Kablan, 1997), (Talinli et al., 2010), (Tasri & Susilawati, 2014)
	Noise pollution	(Cavallaro & Ciraolo, 2005), (Diputra, 2018), (Kabir & Shihan, 2003), (Tasri & Susilawati, 2014)
	Land requirement	(Ahmad & Tahar, 2014), (Al Garni et al., 2016), (Diputra, 2018), (Kabir & Shihan, 2003), (Tasri & Susilawati, 2014)
Energy source	Resource availability	(Ahmad & Tahar, 2014), (Akash et al., 1999), (Al Garni et al., 2016), (Diputra, 2018), (Kablan, 1997), (Tasri & Susilawati, 2014)
	Resource durability	(Diputra, 2018), (Tasri & Susilawati, 2014)
	Distance to user	(Diputra, 2018), (Tasri & Susilawati, 2014)

The questionnaires in the preliminary survey and final survey to find the important criteria and sub-criteria in selecting renewable energy sources and technologies for rural electrification were conducted via Google Forms. The questionnaire was divided into three parts; the first part was the introduction of the study and explanation of how to answer the question; the second part was the pairwise comparison and description of the criteria and sub-criteria, and the last part was the personal information of the respondents.

In the previous discussion, this study has already mentioned the respondents in the preliminary survey. For the final survey, the respondents of this survey are the policy/decision-makers and the energy experts in Indonesia's electricity development. The respondents of the first survey are from the Directorate General of Electricity, Secretariat General of the Ministry of Energy and Mineral Resources, Directorate General of New Renewable Energy and Energy Conservation, Directorate General of Oil and Gas, Directorate General of Mineral and Coal, Energy and Mineral Resources Research and Development Agency, Human Resource Development Agency, MEMR, the state-owned electricity companies, and other government agencies and energy companies.

The preliminary survey was conducted from the first until the third week of June 2018 with five respondents. Then, the first survey was conducted from July 25th until September 10th, 2018. This survey targeted 80 energy experts from various government agencies and energy companies. However, only 69 energy experts gave feedback and responses, thus the response rate was 86.2%. All the answers were calculated using AHP method after checking with Consistency Ratio (CR), as explained in the previous chapter. From a total 69 answers, only 40 responses passed the consistency level, and 29 responses had CR higher than 0.1 or 10%. Thus, only 40 responses were used for this study and 29 responses were rejected. The detailed calculation result is presented in the next chapter.

4.4.2 Survey for Selection of Renewable Energy Technology for Rural Electrification in Indonesia

In the survey for selection of renewable energy technology for rural electrification in Indonesia, the methodology did not use AHP, but use the judgment of renewable energy experts in Indonesia. All the respondents were persons having experience in renewable energy projects and knowing the renewable energy development in Indonesia. The questionnaire on finding the suitable renewable energy option for rural electrification was different from the first survey. This second survey used the same criteria and sub-criteria as the AHP survey. In this survey, all sub-criteria were provided the detailed information about five renewable energy technologies: small-scale geothermal power plant, micro hydro power plant, solar power plant, wind turbine power plant and biomass power plant. In this survey, one province was selected, which is North Maluku, as an example of rural energy development which has five different renewable energy sources. The detailed information about energy source, geographic condition, and electricity condition was explained in the previous chapter.

This survey was conducted from October 9th to 27th, 2018, with ten renewable energy experts from the Directorate General of New Renewable Energy and Energy Conservation having a minimum four years' experience in renewable energy projects as respondents. The respondents gave a score on each technology and each sub-criterion, as presented in the appendix. The criteria of evaluation are renewable energy experts giving a score based on their experience and the detailed information provided, taking into consideration as to whether the respondent had no experience in one of the technologies. The score is from 1 to 10, 1 means the worst technology or the lowest value and 10 is the best technology or highest value. All the responses were calculated and are presented in the next chapter.

Chapter 5. Result and Discussion

5.1 Empirical Results

This research follows the methodology framework explained above, to analyze renewable energy sources and technologies for rural electrification in Indonesia. There were two steps to be taken; the first one was to identify the important criteria and sub-criteria and the second one identified the suitable energy sources and technologies for rural electrification. In order to find the important criteria and sub-criteria in selecting renewable energy for rural electrification in Indonesia, this study used the Analytic Hierarchy Process (AHP) method. Based on the AHP model, this research presented a hierarchy using goal, criteria, sub-criteria, and alternative. The criteria and sub-criteria were transformed into pairwise comparison and distributed to respondents as a questionnaire for the first survey. The results calculated in the matrix form were then used to estimate the weights and ranks of each criterion and sub-criterion.

Moreover, to find the most suitable renewable energy source and technology for rural electrification, this study used scoring of renewable energy alternatives obtained from the second survey. In the questionnaire, all sub-criteria were provided along with the information of each renewable energy source and technology. The questions prompted respondents to give a score in each sub-criterion and each renewable technology. The result was then used to calculate the final score of each sub-criterion. Finally, the final scores determined the most suitable renewable energy source and technology for rural electrification in Indonesia. Details of the results are presented and illustrated in the subchapter below.

5.1.1 Consistency Analysis

The AHP is a model that allows respondents to choose/evaluate options according to their personal preference and opinion. Therefore, the absolute consistency of the results of the AHP method are very difficult to obtain. Realizing this condition, Saaty (1987) proposed a limit level of consistency ratio (CR). In his research, he concluded that there are limits to the inconsistency of judgment that can still be tolerated if CR is less than 0.10 or 10%. From a total of 69 responses from energy experts, only 40 responses answered within the limit of a consistency ratio of less than or equal to 0.10. The other 29 responses had CR higher than 0.1. With such result, these 29 responses will not be used in this study. The distribution of respondents' consistency is presented in Figure 8.

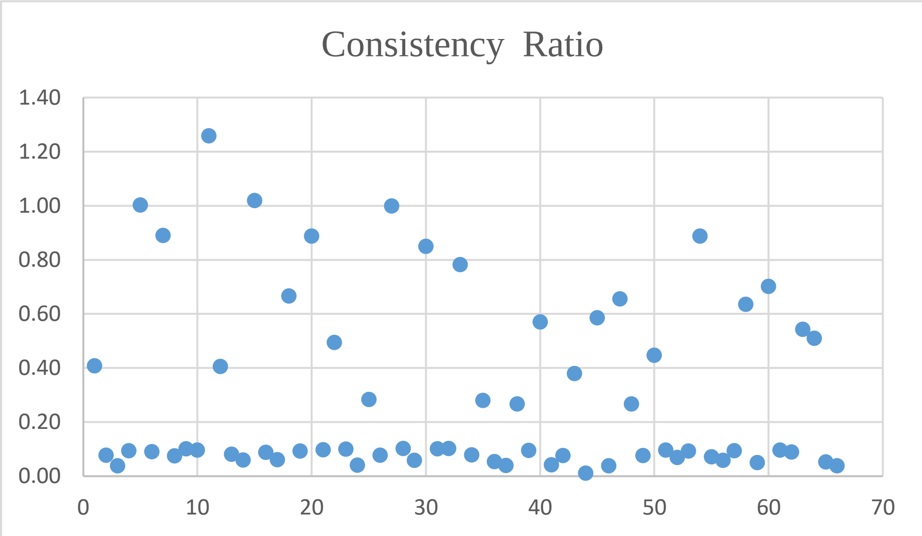

Figure 8. Distribution of respondents' consistency

5.1.2 Estimated Weights of Criteria

In this section, the result of pairwise comparison of the main criteria will be discussed. The main criteria were economic, technical, socio-political, energy source and environmental. Based on the calculation of the result, energy experts considered that the energy source criterion was the most important criterion in choosing renewable energy source and technology for rural electrification in Indonesia. The second one was environmental, followed by socio-political, technical and economic as the least important criteria. The result is explained in Table 11 and Figure 9.

Table 11. The result of weighting and ranking for main criteria

Criteria	Priority Weight	Priority Weight (%)	Rank
technical	0.1594	15.94%	4
economical	0.1042	10.42%	5
socio-political	0.1773	17.73%	3
environmental	0.2006	20.06%	2
energy source	0.3585	35.85%	1

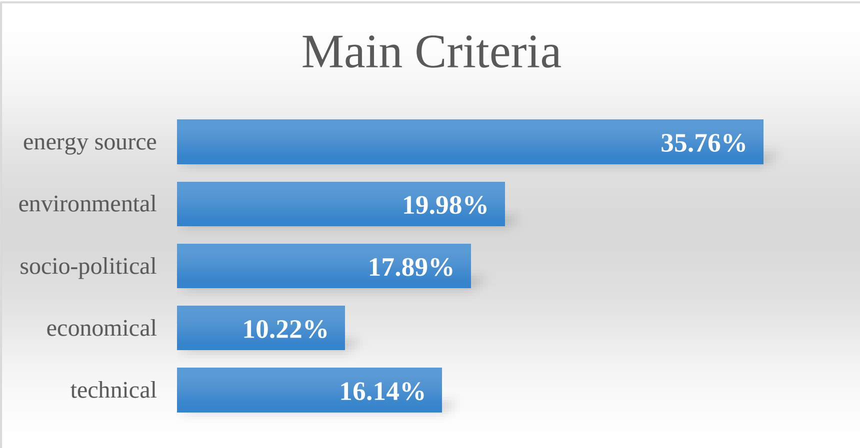

Figure 9. The result of weighting and ranking for main criteria

5.1.3 Estimated Weights of Sub-criteria

This section discusses the result of calculation in comparing sub-criteria in this research. This research used eighteen sub-criteria which were grouped into five criteria. All the sub-criteria were weighted and ranked in five different criteria as local priorities.

After combining energy experts' answers, affordability was the most important sub-criterion that should be considered in the economic criteria, since almost half of the energy experts thought that this was the most important. In contrast, energy experts thought that profitability was the least important sub-criterion that should be considered. Operation and maintenance cost and capital cost ranked as the second and third important sub-criterion, respectively. Detailed information of weight and rank in the economic criterion is explained in Table 12 and Figure 10.

Table 12. The result of weighting and ranking for economic criteria

Sub-Criteria	Priority Weight	Priority Weight (%)	Rank
capital cost	0.1621	16.21%	3
operation and maintenance cost	0.2667	26.67%	2
profitability	0.1364	13.64%	4
affordability	0.4348	43.48%	1

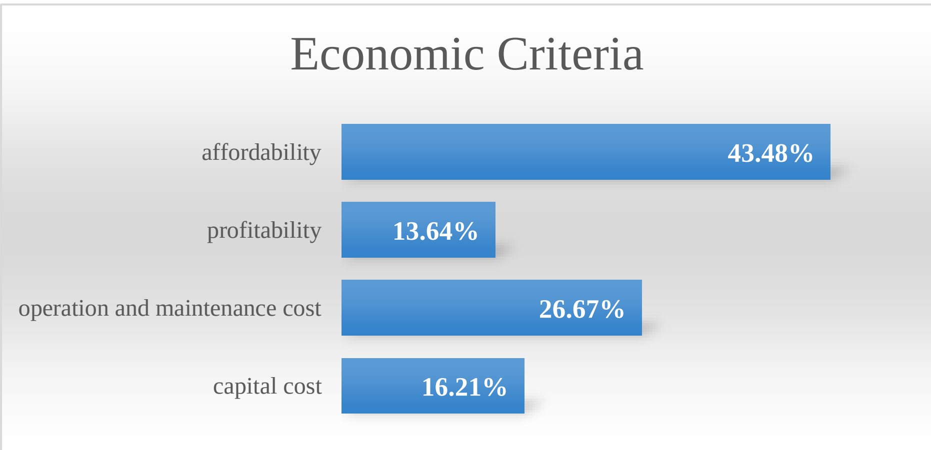

Figure 10. Local priorities in economic criteria

In the technological aspect, technology performance was the most important sub-criterion in selecting renewable energy source and technology for rural electrification in Indonesia. The second most important factor was the availability of equipment. There was only a slight difference between these two sub-criteria. In contrast, energy experts thought that maturity of the technology was the least important sub-criterion that should be considered. Ease of decentralization and training requirement become the third and fourth most important criteria, respectively. The detailed results are shown in Table 13 and illustrated in Figure 11.

Table 13. Estimated weight and rank in technological criteria

Sub-Criteria	Priority Weight	Priority Weight (%)	Rank
maturity of technology	0.1353	13.53%	5
technology performance	0.2585	25.85%	1
availability of equipment and parts	0.2363	23.63%	2
training requirement	0.1778	17.78%	4
ease of decentralization	0.1921	19.21%	3

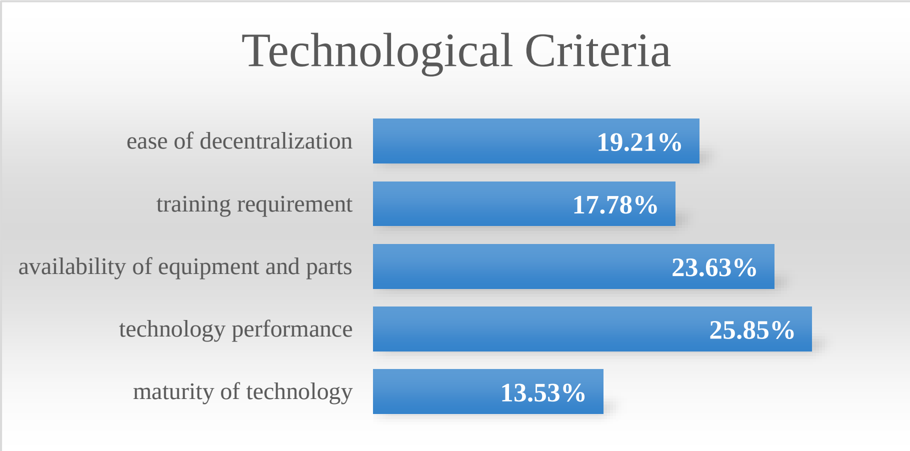

Figure 11. Weight and rank in technological criteria

From the socio-political point of view, energy experts thought that public acceptance was the most important sub-criterion in selecting renewable energy sources and technologies for rural electrification in Indonesia. Government policy support was the second most important sub-criterion and job creation the least important criterion. The detailed results in the socio-political criteria are shown in Table 14 and illustrated in Figure 12.

Table 14. Estimated weight and rank in the socio-political criteria

Sub-Criteria	Priority Weight	Priority Weight (%)	Rank
job creation	0.2823	28.23%	3
public acceptance	0.3818	38.18%	1
government policy	0.3358	33.58%	2

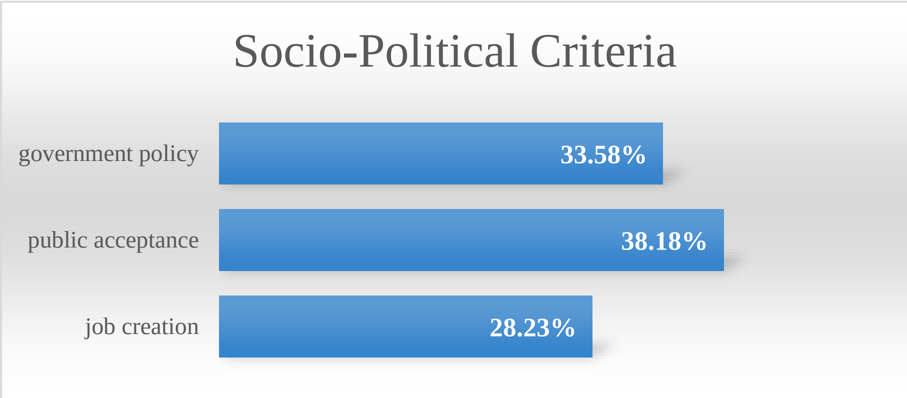

Figure 12. Weight and rank in the socio-political criteria

For the environmental criterion, energy experts considered land requirement as the most important sub-criterion in selecting renewable energy sources and technologies for rural electrification in Indonesia. Land requirement dominates as the environmental criterion with almost 50% of the vote. The other sub-criteria, which are CO2 emission and noise pollution, were the second and third most important, respectively. More detailed information is presented in Table 15 and Figure 13 below.

Table 15. Estimated weight and rank in the environmental criteria

Sub-Criteria	Priority Weight	Priority Weight (%)	Rank
CO2 emission	0.2959	29.59%	2
noise pollution	0.2044	20.44%	3
land requirement	0.4998	49.98%	1

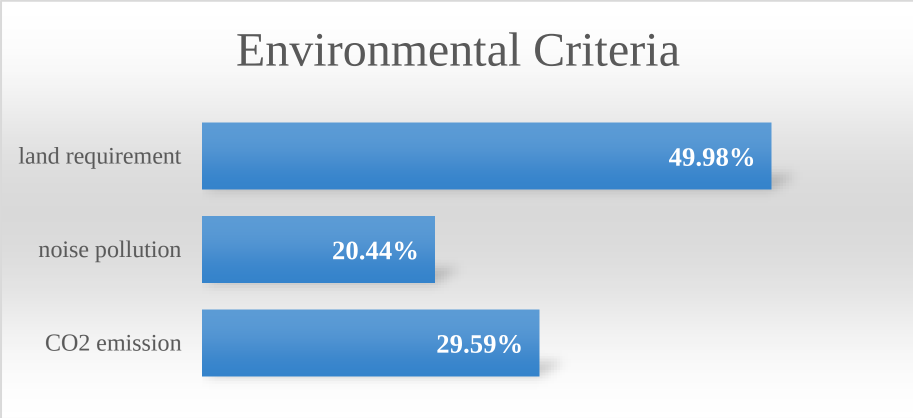

Figure 13. Weight and rank in the environmental criteria

Based on the calculation of all the answers, energy experts thought that availability of energy source was the most important sub-criterion in the energy source criteria. Almost 50% of energy experts chose this as the most important sub-criterion in selecting renewable energy sources and technologies for rural electrification in Indonesia. Resource durability was the second most important sub-criterion while distance to user was the least important sub-criterion in the energy source criteria. The detailed information of the result is represented in Table 16 and Figure 14.

Table 16. Estimated weight and rank in the energy source criteria

Sub-Criteria	Priority Weight	Priority Weight (%)	Rank
resource availability	0.4659	46.59%	1
resource durability	0.3080	30.80%	2
distance to user	0.2261	22.61%	3

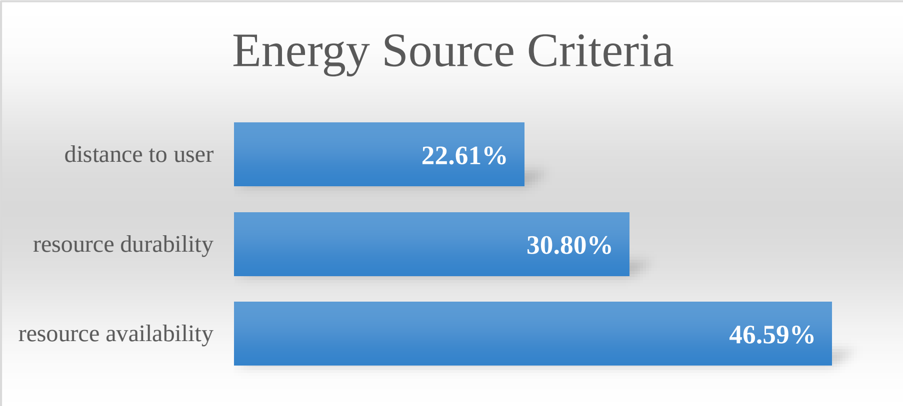

Figure 14. Weight and rank of the energy source criteria

5.1.4 The Result of Global Priorities

After finding the weights and ranks of local priorities, as described above, the next step is to find the weights and ranks of local priorities. Global priorities are the result of calculating the weight of criteria (parent value) multiplied with the weights of each sub-criterion (sibling value) (Heo et al., 2010). The result of global priorities is shown in Table 17 and illustrated in Figure 15.

The result of global priorities shows that the availability of energy source to produce electricity is the most important sub-criterion among the eighteen sub-criteria. The second most important criterion is resource durability from the energy source criteria. The most important sub-criterion in the environmental criteria, land requirement, becomes the third most important sub-criterion. Technology performance, from technological criteria, and public acceptance, from socio-political criteria, rank as tenth and fifth, respectively. In the lowest rank of global priorities is profitability, and the second lowest rank is capital cost. These sub-criteria are from the economic criteria.

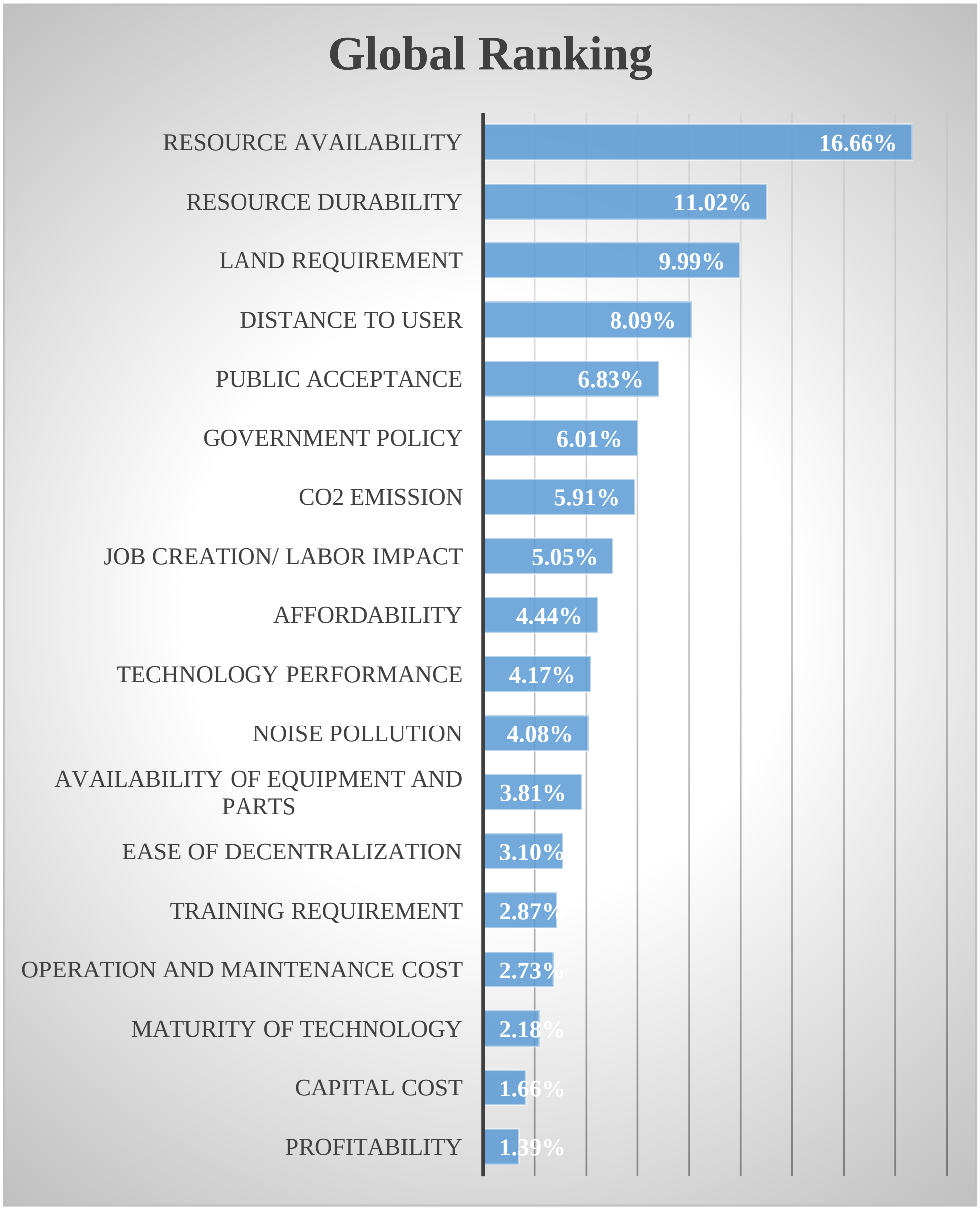

Figure 15. The result of the global priority

Table 17. Summary result of the first survey

Local		Local		Global	Rank
Economic	0.1022	capital cost (E1)	0.1621	0.0166	17
		operation and maintenance cost (E2)	0.2667	0.0273	15
		profitability (E3)	0.1364	0.0139	18
		affordability (E4)	0.4348	0.0444	9
Technological	0.1614	maturity of technology (T1)	0.1353	0.0218	16
		technology performance (T2)	0.2585	0.0417	10
		availability of equipment and parts (T3)	0.2363	0.0381	12
		training requirement (T4)	0.1778	0.0287	14
		ease of decentralization (T5)	0.1921	0.0310	13
Socio-political	0.1789	job creation/ labor impact (Sp1)	0.2823	0.0505	8
		public acceptance (Sp2)	0.3818	0.0683	5
		government policy (Sp3)	0.3358	0.0601	6
Environmental	0.1998	CO2 emission (En1)	0.2959	0.0591	7
		noise pollution (En2)	0.2044	0.0408	11
		land requirement (En3)	0.4998	0.0999	3
Energy source	0.3576	resource availability (Es1)	0.4659	0.1666	1
		resource durability (Es2)	0.3080	0.1102	2
		distance to user (Es3)	0.2261	0.0809	4

5.1.5 Estimated Alternative Energy for Rural Electrification

The purpose of the second survey was to identify the most suitable renewable energy source and technology for rural areas in Indonesia, with North Maluku province as the case study. In the second survey, ten renewable energy experts were asked to give scores on five different energy alternatives based on the sub-criteria information, and their experiences or opinions in renewable energy projects. All the responses were accumulated and averaged, as shown in Table 19. Adapting the AHP method in ranking alternatives, the average scores of each sub-criterion (obtained from second survey) were multiplied with the weights of sub-criteria which were obtained from the AHP method (Table 18). The result of matrix calculation, as shown in Table 20, explains that renewable energy sources and technologies in North Maluku Province, ranked from highest to lowest, are: micro hydro, biomass, solar, geothermal and wind.

Another way to rank the renewable energy alternatives is by calculating the average score for each renewable energy alternative and ranking them. From the result shown in Table 21, the ranking of renewable energy alternatives obtained using this method is the same as that obtained by adapting AHP method.

Table 18. The weight of sub-criteria from the first result

0.1621
0.2667
0.1364
0.4348
0.1353
0.2585
0.2363
0.1778
0.1921
0.2823
0.3818
0.3358
0.2959
0.2044
0.4998
0.4659
0.3080
0.2261

Table 19. The result of the second survey (average of ten respondents)

	E1	E2	E3	E4	T1	T2	T3	T4	T5	Sp1	Sp2	Sp3	En1	En2	En3	Es1	Es2	Es3
geothermal	5.1	6.3	6.9	6.9	7.0	7.5	5.7	6.2	6.4	7.6	5.8	7.05	6.9	6.7	6.1	8.2	8.3	6.5
micro hydro	7.4	7.0	7.1	7.6	7.5	7.3	7.6	7.2	7.6	7	7.5	7.3	7.2	6.8	6.3	8.1	7.5	6.9
solar	7.1	7.0	6.8	6.3	7.5	5.7	6.4	7	7.2	6.4	7.4	6.6	7.5	7.9	6.3	7.3	5.9	7.7
wind	5.8	5.5	6.1	6.3	6.6	6.1	5.3	6.2	6.7	6.4	6.5	6.3	7.3	5.9	5.7	6.5	5.7	5.6
biomass	7.1	6.0	6.5	7.2	7.5	7.6	7.4	7.2	7.3	8.1	6.9	6.5	6.5	7.1	6	6.5	6.6	6.9

Table 20. Ranking of renewable energy technology

	weight	rank
geothermal	34.05	4
micro hydro	36.38	1
solar	34.10	3
wind	30.76	5
biomass	34.28	2

Table 21. Ranking of renewable energy technology based on the average result

	total average	rank
geothermal	6.73	4
micro hydro	7.27	1
solar	6.89	3
wind	6.14	5
biomass	6.94	2

5.2 Discussion

5.2.1 Local Priorities

In this section, the result of this study will be discussed to analyze the important criteria and sub-criteria that should be considered by policy and decision-makers in selecting renewable energy for rural electrification in Indonesia. Based on the result, the judgment of energy experts shows that the energy source criterion is the most important criterion. This result is similar to previous study which stated that energy source is the most important criterion for renewable energy selection in Indonesia (Tasri & Susilawati, 2014). Another study also estimated that energy source is the most important criterion in energy planning in Indonesia (Diputra, 2018). Besides those studies, the Indonesian government also supports the idea that energy source is an important aspect in choosing renewable energy. Indonesian law number 30, year 2007, about energy explains that, in building a power plant, the developer should maximize the utilization of local energy. The utilization of the available local renewable energy for electricity generation will help in realizing the sustainability of energy in the local area. In other words, by ensuring the availability of energy source, a country with sustainable energy can be created.

Environmental criterion is the second most important criterion for selecting renewable energy and technology for rural electrification in Indonesia. This result has similarity with a previous study, which considers environmental criterion as the second most important criterion in evaluating renewable energy source for a rural area in Columbia (Robles & Ospino, 2017). Environmental criterion is also the second most important criterion after energy source criterion in an assessment of energy planning in Indonesia (Diputra, 2018). The result indicates that Indonesia still puts attention on environmental effect, since using renewable energy for power generation reduces negative effects on the environment compared to using fossil energy. The sub-criteria considered under this criterion are CO2 emission, noise emission, and land requirement. This result also reflects how Indonesia places environmental effect as one of the most important aspects to consider, because Indonesia's current condition in those sub-criteria still needs attention. For example, in 2016 there were 201 cases of power plant development that were delayed due to land acquisition problems (201 Kasus Hambat Proyek 35,000MW, 72% Masalah Pembebasan Lahan, n.d.). Therefore, the government established regulation to solve land acquisition problems to accelerate power generation development through presidential degree number 4, year 2016. Moreover, in order to tackle high level of CO2 emission, Indonesia pledged on the INDC in the Paris Agreement Conference. By pledging, Indonesia needs to reduce carbon emission by avoiding fossil energy power plant and prioritizing renewable energy power plant, which has lower carbon emission.

Socio-political criterion is the third most important criterion in selecting renewable energy source and technology for rural electrification in Indonesia. The sub-criteria considered under socio-political criteria are job creation, public acceptance, and government support. This result indicates that energy experts believe the effect of renewable energy power plant development on social or political condition is important to a certain extent. It would be ideal if there were a renewable energy power plant that can create massive job opportunities, support government policy/program and be accepted by the people or local communities. To fulfill the socio-political criterion, the power plant should have a good plan that consists of thorough planning, developing and operating and maintaining. In addition, the renewable energy power plant should be supported by all stakeholders, including people/community, local government, central government, energy companies as well as investors. There is one example of solar photovoltaic development in Indonesia that was supported by all stakeholders. The project is the installation of solar PV for Karampuang island, South Sulawesi. That project was funded by Millennium Challenge Corporation (MCC), a foundation set up by the United States to provide grants for renewable energy power plant development in remote areas. The project was also supported by the Ministry of National Development Planning Agency (Bappenas), the US Embassy, the Ministry of Foreign Affairs, the Ministry of Energy and Mineral Resources, PT. Trinitan Global as a developer and the local people. After the project, share ownership was divided so that local community has 51% share ownership and PT. Trinitan Global has 49% share ownership (Walker et al., 2013) (Electrifying Karampuang: Partnership Model to Manage Solar Power Plant Involves Community and

Private Stakeholders - Millennium Challenge Account - Indonesia, n.d.). All in all, the participation, cooperation, and support of all stakeholders are key in ensuring the sustainability of renewable energy power plants.

This research identified that technical criterion is the second least important criterion for selecting renewable energy source and technology for rural electrification in Indonesia. This finding is quite different to Rojas-Zerpa and Yusta (2015) who found that technology is the most important criterion in energy planning for rural villages of Venezuela. Heo et al. (2010) also found that technological criterion is the most important criterion for renewable energy dissemination in South Korea from an energy specialist point of view. The different result is caused by the different economic and geographical conditions. In a developed country, most people use advanced technology, while, in developing countries, they still use outdated technology. The advanced renewable technology power plant has the advantage of being able to produce high quality and quantity of electricity. However, advanced technology is costly, and this might the reason why energy experts thinks that the technology criterion is not that important compared with the energy source, environmental and socio-political criteria in the case for accelerating electrification in a rural area. For rural electrification, an easy to operate and easy to maintain power plant technology is more important than the advanced technology, the justification being based on designing a sustainable off-grid project for rural electrification (The World Bank & The Energy and Mining Sector Board, 2008).

Rural electrification means providing electricity in the rural area, remote area, and isolated area. It will be difficult if providing electricity uses technology which needs a professional technician to maintain and operate, or power plant technology with foreign product of equipment and parts. This will create difficulties in replacing the power plant parts.

This research found that economic criterion is the least important of the criteria in selecting renewable energy source and technology for rural electrification in Indonesia. This result has opposite finding compared to the result from Heo et al. (2010) which found that the economic criterion is the most important of the criteria in renewable energy dissemination in South Korea. Kabir and Shihan (2003), Ahmad and Tahar (2014) and Al Garni et al. (2016) also found that economic criterion is the most important technology that should be considered in selecting renewable energy source and technology in Bangladesh, Malaysia and Saudi Arabia, respectively. The supportive research for this finding is research from Robles and Ospino (2017) which found that economic criterion was the least ranked criterion before risk criterion for evaluating renewable energy source in the rural area of Columbia. (Demirtas, 2013). The research also found that economics was the least important criterion in selecting the best renewable energy technology for sustainable energy planning in Turkey.

By comparing the previous researches and the result of this study, it is explained that the economic criterion is placed as the least important for building renewable energy power plants in the rural area and also for sustainability purposes. For building a renewable energy power plant in the rural area of Indonesia, energy experts think that economic criterion needs to be placed last and consider the other criteria as more important in accelerating rural electrification and supporting rural development. The Indonesia government has an ambiguous target in increasing the renewable energy percentage to 23% in the energy mix by 2025. Indonesia seems to have ignored the economic criteria or factors for accelerating rural electrification. To achieve this, Indonesia has many renewable energy projects despite a limited budget. Indonesia has asked for participation of foreign investors in the renewable energy development program. Indonesia is in a dilemma condition; it wants to achieve the target in renewable energy power plants by building many renewable energy power plants and also building a renewable energy power plant for rural electrification, but, on the other hand, Indonesia is not a rich country; Indonesia needs a budget for renewable energy development. One of the solutions offered is to open the electricity business for small-scale renewable energy, as regulated in MEMR regulation number 38, the year 2016, and establish new regulations of renewable energy prices with MEMR regulation number 50, the year 2017. Even though the Indonesia government has made new regulations to invite investor interested in building small-scale power plants and building renewable energy sources, the regulation cannot work very well because many investors have said that the new regulations about renewable energy prices are not attractive because they do not give the investors any economic benefit (Power in Indonesia: Investment and Taxation Guide, 2017). To attract the investors in participating in the renewable energy projects, the government should create a new regulation that can give benefit on two sides, the government side and also the investor side, as well as the people's side.

5.2.2 Global Priorities

This section will discuss all sub-criteria based on the global priorities result. This section uses a similar framework to Ghimire Prasad (2016) and Diputra (2018) which will divide the analysis into three groups; the first is the high importance sub-criteria, the second group is the medium importance sub-criteria and the third group is the least important sub-criteria in selecting renewable energy sources and technologies for rural electrification in Indonesia. The sub-criteria with weight of more than 6% in the weight of global priorities will be categorized as a highly important sub-criteria group.

Table 22. High importance sub-criteria

Sub-Criteria	Priority Weight	Priority Weight (%)	Rank
resource availability	0.1003	16.66%	1
resource durability	0.1104	11.02%	2
land requirement	0.0811	9.99%	3
distance to user	0.1670	8.09%	4
public acceptance	0.0501	6.83%	5
government policy	0.0594	6.01%	6

Table 22 shows the sub-criteria categorized in the high importance criteria group. All the sub-criteria in that group must be considered before selecting renewable energy source and technology for rural electrification in Indonesia. All sub-criteria in the energy source criteria and some criteria in environmental and socio-political criteria are categorized in the high importance sub-criteria; it can be inferred that the availability of the renewable energy supply, the clear land acquisition, support from local people and government are the most important aspects that should be fulfilled in selecting a renewable energy source. This finding is in line with MEMR regulation number 38, the year 2016, that regulates the small-scale power generation for remote area, small islands and border area to use the local energy source to maintain a sustainable supply and electricity.

Table 23. Medium importance sub-criteria

Sub-Criteria	Priority Weight	Priority Weight (%)	Rank
CO2 emission	0.0595	5.91%	7
job creation/ labor impact	0.0453	5.05%	8
affordability	0.0278	4.44%	9
technology performance	0.0306	4.17%	10
noise pollution	0.0677	4.08%	11
availability of equipment and parts	0.0377	3.81%	12
ease of decentralization	0.0412	3.10%	13

Table 23 shows all sub-criteria with the priority weight in intervals of 3% and 6% and categorized as an important medium criterion in selecting renewable energy source and technology for rural electrification in Indonesia. Table 24 shows the least important sub-criteria with the priority weight of less than 3%. The last group is the sub-criteria which should be the last consideration of selecting renewable energy source and technology for rural electrification in Indonesia based on energy experts' point of view. Most of them are in the economic criteria and the others are from the technological criteria. In the group of least important sub-criteria, the profitability sub-criterion is the least important. It indicates that, for rural electrification in Indonesia using renewable energy, energy experts seem to ignore the profit that could be produced by building renewable energy power generation.

Table 24. Least important sub-criteria

Sub-Criteria	Priority Weight	Priority Weight (%)	Rank
training requirement	0.0410	2.87%	14
operation and maintenance cost	0.0169	2.73%	15
maturity of technology	0.0283	2.18%	16
capital cost	0.0142	1.66%	17
profitability	0.0216	1.39%	18

5.2.3 Comparative analysis

This section discusses the comparative analysis of the respondents in the first survey. The survey was conducted to find the important criteria and sub-criteria in choosing renewable energy sources and technologies for rural electrification in Indonesia. The responses of the survey can be categorized as two groups, energy experts from government and energy experts from energy companies. The comparison of the two groups is shown in Figure 16-Figure 22.

Figure 16 shows the big differences of responses from government and the state-owned energy companies in regard to socio-political criteria. The picture indicates the different perspectives of government and the state-owned energy companies; the energy experts from the state-owned energy companies put the socio-political criterion as the second most important criterion while the energy expert from the government put it as a second least important criterion.

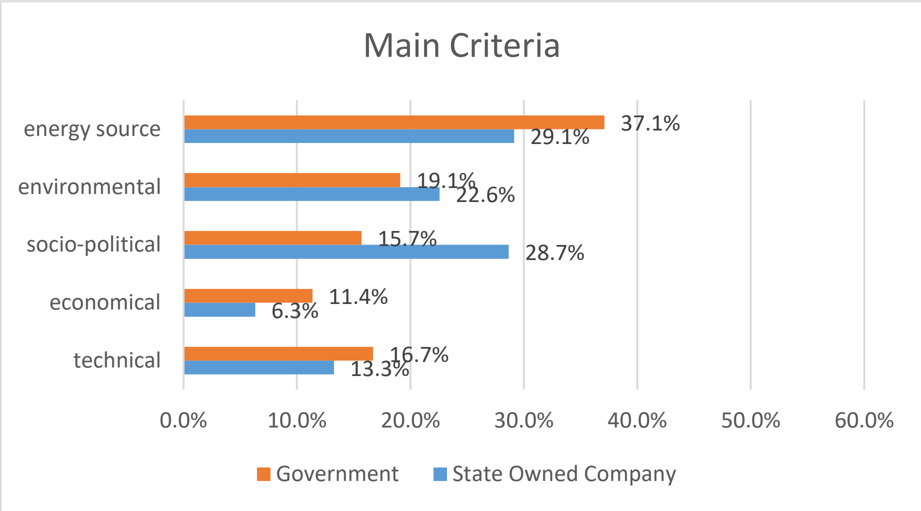

Figure 16. Comparison of main criteria

The difference of responses was caused by the different job and function of the two groups. Based on law number 30, the year 2009, the function and job of the government, which consists of central government and local government, is to create policy, regulation and to supervise the electricity development in Indonesia, while, the state-owned electricity companies are responsible for carrying out electricity supply business, starting from the generation, transmission, distribution, and sale of electricity.

In creating regulation and policy, the government usually uses a top-bottom method, which more focuses on purpose, in this case, the acceleration of electrification to all Indonesia people. The government creates the program and regulations that can support in accelerating electrification, how people can accept the technology and how people can get electricity and seem to rule out the further effect on the people such as how electricity generation can be sustained, how people can maintain it, and how it can have positive impact on the people. On the other hand, electricity companies plan and build electricity infrastructure based on the bottom-up method, they consider what the problem is in the local condition and also the local people's need so that the energy company is more aware of the post effect of building electricity generation for the local people.

Looking at the component of socio-political criteria, the energy experts from the government side think that public acceptance is the most important sub-criteria. On the other hand, the energy experts from the energy companies thinks that job creation/labor impact is the most important factor. As mentioned above, the electricity company has direct interaction with the local people, so they know what people need and what is important in utilizing the electricity. For the government, the regulation and policy come from the central government with collaboration with local government, which has direct interaction with the local people. In an ideal condition, the government should be able to understand the local people. Some good connections in rural electrification planning are missing. The government should not only focus on how the public accepts the rural electrification, but how the electricity can create economic value to the local people. The electricity companies seem to understand the local people's need as regard the labor impact of electricity generation. That is not the direct impact of rural electrification, but the indirect impact, because, by providing electricity continuously, people can do economic activities and it has an effect in increasing their economic value. For example, in North Maluku case, people who live there mostly work as a fisherman. They need cooling storage to keep the fish fresh. To do that, people need electricity continuously, to build cooling storage and also produce ice blocks. By doing this, the people can sell the fish to a big market or the bigger islands. As a result, people can improve their economic condition, so they can keep pay for electricity because they realize how important electricity is. The current government program to provide electricity in a rural area is by providing the people who live in rural areas with a Solar PV lamp kit. This might be used for lighting by local people, but, in reality, many people sell those kits to the market to get money, because they don't just need money for the electricity and lighting.

The other thing that can be discussed is land requirement; there is a huge difference of opinion between the energy experts from government and those from electricity/energy companies, as shown in Figure 20. The government side thinks that the land requirement is the most important sub-criterion, but electricity/energy companies have the opposite opinion. This happens because of most of the delayed power generation projects are caused by land acquisition problems. This problem becomes a burden to both institutions. The government has more consideration for this problem because, as a regulator, the government has more power to reduce the land acquisition problem. One of the government regulations to solve the land acquisition problem to accelerate building electricity infrastructure is presidential law number 04, the year 2014.

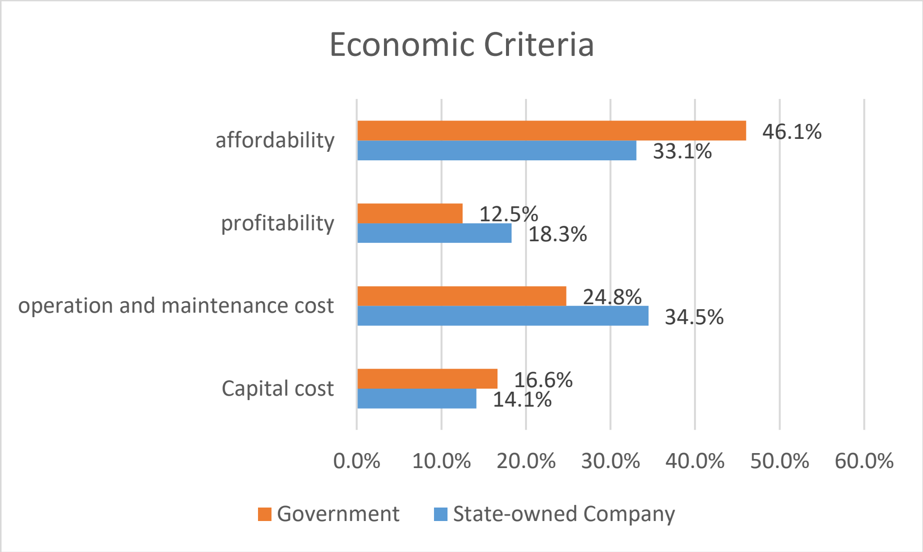

Figure 17. Comparison of local priorities in economic criteria

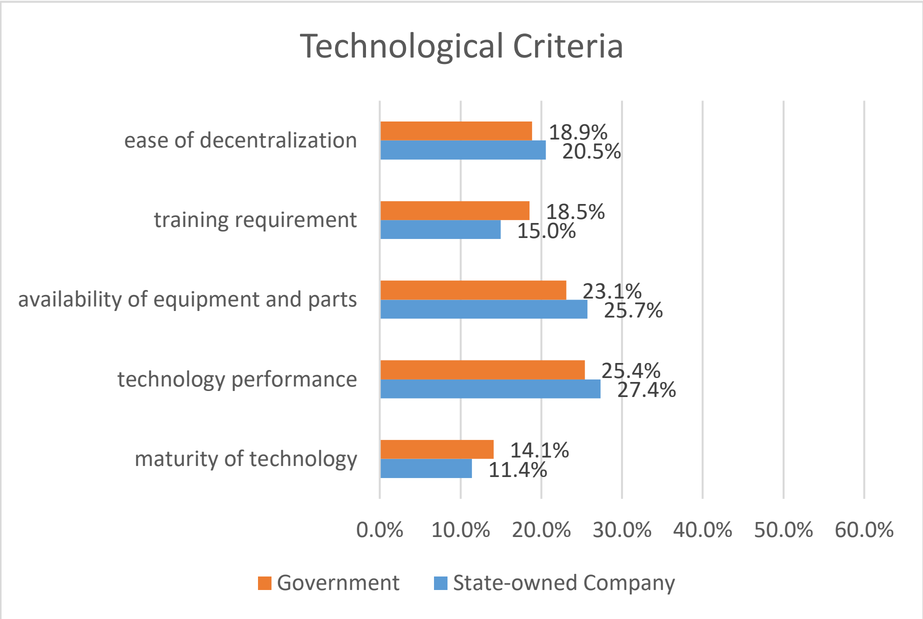

Figure 18. Comparison of local priorities in technological criteria

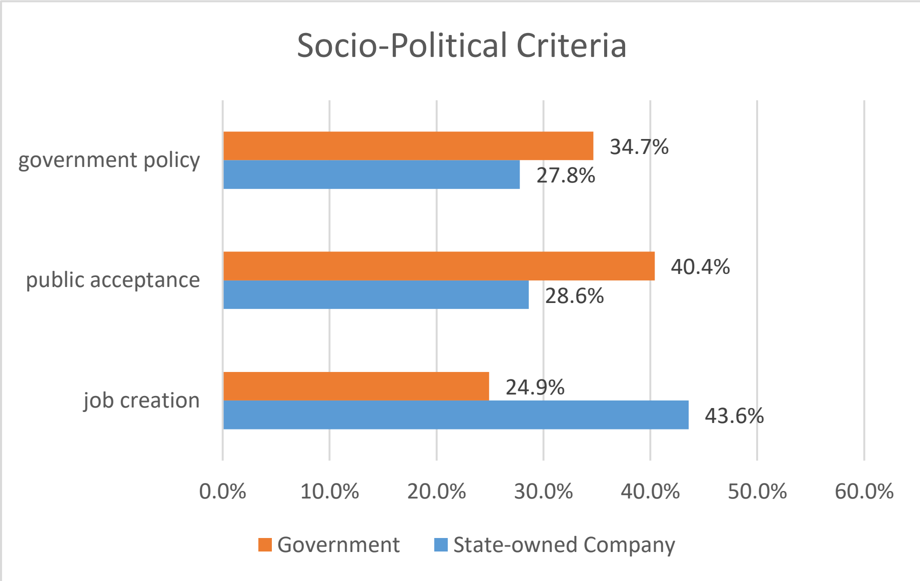

Figure 19. Comparison of local priorities in socio-political criteria

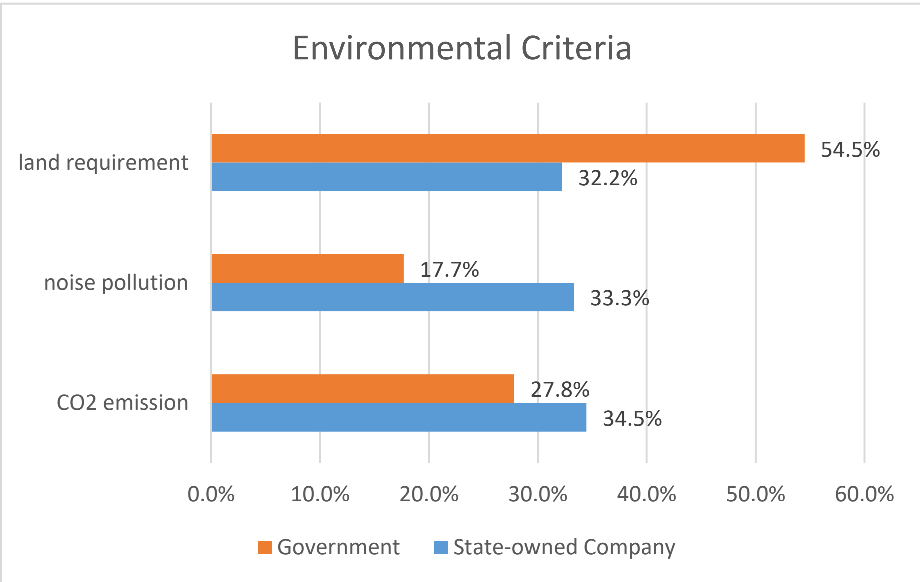

Figure 20. Comparison of local priorities in environmental criteria

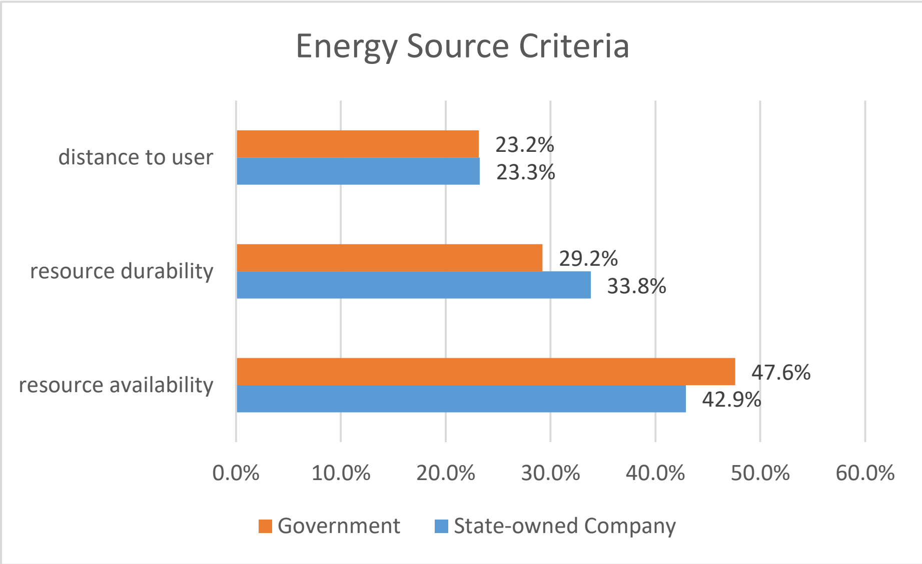

Figure 21. Comparison of local priorities in energy source criteria

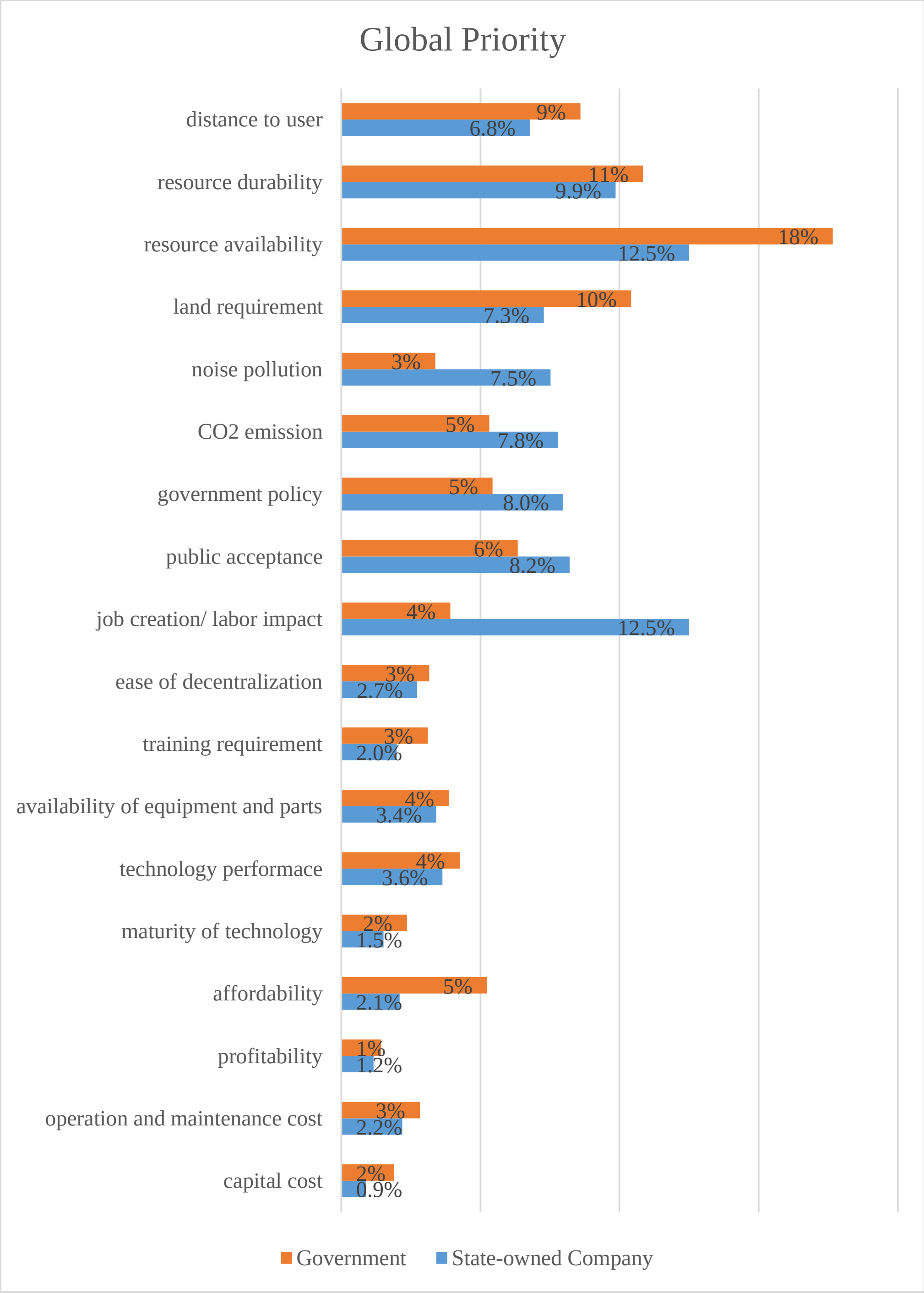

Figure 22. Comparison of sub-criteria in global priorities

5.2.4 The Alternative Renewable Energy Sources

This section discusses the result of scoring renewable energy alternative technologies in North Maluku by renewable energy experts, for finding the most suitable renewable energy source and the technology for rural electrification in Indonesia. After gathering the score of renewable energy technologies from ten renewable energy experts, this study averages all ten responses and the result is shown in Table 19.

By analyzing each energy alternative with all the sub-criteria, geothermal energy got the highest score, both in resource durability and resource availability. This because the geothermal energy can supply energy 24 hours a day and 365 days a year without energy storage, or the resource availability because geothermal energy source in North Maluku is available to produce electricity in that area, whereas geothermal energy got the lowest score in capital cost sub-criteria. This result might be because the high capital cost can bring adverse effect to the other sub-criteria, such as the affordability price criterion. The high capital cost, which includes exploration cost, is one of the barriers as mentioned in the report (International Renewable Energy Agency (IRENA), 2017; National Energy Council, 2017).

In micro hydro energy, the highest sub-criteria score is the resource availability; this is because micro hydro is one of the energies that are available to generate electricity in that area. In micro hydro energy technologies, the lowest score is land requirement. This might be because many hydropower plant projects have problems with land acquisition. Because the hydro power plant should be near a water reserve, in some areas finding the right location and acquisition problem free land is still tricky. That might be one of the reasons why the land requirement problem has the lowest score sub-criteria for micro hydro power plants.

Solar energy got the highest score from renewable energy experts in the noise sub-criterion; this because the solar power plant is categorized as a quiet power plant, because, in producing electricity, solar energy uses chemical and electrical reaction, not a mechanical process such as do a diesel power plant or wind turbine power plant. On the other hand, solar power plant got the lowest score in the technology performance sub-criteria; this is because a solar power plant cannot be operated at full nameplate capacity. That can be called as a low capacity factor power plant; solar power plants only have a capacity factor less than 25% and can only produce electricity while the solar panel receives solar irradiation (Liefting, 2008; National Energy Council, 2017).

For wind turbine energy, the highest score was the CO_2 emission sub-criterion; this was because wind turbine generates electricity without fuel combustion and only uses wind energy from nature. The level of CO_2 emission is also the lowest CO_2 emission technology compared with other renewable energy technology (National Energy Council, 2017). The lowest sub-criterion is the availability of equipment and parts, this because most of the equipment and parts of wind turbine were imported, for example, all 30 turbines used for the Jeneponto wind turbine power plant are manufactured from Spain (Sidrap (Indonesia) - Wind farms - Online access - The Wind Power, n.d.).

Biomass energy had highest score in the job creation/labor impact sub-criterion, the experts had the same opinion as a report from the European Union (2011) and research from Chatzimouratidis and Pilavachi (2008). Generating electricity with biomass energy can create many jobs because there are two main activities to generate electricity, operating and maintenance and producing the fuel. The lowest score was in the operation and maintenance cost sub-criterion and land requirement. As mentioned, the process to produce biofuel/biogas, which is included in operation and maintenance cost, has an impact on high operation maintenance cost and needs a large area to produce the fuel.

By categorizing based on the criterion, in the economic criteria, among all alternatives and all sub-criteria, the lowest score was geothermal in the capital cost sub-criteria. As mentioned in the previous discussion, the capital cost of geothermal energy was expensive because the exploration cost is included to capital cost. In a different situation, the highest score of economic criterion was affordability of micro hydro energy; this is because the price of micro hydro energy is low.

In the technological criteria, the lowest score was the availability of equipment and the parts sub-criterion of wind turbine energy; as mentioned before, the equipment and parts of wind turbine energy are imported. It makes it difficult to get the equipment and parts if the power plant is built in the rural area. In the technological criteria, there were three identical highest scores, the technology performance of biomass, availability of equipment and parts of micro hydro and ease of decentralization of micro hydro. In this study, the indicator of technology performance was the capacity factor power plant; in the specification, the capacity factor of biomass is the highest compared with other technologies. Other highest score sub-criteria were the availability of equipment and parts and ease of decentralization of micro hydro, because micro hydro is a very mature technology, it is easy to operate and maintain and most of the equipment and parts are produced domestically. Because a micro hydro power plant can be operated 24 hours a day and 365 days a year, it can be used without additional energy storage and can produce stable electricity; this technology is accessible to decentralize and connected to the grid.

In the socio-political criteria, the lowest score among energy alternatives and the sub-criteria was public acceptance of geothermal. The renewable energy experts think that geothermal energy for generating electricity is difficult to be accepted by people. This might be because many people believe that by building a geothermal power plant, the soil water reserve will decrease, consequently people who live nearby protested and opposed the geothermal power plant project. The highest score in the socio-political criteria is from the job creation sub-criterion of biomass; as mentioned in previous discussion, biomass can create jobs because it has more steps in the generating electricity process.

In the environmental criteria, the lowest score was the land requirement of wind. The wind turbine needs more space to maintain the safety zone with the local people, which might be the reason why renewable energy experts gave a low score in the land requirement of the wind turbine. The highest score in the environmental criteria is noise pollution of solar energy; as explained in the previous discussion, solar energy is categorized as quiet power plant technology because electricity is generated by a chemical and electrical process.

In the energy source sub-criteria, the lowest score was in the distance of users of wind energy. As mentioned in the previous discussion, the distance of wind turbines should be maintained to create a safety zone. Based on "Urban Energy Transition: Renewable Strategies for Cities and Regions" (Droege, n.d.), the ideal distance of a wind turbine power plant is ten times the wind tower's height. The highest score in the energy source criteria is resource durability of geothermal; this is due to the fact that geothermal energy source can be used over a long time and every day, 24 hours a day and 365 days a year.

Figure 20 shows the result of scoring the sub-criteria in each energy alternative multiplied with the weight of the sub-criteria from the AHP method. The result found that micro hydro has many advantages compared to the other technology. Some of the advantages are mentioned in the previous discussion, for example, micro hydro power generation can produce stable electricity (not intermittent electricity). Micro hydro technology is also a very mature technology and most of the parts and equipment are domestically produced, which will make easy in operating and maintaining. The micro hydro power plant is also easy to decentralize and connected to the electricity grid. Other than that, the capacity factor of this technology is sufficiently high that price will be low.

The other result shown in Figure 21 is the average of scoring the renewable energy technologies. It shows the same rank as the previous result, both the results identified that micro hydro is the best energy alternative in North Maluku and the second one is biomass, number three is solar, fourth is geothermal energy, and the last one is wind energy.

In summary, in finding the most important criteria and sub-criteria, this study used AHP method with respondents being energy experts from the government and energy companies. The result found that the most important criterion in selecting renewable energy for rural electrification is energy source. The energy source criterion has the highest score with 35.76%, followed by environmental criterion, socio-political criterion, technological criterion and, finally, economic criterion. That result identified that, in building renewable energy for rural electrification, the most important thing is ensuring the energy source to get the sustainability of electricity and it seems to ignore the other criteria. Looking at the sub-criteria in depth, in the economic criteria the most important criterion is the affordability sub-criterion, while, in the technological criteria, the most important sub-criterion is technology performance. In the socio-political criteria, the most important is the public acceptance criterion, in environmental criteria it is the land requirement sub-criterion and, in energy source criteria, it is the resource availability. In global ranking format, the most important sub-criterion comparing all sub-criteria is the resource availability and the least important is the affordability sub-criterion. By comparing the responses from the government side and energy company side, this study found a big difference of responses in socio-political terms. This is because of a different approach in responding to rural electrification using renewable energy.

In the second survey, to find the suitable renewable energy for rural electrification in Indonesia, this study chose one case area, North Maluku. In the survey, all the sub-criteria used in the first survey were provided with detailed information to each renewable energy alternatives. The score was evaluated by renewable energy experts who were experienced in renewable energy projects. The result of this survey shows that micro hydro power plant got the highest score with 7.27 on a 10-point scale. By combining the AHP result and the scoring of sub-criteria in each renewable energy alternative, the result is the same, micro hydro got the highest weight with 36.38. The ranking of energy alternatives after micro hydro are biomass, solar, geothermal and, finally, wind energy. Comparing with other renewable energy, micro hydro has many advantages for rural electrification in Indonesia, such as from an economic aspect it can produce cheap electricity and in technological terms, micro hydro is categorized as a very mature technology.

After analyzing the result of this study, this section will highlight the important finding, which is the characteristic of rural electrification using renewable energy in Indonesia. For providing electricity in the rural area, the most important thing is ensuring the energy supply, because, with that, the electricity production will be continuously maintained. Other than that, by choosing the renewable energy that can be used anytime and for a long time, so electricity production does not require energy storage. Moreover, ease of use and easy to maintain are also important, because, with easy technology, local people who do not have a high education background can maintain and operate it easily. The other important thing is the electricity price; renewable energy for the rural area should be a renewable energy that can produce affordable electricity for the local people. To realize that kind of technology, all elements need to participate, starting from the government, both local and central, the local people, the energy company and also the investors need to have good cooperation.

The government, which has authority in electricity development and regulation, needs to take the lead in developing rural electrification using renewable energy. The current Indonesian government program for accelerating electrification in rural area using renewable energy is LTSHE (Lampu Tenaga Surya Hemat Energy)/energy efficient solar lamp. In the perception of sustainability energy, the LTSHE program is not the best solution for providing electricity in the rural area. This is because LTSHE can only sustain for a short period, and many people who get the LTSHE are selling the lamps to get money, instead of getting electricity. A better program should be created in order to build power plants with sustainable electricity and affordable price for the rural area.

At the beginning of 2016, the government created Program Indonesia Terang (PIT)/Indonesia Bright program to provide electricity in villages without electricity. This program has a good start on planning the rural electrification using three approaches.

- First, extended grid connection. PLN as a state-owned electricity company, built an extended distribution line and connected the electricity from the nearest grid system to villages in rural areas. PLN will choose this option taking into consideration the location of the villages as regard to the nearest grid system, the spread of houses and the electricity demand. PLN will build the extended grid if they think extending the grid will bring positive economic impact. PLN will not build an extended grid if it does not have economic value.
- Second, build a mini-grid or microgrid to the rural area in which the houses are concentrated in one area. In Indonesia, a microgrid was built by the government and affords an asset to the local people to operate the microgrid. Now, GOI is giving open access for investors to invest and

build a microgrid in the rural area. For the electricity price, this can be discussed with the local government if the investor builds an off-grid microgrid, but, if the investor connects the microgrid to PLN's grid, the investor need to deal with the price of electricity with PLN using a tariff mechanism. The electricity for a micro grid can be generated by using diesel and renewable energy resources or can be combined between diesel and a renewable energy power plant.

- Third, installed solar home system (SHS) for an individual house. This option will be chosen for providing electricity in the isolated area with the characteristic of the houses/demand spread with wide distance between one houses to another. Installing SHS in rural area houses is the fastest way to get the electricity' most SHS in Indonesia are installed with a government budget and operated by the household.

The "Bright Indonesia" had a good plan, starting from development planning, investment planning, and also the subsidy and tariff mechanism planning. This program also has good cooperation with local government, electricity companies and other ministries in Indonesia. However, unfortunately, this program was canceled as soon as the ministry was changed. A future rural electricity program that can be a solution and replacement program for "Bright Indonesia" is to build a micro-grid with a hybrid renewable energy power plant. That program can maximize the utilization of the available renewable energy source. It can use a combination of renewable energy sources, wind, biomass, micro hydro, geothermal and solar. The purpose of building the micro hydro is that it is easy to decentralize and suitable for rural electrification and for guaranteeing a sustainable electricity supply.

Other than a rural electrification program, regulation which can support the renewable energy for rural electrification should be provided. Several regulations have been published by the government for renewable energy development and rural electrification. For example, MEMR regulation number 38, the year 2016, is a mechanism of small-scale power supply business to accelerate rural electrification in remote borders and isolated islands, and MEMR regulation number 50, the year 2017, is about mechanism and price in the utilization of renewable energy for electricity generation. That regulation seems not attractive for investors to invest in renewable energy and rural electrification in Indonesia. The participation of investors in Indonesia's renewable energy development is important because Indonesia is not a rich country. In order to attract investment and increase the renewable energy development, the government should create regulation that can have positive effects to both sides.

Chapter 6. Conclusions

6.1 Overall Conclusion

This study discussed the electricity development plan in Indonesia, specifically on the rural electrification development plan and also renewable energy potential in Indonesia. At the end of 2017, Indonesia achieved a 95.35% electrification ratio, which is quite high, but, in reality, more than 2,500 villages are not yet electrified. Most of those villages are located in rural area, isolated area, border area, and small islands in the eastern part of Indonesia. To deal with that problem, the government of Indonesia targeted on providing electricity to all villages in Indonesia and fulfilling the target on 100% villages electrified in 2019. Other than that, Indonesia has an ambitious target to achieve 23% of renewable energy in the total energy mix by 2025 as targeted in government regulation number 79, the year 2014, in the national energy policy and 23% renewable energy in total electricity generation by 2027 (RUPTL PT PLN (PERSERO) 2018-2027 Kebijakan Ketenagalistrikan, 2018). The abundant renewable energy potential in Indonesia is one of the reasons why Indonesia set the target on increasing renewable energy in the energy mix. Based on that condition, the Indonesia government has programs for providing electricity in the rural area of Indonesia using renewable energy. Following the government program, this study aims to analyze the renewable energy sources and technologies for rural electrification with detailing two objectives, finding the most important criterion and sub-criterion in selecting renewable energy source and technology for rural electrification and finding the suitable renewable energy source and technology for rural electrification in Indonesia.

This study used the Analytic Hierarchy Process (AHP) method in finding the most important criterion and sub-criterion in selecting renewable energy source and technology for rural electrification in Indonesia. The five criteria used in this study are technological, socio-political, economic, environmental and energy source. The eighteen sub-criteria used in this study are divided into five different criteria. In the economic criteria are the capital cost, operation, and maintenance cost, profitability and affordability sub-criteria. In technological criteria, the sub-criteria are the maturity of the technology, technology performance, availability of equipment and parts, training requirements and ease of decentralization. The socio-political criteria, consist of job creation, public acceptance, and government policy sub-criteria. In environmental criteria are CO2 emission, noise pollution, and land requirement sub-criteria. Energy source criteria consist of resource availability, resource durability, and distance to user sub-criteria. All criteria and sub-criteria were asked to energy experts from government and energy/electricity companies following the AHP method. For finding the suitable renewable energy source and technology for rural electrification in Indonesia, this survey used scoring on five renewable energy alternatives. The scoring energy alternative used one study case of rural electrification in Indonesia, North

Maluku Province. The detailed information on sub-criteria of energy alternative was provided and renewable energy experts experienced in a renewable energy projects in Indonesia were asked in order to obtain the score on each technology. After aggregating the responses and calculating as group opinion, this study came up with four findings:

First, the result of the AHP method showed that the most important criterion for selecting renewable energy for rural electrification in Indonesia is the energy source. It dominated with 35.7% from a total five criteria, followed by the environmental, socio-political, technological and economic criterion with 19.9%, 17.8%, 16.1%, and 10.2%, respectively. Going through the components that construct the energy source criterion, the resource availability and resource durability were the dominant sub-criteria. From this finding, it can be explained that the sustainable energy source accounts for the most consideration in selecting a renewable energy power plant for the rural area of Indonesia. This is one of the unique characteristics of rural electrification. Mostly, the economic aspect has the highest consideration in building a large-scale renewable energy power plant.

In contrast, the availability of energy source is the most important thing for rural electrification, and the other criteria, such as socio-political, environmental, technological and economic, appear to be ignored. The reason is that, by ensuring the availability of energy source, it can ensure the electricity production. To support this, the utilization of a local renewable energy source could be one of the answers. The government has established regulation to support small-scale power plants for an isolated area, border area and small island and also introduced a regulation on renewable energy tariffs.

Second, according to expert opinion, six important sub-criteria should be considered in selecting a renewable energy source for rural electrification in Indonesia. Those are the resource availability, resource durability, land requirement, distance to the user, public acceptance and government policy. Based on the finding, in selecting a renewable energy source and technology for a rural area, the government or energy company should ensure the renewable energy source in order to provide sustainability of the electricity, clear of land acquisition problems, located near the local people, accepted by the people, and supporting the government policy.

Third, there are significant differences between energy experts from the government and from the energy companies in the socio-political criterion with 13% difference. That happened because of the different approach to rural electrification; the energy companies used a bottom up method that allowed them to analyze the people's needs from their direct interaction, while the government used a top-bottom approach. The government focused on the goal then made the strategy based on the goal, so the government cannot provide all the needs of the local people. There is one missing point in how the government is implementing the strategy to realize the goal; there is a lack of feedback from the people, so there is no evaluating from the bottom. By deeply analyzing the sub-criteria, the government considers public acceptance as the most important sub-criteria in providing electricity using renewable energy in the rural area, while the energy experts thinks that job creation is the most important sub-criteria. The primary purpose of rural electrification is not only giving electricity to people, but also increasing the economic condition. Based on this result, both government and energy company experts expect that, by giving people electricity, it will create economic activity and increase the economic condition. However, the government thinks about the expectation of the process of increasing the economy by providing electricity while the energy companies are thinking about the long-term effect after providing electricity. The government thinks that, by building a renewable energy power plant that is accepted by people, the people will have greater responsibility to take care of the power plant so that the power plant will sustain over a long time. The government expects the people will use the electricity to perform economic activities and this will increase the economic condition. On the other hand, the energy companies are more thinking about the long-term effect of providing electricity, in that, by providing sustainable electricity, people will use electricity for performing economic activity, so that it will create more jobs.

Fourth, by choosing North Maluku as an example in rural electrification, this study found that micro hydro is the most suitable renewable energy source for rural electrification in Indonesia. By averaging the survey result, micro hydro got 7.27 points as the highest score, followed by biomass with 6.94, solar with 6.89, geothermal with 6.73 and wind with 6.14. By adapting the AHP method, the rank of micro hydro also become the first rank with the same order. In comparison with other technologies, micro hydro has several advantages that make the technology is a suitable technology for rural electrification. Micro hydro energy can be used for 24 hours a day and 365 days a year with enough water reserves. It affects producing more stable electricity and makes the price of the electricitycheap because it does not require an additional storage system. By providing stable electricity, it will be easy to connect off-grid to the electricity grid because it will not create an unstable grid system. Micro hydro is also a very mature technology and most of the parts and equipment are domestic product, which makes micro hydro easy for operating and maintaining. The capacity factor of this technology is sufficiently high so that the price for it will be low and suitable for rural electrification.

6.2 Policy Implication and Academic Contribution

This study aimed to analyze the renewable energies and technologies for rural electrification in Indonesia through weighting the criteria and sub-criteria in selecting the renewable energies and technologies, and also finding the most suitable renewable energy alternative. As the result of this study, the important criteria and sub-criteria and the most suitable energy alternative can be used for a policy suggestion in improving renewable energy policy in Indonesia. It can help policy makers and also electricity developers/electricity companies in selecting the best renewable energy for rural electrification in Indonesia. Moreover, it can help government to evaluate the current rural electrification using a renewable energy plan and make it better. For example, the current renewable development plan for electricity generation in North Maluku massively uses solar; however, based on this study, the government can utilize micro hydro energy for electricity generation. Using the most important criteria and sub-criteria derived from the study can help the government in prioritizing the problem in rural electrification that should be solved first.

As regard the academic contribution, this research contributes as one of the academic researches using combined AHP method and scoring to find the important criteria and sub-criteria in selecting the suitable renewable energies and technologies for rural electrification in Indonesia and also to find the most suitable energy alternatives. The framework of this study can be used for further study in finding the suitable renewable energy for rural electrification in other specific areas, and the result can be used as a suggestion for policy making.

6.3 Study Limitation and Future Work

This study was conducted with the purpose on analyzing the renewable energy source and technology for rural electrification in Indonesia, by finding the most important criteria and sub-criteria and also selecting the most suitable renewable energy source for rural electrification. The criteria and sub-criteria obtained in the study were the responses of energy experts from the central government and energy/electricity companies. To develop this study for future research, the variety of the respondents should be increased by asking the local government and local energy company who has responsibility for that area, in order to get a more comprehensive analysis and result so that the result can be more applicable in that area. As explained at the beginning of this study, this study has limitation by analyzing the most suitable renewable energy for rural electrification only in one specific province, North Maluku. In the future, the research can be developed by selecting other specific rural areas of Indonesia and also can be used for general rural electrification in Indonesia by asking the energy experts from several areas of Indonesia. For other future work, this study can be used for evaluating the technology for power generation in Indonesia.

In this study, the framework used the combination of AHP method and scoring the alternatives; in future study, it can be developed by using the AHP method for the overall process, starting from finding the important criteria and sub-criteria through to selecting the most suitable renewable energies and technologies for rural electrification in Indonesia.

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Appendix 1: Survey 1

Questionnaire on "Analysis on Renewable Energy Sources and Technologies for Rural Electrification in Indonesia using AHP"

This questionnaire is used as one of the methodologies for my research entitled "Analysis on Renewable Energy Sources and Technologies for Rural Electrification in Indonesia using AHP". All your answer will be analyzed and formulated to find the ranking of criteria and sub-criteria/factor on choosing the suitable renewable energy source for generating electricity in rural areas of Indonesia.

In this questionnaire, all your information and your answer are remained confidential and used only for academic research purpose. All your comments, suggestions or questions about this questionnaire are welcome, you can contact me by email: alfinazuss@snu.ac.kr and alfina.zussida@gmail.com

The answer of this questionnaire will be analyzed using Analytic Hierarchy Process (AHP) to know the important criteria and sub-criteria that must be considered by decision-makers on choosing renewable energy source for rural areas in Indonesia. In this questionnaire, the pairwise comparison questions enable the respondents to compare the relative importance between two criteria or two sub-criteria and in the end, criteria and sub-criteria will be calculated and ranked using AHP method.

Alfina Zussida
Seoul National University

How to answer this questionnaire?

In this questionnaire, the pairwise comparison questions are based on hierarchy tree below, with five criteria and eighteen sub-criteria. The importance of each criterion and sub-criterion will be evaluated using qualitative and quantitative methods.

You only need to give your judgment based on your own preference and choose the most important factor from two criteria or sub-criteria.

Example: You have to compare the relative importance between A and B, to answer the question, you can choose one option among all nine options, which much more represent your view or preference.

A	1	2	3	4	5	6	7	8	9	B

Guidance

1: if A is EXTREMELY MORE IMPORTANT than B

2: if A is VERY STRONGLY MORE IMPORTANT than B

3: if A is STRONGLY MORE IMPORTANT than B

4: if A is MODERATELY MORE IMPORTANT than B

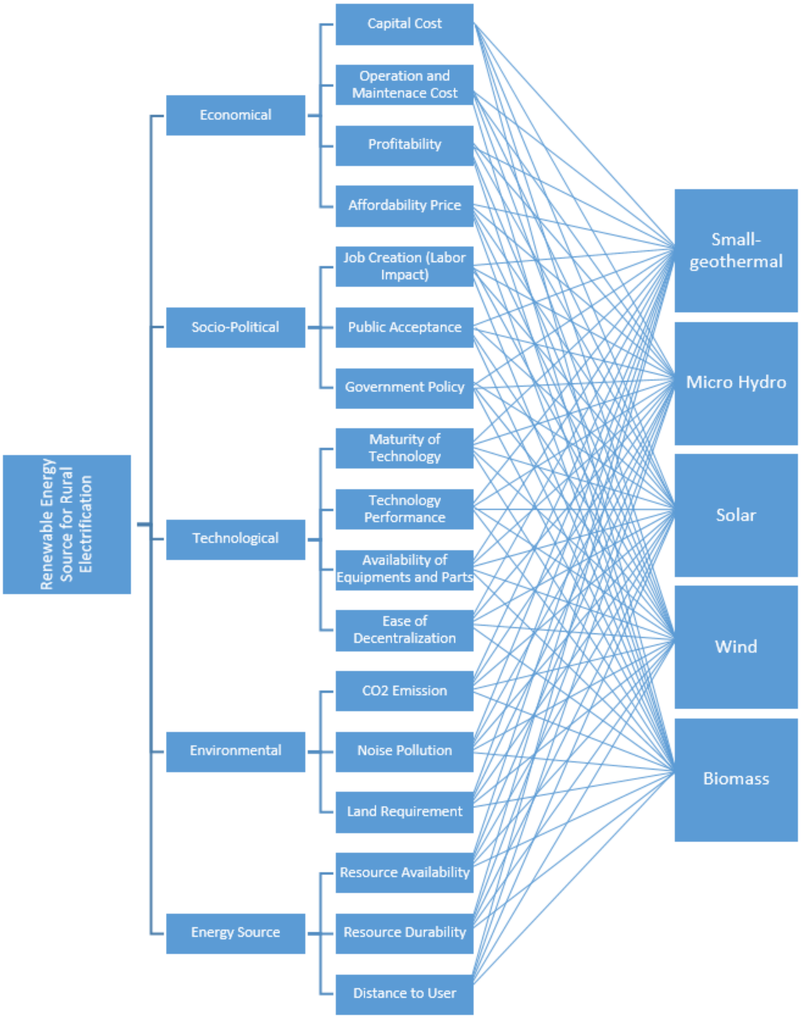
5: if A and B are EQUALLY IMPORTANT

6: if B is MODERATELY MORE IMPORTANT than A

7: if B is STRONGLY MORE IMPORTANT than A

8: if B is VERY STRONGLY MORE IMPORTANT than A

9: if B is EXTREMELY MORE IMPORTANT than A



You must note that the degree of importance for left side criterion, in this case, is A, continuous to decline from 1 to 4 while the level of importance for right criterion, in this case, is B, continuous to increase from 6 to 9. And if you believe that the two options are equally important, you can choose 5 as your answer.

If you already have a thorough understanding of this questionnaire then let's move forward to the actual questions.

Assessment the Factors on Selecting Suitable Renewable Energy Source for Rural Area in Indonesia: Main Criteria

Providing electricity to rural areas using local energy source become important to support the regional development and moreover for national development. Every renewable energy source has its own value become the best energy source to be chosen from. On selecting the suitable renewable energy source for rural electrification, several criteria should be considered by the decision makers. In this section, you have to provide your judgment in comparing the relative importance between two main criteria in selecting renewable energy source for rural areas in Indonesia.

Description of each main criterion:

A. Economical criterion

This criterion is used as a measurement of cost and benefit of renewable energy sources for rural electrification.

B. Socio-Political Criterion

This criterion becoming as consideration in selecting the renewable energy source for rural electrification on socio and political matter. Example the effect of socio-political matter is creating job opportunity for local people after choosing one specific renewable energy.

C. Technical Criterion

This criterion used as an evaluation on selecting the renewable energy for rural electrification based on technical aspect and technology.

D. Environmental Criterion

This criterion is used to measure the environmental effect that might happen after choosing the renewable energy source for generating electricity.

E. Energy Source Criterion

The criterion is used to measure the quality of a renewable energy source that will be used for generating electricity in rural areas.

Question: In decision-making process of selecting renewable energy source for generating electricity in the rural area, which is the criterion that you consider more important?

	1	2	3	4	5	6	7	8	9	
Economical	○	○	○	○	○	○	○	○	○	Socio-Political

	1	2	3	4	5	6	7	8	9	
Economical	○	○	○	○	○	○	○	○	○	Technical

	1	2	3	4	5	6	7	8	9	
Economical	○	○	○	○	○	○	○	○	○	Environmental

	1	2	3	4	5	6	7	8	9	
Economical	○	○	○	○	○	○	○	○	○	Energy Source

	1	2	3	4	5	6	7	8	9	
Socio-Political	○	○	○	○	○	○	○	○	○	Technical

Socio-Political ○ ○ ○ ○ ○ ○ ○ ○ ○ Environmental

1 2 3 4 5 6 7 8 9

Socio-Political ○ ○ ○ ○ ○ ○ ○ ○ ○ Energy Source

1 2 3 4 5 6 7 8 9

Technical ○ ○ ○ ○ ○ ○ ○ ○ ○ Environmental

1 2 3 4 5 6 7 8 9

Technical ○ ○ ○ ○ ○ ○ ○ ○ ○ Energy Source

1 2 3 4 5 6 7 8 9

Environmental ○ ○ ○ ○ ○ ○ ○ ○ ○ Energy Source

Selection in Economical Criterion

Choosing renewable energy source for generating electricity in rural area are considering the various criteria support, one of that criterion is the economical criterion. In this section, you have to provide your personal judgment in comparing two relative important of two factors in the economical criterion, by the following question:

Description of each factor:

A. Capital cost

The factor is used to measure the initial investment/cost needed to invest until the electricity can be delivered to the consumer. For example, the initial cost to build a small geothermal power plant is higher than build a biomass power plant.

B. Operation and maintenance cost

   This factor is used to evaluate the cost to maintain and operate the specific renewable energy power plant.

C. Profitability

   This factor indicates the different profitability of renewable energy power plants.

D. Affordability price

   This factor indicates the ability of local people to purchase the energy that generated from a renewable energy source

In decision-making process of selecting renewable energy for generating electricity in the rural area, which factor that you consider more important?

Selection in Socio-Political Criterion

Choosing renewable energy source for generating electricity in rural area are considering the various criteria support, one of that criterion is the socio-political criterion. In this section, you have to provide your personal judgment in comparing two relative important of two factors in the socio-political criterion, by the following question:

Description of each factor

A. Job Creation (Labor Impact)

   This factor is used to measure the ability of renewable energy power plant on creating a job for local people.

B. Public Acceptance

   This factor is used to measure the acceptance and support of the local people toward renewable energy power generation.

C. Government Policy

This factor is used to measure whether utilization of specific renewable energy source for rural electrification is able to support current government policy on sustainable development or not.

In decision-making process of selecting renewable energy for generating electricity in the rural area, which factor that you consider more important?

	1	2	3	4	5	6	7	8	9	
Job Creation (Labor Impact)	○	○	○	○	○	○	○	○	○	Public Acceptance

	1	2	3	4	5	6	7	8	9	
Job Creation (Labor Impact)	○	○	○	○	○	○	○	○	○	Support to Government Policy

	1	2	3	4	5	6	7	8	9	
Public Acceptance	○	○	○	○	○	○	○	○	○	Support to Government Policy

Selection in Technical Criterion

Choosing renewable energy source for generating electricity in rural area are considering the various criteria support, one of that criterion is the technical criterion. In this section, you have to provide your personal judgment in comparing two relative important of two factors in the technical criterion, by the following question:

Description of each factor

A. Maturity of Technology

This factor is used to determine the maturity of technology on the renewable energy power plant. The maturity of technology can be explained as the technology that has been used for long enough, less risk and has been commercializing.

B. Technology Performance

This factor is used to evaluate the performance of renewable energy power plant technology whether the technologies can be well operated and has good performance or not.

C. Availability of Equipment and Parts

This factor is used to consider the equipment and parts availability of each different renewable energy technology.

D. Training Requirement

This factor is used to consider the requirement of personal training or skill training for operating and maintaining the renewable energy power plant.

E. Ease of Decentralization

This factor is used to consider the ability of renewable energy power plant to connect to the grid.

In decision-making process of selecting renewable energy for generating electricity in the rural area, which factor that you consider more important?

	1	2	3	4	5	6	7	8	9	
Maturity of Technology	○	○	○	○	○	○	○	○	○	Technology Performance

	1	2	3	4	5	6	7	8	9	
Maturity of Technology	○	○	○	○	○	○	○	○	○	Availability of Equipments and Parts

	1	2	3	4	5	6	7	8	9	
Maturity of Technology	○	○	○	○	○	○	○	○	○	Training Requirement

	1	2	3	4	5	6	7	8	9	
Maturity of Technology	○	○	○	○	○	○	○	○	○	Ease of Decentralizati on

	1	2	3	4	5	6	7	8	9	
Technology Performance	○	○	○	○	○	○	○	○	○	Availability of Equipments and Parts

	1	2	3	4	5	6	7	8	9	
Technology Performance	○	○	○	○	○	○	○	○	○	Training Requirement

	1	2	3	4	5	6	7	8	9	
Technology Performance	○	○	○	○	○	○	○	○	○	Ease of Decentralization

	1	2	3	4	5	6	7	8	9	
Availability of Equipments and Parts	○	○	○	○	○	○	○	○	○	Training Requirement

	1	2	3	4	5	6	7	8	9	
Availability of Equipments and Parts	○	○	○	○	○	○	○	○	○	Ease of Decentralization

	1	2	3	4	5	6	7	8	9	
Training Requirement	○	○	○	○	○	○	○	○	○	Ease of Decentralization

Selection in Environmental Criterion

Choosing renewable energy source for generating electricity in rural area are considering the various criteria support, one of that criterion is the environmental criterion. In this section, you have to provide your personal judgment in comparing two relative important of two factors in the environmental criterion, by the following question:

Description of each factor

A. CO2 Emission

This factor is used to consider the amount of CO2 emission produced by the renewable energy power plant.

B. Noise Pollution

This factor is used to consider the noise produced by the renewable energy power plant.

C. Land Requirement

This factor is used to consider the required area to build the renewable energy power plant.

In decision-making process of selecting renewable energy for generating electricity in the rural area, which factor that you consider more important?

	1	2	3	4	5	6	7	8	9	
CO2 Emission	○	○	○	○	○	○	○	○	○	Noise Pollution

	1	2	3	4	5	6	7	8	9	
CO2 Emission	○	○	○	○	○	○	○	○	○	Land Requirement

	1	2	3	4	5	6	7	8	9	
Noise Pollution	○	○	○	○	○	○	○	○	○	Land Requirement

Selection in Energy Source Criterion

Choosing renewable energy source for generating electricity in rural area are considering the various criteria support, one of that criterion is energy source criterion. In this section, you have to provide your personal judgment in comparing two relative important of two factors in energy source criterion, by the following question:

Description of each factor:

A. Resource Availability

This factor is used to measure the ability of renewable energy sources can supply the electricity generation in that area. For example, In North Maluku have five different renewable energy sources that can be used for generating electricity that are, solar energy, wind energy, biomass energy, geothermal energy and micro-hydro energy.

B. Resource Durability

This factor is used to measure the long period of the renewable energy source for generating electricity. For example, biomass tends to have a shorter duration in supplying energy sources because it will depend on the biological process and climate.

C. Distance to User

This factor is used to explain the important level of the distance the energy sources to the consumer, more distance from the energy may increase the losses of electricity in transmission process and also will cost the construction.

In decision-making process of selecting renewable energy for generating electricity in the rural area, which factor that you consider more important?

	1	2	3	4	5	6	7	8	9	
Resource Availability	○	○	○	○	○	○	○	○	○	Resource Durability

	1	2	3	4	5	6	7	8	9	
Resource Availability	○	○	○	○	○	○	○	○	○	Distance to User

	1	2	3	4	5	6	7	8	9	
Resource Durability	○	○	○	○	○	○	○	○	○	Distance to User

Additional Information

Name:

Working Unit:

- Secretary-General
- Inspector General
- National Energy Council (DEN)
- Directorate General of New Renewable Energy and Energy Conservation
- Directorate General of Oil and Gas
- Directorate General of Mineral and Coal
- Directorate General of Electricity
- Geological Agency
- Energy and Mineral Resources Research and Development Agency
- Human Resource Development Agency Ministry of Energy and Mineral Resources
- Local Government
- State-owned company in Energy Sector
- Special Task Forces for Upstream Oil and Gas Business Activities (SKK-Migas)
- Other Ministries
- Other Government Agency
- Other

Working Experience

- 2 - 4 years
- 4 - 6 years
- 6 - 8 years
- 8 - 10 years
- > 10 years

Have Experience in Renewable Energy Project?

Comments

Appendix 2: Survey 2

Questionnaire "Analysis of Renewable Energy Sources and Technologies for Rural Electrification in Indonesia"

This survey is designed for a thesis with the title "Analysis of Renewable Energy Sources and Technologies for Rural Electrification in Indonesia using AHP". This survey is the second survey, in the first survey, we try to find the weight and ranking of criteria and sub-criteria which become decision consideration on renewable energy development for rural electrification. In this survey, we try to find the preference and consideration of renewable energy expert on choosing the suitable renewable energy source for rural electrification in Indonesia.

This survey will provide with the detailed information of criteria and sub-criteria which might become the consideration of decision maker and renewable energy expert on choosing the suitable renewable energy for rural electrification in Indonesia. I expect you to be able to provide an evaluation and rated on each criterion and sub-criteria for each energy choice.

All your information and answer in this questionnaire are remained confidential and used only for academic research purpose. All your comments, suggestions or questions about this questionnaire are welcome, you can contact me by email: alfinazuss@snu.ac.kr and alfina.zussida@gmail.com.

Alfina Zussida
Seoul National University

How to answer this survey?

This survey will provide information about economic criteria, technological criteria, socio-political criteria, environmental criteria, and energy source criteria in five renewable energy technology options. There are three sub-criteria from 18 sub-criteria which no detailed information because of limited research. For that three sub-criteria you can have your opinion about that based on your experience. To answer this survey you only need to evaluate and rate based on your preference as a renewable energy expert on deciding the renewable energy technology for rural electrification. The rate option is from 1 to 10; 1 means worst and 10 means the best.

Example:

Energy Source / Criteria/sub-criteria	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
Economy (Overall)	4	5	8	3	7
Capital cost	7	8	3	3	8
. .	…	….	…	…	…
affordability	…..	….	….	….	….

Information about criteria and sub-criteria of the technologies.

- ✓ **Economic Criterion**, this criterion is used as a measurement of cost and benefit of renewable energy sources for rural electrification. There are four sub-criteria in this economic criterion;
  1. Capital cost, this factor is used to measure the initial investment/cost needed to invest until the electricity can be delivered to the consumer. Based on report "Technology data for the Indonesian power sector, catalog for generation and storage of electricity" (National Energy

Council, 2017) cost for build renewable energy power plant is explained in the following data;

2. Operation and maintenance cost, this factor is used to evaluate the cost to maintain and operate the renewable energy power plant. Based on report “Technology data for the Indonesian power sector, catalog for generation and storage of electricity” (National Energy Council, 2017) cost for operating and maintaining renewable energy power plant is explained in the following data;
3. Profitability, this factor indicates the different profitability of renewable energy power plants. This research cannot provide data about the profitable value of each renewable energy technologies.
4. Affordability price, this factor is the ability of local people to purchase the energy that generated from the renewable energy source. This research will choose North Maluku as the example of finding the suitable renewable energy source for rural electrification. There is no research and data about affordability electricity price in North Maluku, to know the affordability price of that renewable technology this research will use the electricity generation cost on producing electricity with small-scale power generation compare with renewable energy price. Based on (MEMR,2018) cost for producing electricity with small-scale power generation in North Maluku is Small scale: 2.677Rp/kWh or 0.2 US$/kWh and renewable energy price (International Renewable Energy Agency (IRENA), 2018) will be explained in the table below.

Table 1. Information about Factors in Economic Criterion

Sub-Criteria	Unit	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
capital cost	M$/MWe	4.50	2.60	0.83	4.00	1.7
operation and maintenance cost	Fixed $/MWe/year	20,000	53,000	15,000	73,200	47,600
	Variable $/MWh	0.37	0.50	-	-	3.00
profitability	-	-	-	-	-	-
affordability	Small scale: 2.677Rp/kWh, 0.2 US$/kWh	0.04 US$/kWh (lowest) 0.14 US$/kWh (high)	0.047 US$/kWh	0.10 US$/kWh	0.06 US$/kWh	0.04 US$/kWh

Please answer this survey by giving score of criteria and sub criteria for each technologies based on your preference on table above and experience, with rate option 1 to 10. <<1 means the worst and 10 means the best>>

Table2. Evaluation in Economic criterion

Energy Source / Criteria/sub-criteria	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
Economy (Overall)					
capital cost					
operation and maintenance cost					
profitability					
affordability					

✓ **Technological Criterion,** this criterion used as an evaluation on selecting the renewable energy for rural electrification based on technical aspect and technology. There are five sub-criteria in this economic criterion;

1. Maturity of Technology, this factor is used to determine the maturity of technology on renewable energy power plant. The maturity of technology can be explained as the technology that has been used for long enough, less risk and has been commercialize. The maturity of renewable technology in Indonesia are explained in report “Technology data for the Indonesian power sector, catalogue for generation and storage of electricity” (National Energy Council, 2017).
2. Technology Performance, this factor is used to evaluate the performance of renewable energy power plant technology whether the technologies can be well operated and has good performance or not. In “Technology data for the Indonesian power sector, catalogue for generation and storage of electricity” (National Energy Council, 2017), technology performance is associated with a capacity factor, which

means the ratio of the actual electricity output to the potential electricity that possible based on the nameplate.

3. Availability of Equipment and Parts, this factor is used to consider the equipment and parts availability of each different renewable energy technology. In this research, the availability of equipment and part can be explained with a minimum local component which should be used to build renewable energy power plant. Industrial ministry decree no 54/M-IND/PER/3/2012 and No.05/M-IND/PER/2/2017 force the minimum local content/product for building a renewable energy power plant (National Energy Council, 2017), all the detail minimum requirement displayed in the table below.
4. Training Requirement, this factor is used to consider the requirement of personal training or skill training for operating and maintaining the renewable energy power plant. In operating and maintaining the process, the requirement of the skilled employee are varied in every technology, some technology needs high skilled employee (professional), some need more medium skilled employee (technician) and some need low skilled employee (unskilled employee). In the report "Skill and Occupational Needs in Renewable Energy" biomass power plant need more employee than other technologies because the technology needs biomass production (Union European, 2011).
5. Ease of Decentralization, this factor is used to consider the ability of renewable energy power plant to connect to the grid or independently supply small grid/off-grid. Information about ease decentralization of renewable energy power plant is not provided in this research due to limited information, for the additional information, many solar photovoltaic was built in Indonesia for off-grid electricity supply and grid-connected electricity supply.

Table 3. Information about Factors in Technological Criterion

Sub-Criteria	Unit	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
maturity of technology	(National Energy Council, 2017)	Emerging technology	Very mature technology	Emerging technology	Emerging technology	Mature technology
technology performance	Capacity Factor	60-80%	49%	28%	45%	85-95%
availability of equipment and parts	The local requirement for power plant 0-15MW	42.00 %	70.76 %	45.90 %	-	70.79 %
training requirement	The skilled worker that needed for operation and maintenance power plant. (H=high skilled, M=medium skilled and L=low skilled/unskilled)	•Plant managers (H) •Measurement and control engineers (H) • Welders (M) • Pipe Fitters (M) • Plumbers (M) • Machinists (M) • Electricians (M) •Construction equipment operator (M)	• Engineers (civil, mechanical, electrical) (H) • Operations and maintenance technicians (M) • Physical and environmental scientists (hydrologists, ecologists) (H) • Tradespersons	•Photovoltaic maintenance specialists (electricians specializing in solar) (M) • ST maintenance specialists (Plumbers specializing in solar) (M) • CSP maintenance specialists (M)	•Windsmith/mill wright/ mechanical technician or fitter/ wind service mechatronics technician (M, some H) • Operations and maintenance specialists (M) • Powerline	• Biochemists and microbiologists (H) • Laboratory technicians and assistants (M) •Operations and maintenance specialists (M,L) Biomass production • Agricultural scientists (H) • Biomass production managers (H,M)

		•HVAC technicians (M)	(M)	• Inspectors (M,L) • Recycling specialists (H)	technician (M) • Field electricians (M)	• Plant breeders and foresters (H,M) • Agricultural/forestry workers (L) • Transportation workers (L)
ease of decentralization	-	-	-	-	-	-

Please answer this survey by giving a score of criteria and sub-criteria for each technology based on your preference on the table above and experience, with rate option 1 to 10. <<1 means the worst and 10 means the best>>

Table 4. Evaluation in Technological Criterion

Energy Source / Criteria/sub-criteria	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
Technology (Overall)					
maturity of technology					
technology performance					
availability of equipment and parts					
training requirement					
ease of decentralization					

✓ **Socio-Political Criterion**, this criterion becoming as consideration in selecting the renewable energy source for rural electrification on socio and political matter. Example the effect of socio-political matter is creating job opportunity for local people after choosing one specific renewable energy. In this research there is three factor that considered as a socio-political criterion, they are:

1. Job Creation (Labor Impact), this factor is used to measure the ability of renewable energy power plant on creating a job for local people. In the previous research, the biomass power plant can create the largest job opportunity, followed with the geothermal power plant, wind, solar and micro hydro power plant (Chatzimouratidis & Pilavachi, 2008). Job opportunity for renewable energy power plant starting

from manufacturing, design, construction, operation, and maintenance, and energy/fuel production.

2. Public Acceptance, this factor is used to measure the acceptance and support of the local people toward renewable energy power generation. This research chooses North Maluku as sample location on selecting suitable renewable energy for rural electrification. There has been no research about public acceptance of renewable energy in North Maluku, hence, there is no information about public acceptance of renewable energy technology in North Maluku.
3. Government Policy, this factor is used to measure whether utilization of specific renewable energy source for rural electrification is able to support current government policy on sustainable development or not. The government of Indonesia targeted on improving renewable energy portion either in total energy mix or total power generation in Indonesia. Based on electricity supply business plan (RUPTL) 2018-2027, in 2027 GOI targeted to build several renewable energy power plant, 4,583 MW from geothermal power plant, build 811 MW micro hydro power plant, 1,045 MW from solar photovoltaic, 589 MW from wind turbine power plant and 411 MW from biomass power plant (MEMR, 2018)

Table 5. Information about Factors in Socio-Political Criterion

Sub-Criteria	Unit	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
job creation/ labor impact	employees/500MW	27.050	2500	5370	5635	36.055
public acceptance	**Survey about public acceptance on renewable energy technology is not done yet.**	-	-	-	-	-
government policy	Based on RUPTL 2018-2027, target renewable energy power plant to be built until 2027 (in MW)	4583	811	1045	589	411

Please answer this survey by giving a score of criteria and sub-criteria for each technology based on your preference on the table above and experience, with rate option 1 to 10. <<1 means the worst and 10 means the best>>

Table6. Evaluation in Socio-Political Criterion

Energy Source / Criteria/sub-criteria	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
Socio Politic (Overall)					
job creation/ labor impact					
public acceptance					
government policy					

- ✓ **Environmental Criterion,** this criterion is used to measure the environmental effect that might happen after choosing the renewable energy source for generating electricity. In this research there are three factor that considered as an environmental criterion, they are;
  1. CO2 Emission, this factor is used to consider the amount of CO2 emission produced by the renewable energy power plant. In the previous research, biomass power plant counted as the most polluted technology with the highest followed with solar photovoltaic (Chatzimouratidis & Pilavachi, 2008). These two technologies become the most polluted renewable technology because emission counted start form the manufacturing process until generated the electricity.
  2. Noise Pollution, this factor is used to consider the noise produced by the renewable energy power plant. Based on explanation on several reports (National Energy Council, 2017), (International Renewable Energy Agency (IRENA), 2018) and book (Droege.P,2018), explained that wind turbine power plant produce noise pollution with around 43dB.
  3. Land Requirement, this factor is used to consider the required area to build the renewable energy power plant. In report "Technology data for the Indonesian power sector, catalog for generation and storage of electricity" (National Energy Council, 2017) mentioned about the land requirement to build a renewable energy power plant. All information renewable energy type are mentioned except the micro hydro power plant, as a result, land requirement for micro hydro power plant, believed smaller than the medium size of hydro power plant which required around 14.000m2/MWe.

Table 7. Information about Factors in Environmental Criterion

Sub-Criteria	Unit	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
CO2 emission	(mg/kWh)	18.913	22.696	49.174	17,652	58.000
noise pollution	(Droege.P, 2018)	-	-	-	noise	-
land requirement	1000m2/ MWe	30	Less than 14	9	58	35

Please answer this survey by giving a score of criteria and sub-criteria for each technology based on your preference on the table above and experience, with rate option 1 to 10. <<1 means the worst and 10 means the best>>

Table 8. Evaluation in Environmental Criterion

Energy Source / Criteria/sub-criteria	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
Environment (Overall)					
CO2 emission					
noise pollution					
land requirement					

- ✓ **Energy Source Criterion**, the criterion is used to measure the quality of a renewable energy source that will be used for generating electricity in rural areas. In this research there are three factor that considered as an environmental criterion, they are;
  1. Resource Availability/availability of source this factor is used to measure the ability of renewable energy sources to supply the electricity generation in that area.
  2. Resource Durability, this factor is used to measure the long period of the renewable energy source for generating electricity.
  3. Distance to User, this factor is used to explain the important level of the distance the energy sources to the consumer, more distance from the energy may increase the losses of electricity in transmission process and also will cost the construction.

Table 9. Information about Factors in Energy Source Criterion

Sub-Criteria	Unit	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
Resource Availability	North Maluku RE source (Statistik EBTKE 2016, 2016)	580 MW	3036 MW	24 MW	504 MW	34,5 MW
resource durability	(National Energy Council, 2017)	Constant/continuously	Constant/continuously supply based on the availability of water	In daylight	When the wind is around 3-4 m/s to 22-25 m/s	Constant/continuously (with continuously supply)
distance to the user	(Droege.P,2018)	There is no minimum distance requirement	There is no minimum distance requirement	There is no minimum distance requirement	The minimum distance is 10 times the height of a wind power plant.	There is no minimum distance requirement

Please answer this survey by giving a score of criteria and sub-criteria for each technology based on your preference on the table above and experience, with rate option 1 to 10. <<1 means the worst and 10 means the best>>.

Table 10. Evaluation in Energy Source Criterion

Energy Source Criteria/sub-criteria	Small Geothermal	Micro Hydro	Solar	Wind	Biomass
Energy Source (Overall)					
resource availability					
resource durability					
distance to the user					

Respondent information:

Name :

Organization : Directorate General of New, Renewable Energy, and Energy Conversation

Sub-Unit :

Year of Experience :

Thank you for answering the survey…

초록 (Abstract)

1만개가 넘는 섬으로 이루어진 인도네시아는 부존에너지가 풍부하지만 모든 지역에 전력을 공급하기에는 수많은 제약이 있다. 인도네시아 정부는 그 해결책으로 어디에나 풍부한 재생에너지를 활용하여 각 지역별로 적절한 전력공급방안을 제공하고자 노력하고 있다. 이를 실천하기 위해서는 전력이 필요한 도서 지역 및 시골 지역에 가장 적합한 재생에너지원과 재생에너지 기술을 선택할 수 있는 기준을 마련하여야 한다. 본 논문의 목적은 인도네시아 도서 지역 및 시골 지역의 전력공급을 위하여 적절한 재생에너지원 및 재생에너지 기술을 선정하는데 사용될 주요 선정기준을 조사, 연구하고 기준들의 중요도를 비교 분석하고자 한다.

본 연구에 사용한 연구방법론은 계층분석법 (Analytical Hierarchy Process, AHP)이다. 문헌조사를 통하여 선정된 5개 주요 기준 및 18가지 하부 기준을 대상으로 인도네시아의 중앙부처 공무원 및 지역공무원을 대상으로 AHP 설문조사를 실시하였다. 또한 북말루쿠(North Maluku)지역을 대상으로 하여 정부가 제시한 5개 재생에너지원 중 가장 적절한 재생에너지원을 선정하는 별도의 설문조사를 실시하였다.

AHP 설문 분석결과 주요기준 중 ‘에너지원’ 기준이

인도네시아 시골지역 전기화를 위한 재생에너지원과 기술을 선택할 때 가장 중요한 주요 기준이며, 환경, 사회-정치, 기술 및 경제 순으로 나타났다. 하부기준 중에서는 ‘에너지 공급원의 가용성’이 가장 중요하며, ‘수익성’이 가장 중요하지 않은 하부 기준으로 나타났다. 상기 AHP 설문결과를 활용한 북말루쿠 지역을 대상 재생에너지대안 선정설문에서는 가장 적합한 재생에너지원으로 소형수력(micro hydro)이 선정되었으며, 바이오매스, 태양열, 지영, 풍력 에너지 순으로 나타났다. 본 연구결과는 향후 인도네시아 정부의 재생에너지 공급대안 선정과정에는 물론 여러 나라의 재생에너지 공급대안 선정과정에 기초자료로 사용될 수 있을 것이다.

주요어 : 도서지역, 시골지역, 전기화, 재생에너지, 계층분석법(AHP)
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