Master's Thesis in Engineering

Analysis of the Assessment Factors for Energy Planning in Indonesia using Analytic Hierarchy Process

February 2018

Eko Mahar Diputra

Technology Management, Economics and Policy Program

College of Engineering

Seoul National University

Analysis of the Assessment Factors for Energy Planning in Indonesia using Analytic Hierarchy Process

지도교수 허은녕

이 논문을 공학석사 학위 논문으로 제출함

2018 년 2 월

서울대학교 대학원

협동과정 기술경영경제정책전공

Eko Mahar Diputra

에코마하의 공학석사 학위논문을 인준함

2018년 2월

위 원 장____________________(인)

부위원장____________________(인)

위 원____________________(인)

Abstract

Analysis of the Assessment Factors for Energy Planning in Indonesia using Analytic Hierarchy Process

Eko Mahar Diputra

Technology Management, Economics and Policy Program

College of Engineering

Seoul National University

Due to the absence of comprehensive decision-making process in Indonesia's energy planning system, thus for the past decades Indonesia hasn't been able to provide sufficient and sustainable energy scenario to fulfill its energy demand caused by strong economic growth, high population level and increasing standards of living. Despite of abundant endogenous energy resources, Indonesia hasn't been able to cope with the issue of electricity shortage and high dependency on energy imports.

In this regard, this research aims to analyze, identify and rank various assessment criteria and factors that should be taken into account for energy planning in Indonesia. This research used two-phase methodology. In the first phase a comprehensive literature review and expert's inputs were used to identify five key dimensions of criteria and eighteen factors that considered as important indicators for energy planning. In second phase, as the procedure for the aggregation of expert opinions, Analytic Hierarchy Process (AHP) was implemented to rank the importance of each criterion and factor to develop an integrated assessment framework for energy planning system.

From the weights estimation results, the most important criterion for energy planning in Indonesia is the energy resources criterion. Furthermore there are six highly important factors that should be taken into account for energy planning in Indonesia: pollutant and emission, resources durability, resources availability, volatility of energy prices, noise, and distance to user.

Keywords: Analytic Hierarchy Process (AHP), Indonesia, Energy Planning, Criteria, Factors

Student Number: 2016-22092

Contents

List of Tables

List of Figures

1. Introduction

1.1 Motivation

Despite the fact that Indonesia is endowed with abundant energy resources, but this country has not been able to cope with the issue of electricity shortage and high dependence on energy imports. The absence of comprehensive decision-making process in Indonesia’s energy planning system makes the energy sustainability as the idea that is difficult to be realized by the government.

The concept of energy sustainability has become very important and now it is at the core of any regulatory and policy development in the energy sector of all countries in the world. But unfortunately, the challenges of ensuring energy sustainability become increasingly more complicated as the population continues to grow, the depletion of fossil fuels, the unpredictable movement of energy prices, and deterioration of the environment through pollutant releases. To address these challenges, the policy makers in energy sector must take significant steps in order to produce better policies that can ensure sustainability, which covers the long-term provision of energy supplies and also strengthening the role of energy efficiency to reduce energy demand.

For example, by implementing a proper decision-making system in the construction of their energy policies, the policy makers will be able to establish a thorough framework which has taken into account all the key factors, in order to ensure the successful implementation of the plan or policy itself.

But unfortunately, Muliadireja (2005) conveyed the obstacles that have hampered the process of policy making in Indonesia, i.e. the influence of traditions in the past, inadequacy of required information for analysis, substantial role of politicians, lack of implementation, and limited bureaucrat capability. By realizing the importance of proper decision making system for energy plans and policies, this study aims to determine various assessment criteria and factors that should be taken into account for energy planning in Indonesia, which can assist the policy makers in the process of policy making, energy planning and also for investment guide. We seek to conduct a quantitative evaluation in order to establish an effective assessment framework for energy planning system that is practical and tailored with current condition in Indonesia.

1.2 Research Objective

The primary objective of this study is to provide significant input for policy-making process in Indonesia by determining various assessment criteria and factors that should be taken into account for energy planning in Indonesia, and compiling those factors into rank and weight based on their hierarchy and relative importance. This study becomes important because in recent years Indonesian government shows strong commitment to restrain Indonesia's economic reliance on primary sector, while continue to strengthen the role of the secondary and tertiary sectors, which are the energy intensive sectors. Besides that, infrastructure development has also become one of the key programs of the government that provides the multiplier effects within the economy. Certainly to support all these government programs, sustainable energy supply is required.

But unfortunately, this issue has remained as a homework that still can't be resolved by the government. This slow pace of improvement was clarified through a statement from the Ministry of Energy and Mineral Resources of Indonesia (MEMR), that the electrification ratio of Indonesia only reached 92% and still far from the electrification ratio of several neighboring countries in Southeast Asia.

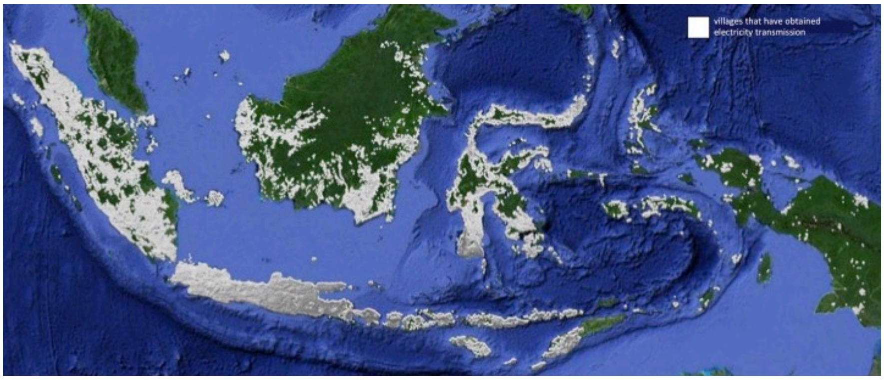


Figure 1. Electricity Distribution in Indonesia

Source: Ministry of Energy and Mineral Resources, 2016

From figure 1, MEMR stated that in the 1st quarter of 2016, there were 12,659 villages that haven't fully obtained the electricity, and as much of 2,519 villages are still 'pitch black'. Moreover, this condition then aggravated by the quality of the available distribution network that hasn't been fully able to meet the electricity demands in the area, so that power outages are very frequent in many regions in Indonesia which certainly give negative impacts to many sectors.

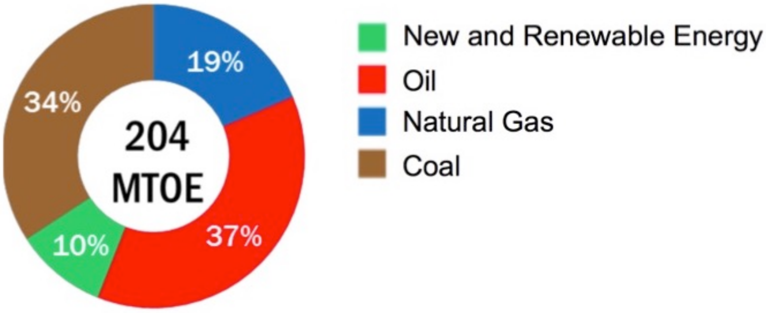


Figure 2. Primary Energy Mix

Source: Ministry of Energy and Mineral Resources, 2016

Another problem in the energy sector in Indonesia is the high dependency on fossil energy sources. The biggest negative impact of fossil energy sources is the degradation of environmental quality through pollutant releases, which mainly consist of greenhouse gases and has increased the amount of CO_2 in the atmosphere. Moreover, high dependence on petroleum products makes Indonesia highly dependent on imports, considering Indonesia's oil reserves are depleted and the capacities of refineries are also limited.

To solve the above-mentioned obstacles and challenges, the preparation of energy plans and policy formulations in the energy sector need to be upgraded and carefully designed, so that Indonesia's abundant energy resources can be optimized to support its economic growth, infrastructure development, industrial reinforcement and social development. In order to produce better decision-making process and energy planning system, the government must establish key criteria and factors that can determine successful implementation of the plan or policy by itself, because thorough understanding and fair assessment in the decision-making process and policy-making will result in good plans and policies.

Therefore, this study is significant to the Indonesian government since the findings and results from this study can be used as an assessment framework with valuable insights and reliable guide for evaluating quantitative and qualitative factors in energy sector in a systematic manner. Moreover, following the enactment of Government Regulation No. 79 of 2014 on The National Energy Policy and President Regulation No. 22 of 2017 on The National Energy Plan, the findings and results of this study can provide significant input to the government in breaking down the long-term energy plans into short-term energy plans as the reference for the policy formulation and implementation.

This study aims to answer the following research questions:

a. What criteria and factors that should be taken into account for energy planning in Indonesia?
b. Which criterion and factor that considered to be the most important for energy planning in Indonesia?

To attain the above-mentioned research questions, extensive literature reviews and a survey involving energy experts in Indonesian government were conducted, meanwhile the Analytic Hierarchy Process (AHP) was implemented for calculating the weights of each criteria and factor. AHP is very useful and popular decision-making tools that uses subjective perception from the respondents (Ghimire, 2016). By implementing AHP, this study establishes various criteria and factors with its relative importance as the key indicators for energy planning in Indonesia.

1.3 Thesis Outline

This study is organized into six chapters as shown in figure 3. Chapter one briefly explains about the introduction of the study, which covers motivation and objective of this study, and also the structure of this study. The second chapter provides the discussion of the problems as the background of this study, which includes the energy resources and energy potential in Indonesia, current situation of Indonesia's energy condition, and Indonesia's energy scenario and energy outlook. In chapter three, extensive literature reviews on the previous studies will be provided, which includes the importance of Multi-Criteria Decision Analysis (MCDA) for decision making and policy making process, selection of AHP as the most appropriate MCDA method for this study, and application of AHP in energy-related topic. The whole discussions on chapter three are used as a basis for starting chapter four, where methodology for this study will be discussed. Detailed description of AHP method will be presented complete with the hierarchy structure that used in this study, and also the selection and description of each criterion and factor. The extensive analysis towards the calculation and estimation results are presented in chapter five, while chapter six includes the overall conclusion of this study, and also the study limitations and scope for future work.

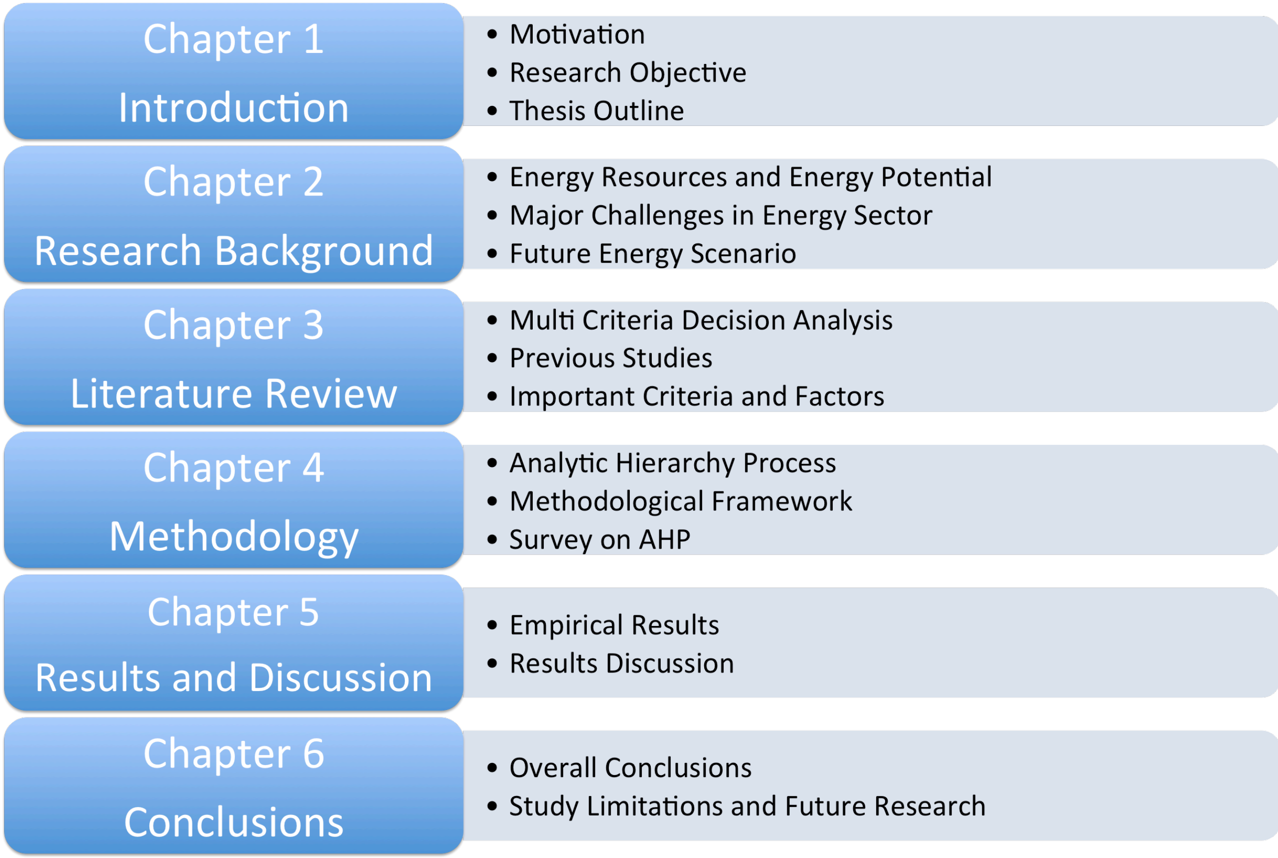


Figure 3. Thesis Outline

2. Research Background

2.1 Indonesia's Energy Resources and Potential

Indonesia is geographically located between two continents, namely the continent of Asia and Australia. Moreover, it is also geologically located among the three earth plates, namely the Pacific Plate, the Eurasian Plate, and also the Australian Plate. This unique location makes this country has a very rich geological structure, including volcanoes. As a country located on the Ring of Fire[1], Indonesia has many active volcanoes scattered from west to east across Indonesia. This particular geological condition is what makes Indonesia very rich in mineral resources and energy potential, ranging from coal, petroleum, natural gas, metallic minerals, geothermal, hydropower, and others. According to the data from Ministry of Energy and Mineral Resources of Indonesia (MEMR), Indonesia's coal potential is estimated more than 150 billion tons, while oil potential at more than 10 billion barrels, and natural gas potential more than 200 trillion cubic feet. The government also estimated that Indonesia can capitalize their oil reserves for 25 remaining years, while for natural gas and coal are

[1]Major area in the basin of the Pacific Ocean where large number of earthquakes and volcanic

60 years and 150 years respectively (MEMR, 2014). In the other side, Indonesia’s potentials on renewable energy are also substantial. This country is endowed with large potential for hydropower energy (75,000 MW), micro/mini hydropower energy (1,013 MW), geothermal energy (29,000 MW), solar power energy (4.80 kWh/m^2/day), biomass potential (32,654 MW), and wind energy (3-6 m/s) (Directorate General of Renewable Energy, 2014).

2.1.1 Oil Resources and Potential

Oil exports was main driving factor for Indonesia’s economic growth since the beginning of its independence period, where Indonesia also experienced the victory of oil boom era in the 1970s. But however nowadays Indonesia’s oil fields are severely depleted, whereas the new oil exploration and oil discovery are also slowing. As the result, in 2004 Indonesia became the net oil importer and has been relying on oil imports to meet its domestic demand. In addition to oil imports, domestic production also continues to be driven at high levels of production, so that Indonesia's oil reserves have declined by 21% over the past decade (Indonesian Petroleum Association, 2012).

Table 1. National Oil Reserves in each Province in Indonesia

Source: MEMR, 2017

No.	Province	Reserves (in Million Barrels)			
		Proven	Probable	Possible	Total
1	Riau	1,190.9	997.0	687.3	2,875.2
2	South Sumatera	660.2	181.8	249.9	1,091.9
3	Central Java	415.4	209.5	293.4	918.3
4	West Java	378.9	109.5	97.8	586.2
5	East Kalimantan	265.1	145.1	53.4	463.6
6	East Java	135.6	65.6	62.9	264.1
7	Riau Islands	96.7	66.1	141.4	304.2
8	Papua	87.5	8.0	0.5	96.0
9	Jambi	79.7	66.1	82.5	228.3
10	Aceh	78.8	23.8	12.5	115.0
11	North Sumatera	66.4	70.6	29.2	166.2
12	Lampung	51.0	0.2	-	51.2
13	South Kalimantan	35.4	5.8	21.3	62.4
14	Central Sulawesi	30.2	2.5	1.0	33.7
15	DKI Jakarta	10.6	1.4	8.1	20.1
16	South Sulawesi	10.5	2.7	-	13.2
17	Maluku	6.9	2.8	2.9	12.6
18	Bangka Belitung	2.7	-	-	2.7
TOTAL		3,602.5	1,958.3	1,744.2	7,305.0

Note: From total 34 Provinces in Indonesia, there are 18 Provinces that have oil reserves

In 2015, Komite Eksplorasi Nasional (KEN)[2] proposed additional potential national oil resources of 5.2 billion BOE[3] comes from completed exploration activities, besides that KEN also proposed an additional oil resources of 16.6 billion BOE from initial exploration activities, which still required further exploration stages. With these findings from KEN, the government believes that by intensifying oil exploration activities with various schemes then the imports dependence can be reduced, while also continuing to increase the capacity of domestic oil refineries in order to supply domestic demand for petroleum products.

The efforts to increase the capacity of national oil refineries have been confirmed in the Rencana Umum Energi Nasional (RUEN)[4], which has been ratified in 2017. The government plans to increase the capacity to more than 2 million barrels per day by 2025 through the construction of new oil refineries, and also by developing the existing facilities so that these refineries can provide an additional capacity of more than 400 thousand BOPD[5].

---

[2]National Exploration Committee formed by the Minister of Energy and Mineral Resources

[3]Barrel of Oil Equivalent

[4]National Energy Plan, which presented in President Regulation Number 22 of 2017

[5]Barrels of Oil per Day

2.1.2 Natural Gas Resources and Potential

Indonesia has 151,331 BCF[6] of natural gas reserves, which mostly located in Sumatera, Papua, Kalimantan and Maluku. In Indonesia, more than 50% of natural gas production and over 60% of natural gas reserves are located in offshore fields. Most of Indonesia's natural gas is exported to many countries with long term contracts, thus making Indonesia as one of the world's largest gas exporters with Qatar, Malaysia and Australia. However, the government still requires that at least 25% of total production must be provided for domestic market to meet DMO[7] requirements.

[6]Billion Cubic Feet

[7]Domestic Market Obligation

Table 2. Natural Gas Reserves in each Province in Indonesia

Source: MEMR, 2017

No.	Province	Reserves (in BCF)			
		Proven	Probable	Possible	Total
1	Riau Islands	47,399.1	1,100.6	1,508.3	50,008.0
2	Papua	16,627.4	4,377.0	5,201.7	26,206.1
3	South Sumatera	8,659.8	2,191.0	2,735.1	13,585.9
4	Timor-Maluku	6,236.9	5,077.0	7,970.2	19,284.0
5	East Kalimantan	5,880.6	2,894.4	2,938.9	11,713.9
6	East Java	2,983.7	1,138.2	1,256.0	5,377.9
7	West Java	2,976.7	347.3	834.6	4,158.6
8	Central Sulawesi	1,729.3	233.2	67.8	2,030.3
9	Aceh	1,420.8	4,720.4	1,375.0	7,516.3
10	Jambi	1,137.4	1,323.4	3,057.0	5,517.8
11	South Kalimantan	988.1	327.9	377.1	1,693.1
12	Central Java	512.3	110.0	374.3	996.5
13	North Sumatera	447.5	503.1	4.9	955.5
14	South Sulawesi	392.7	120.1	21.2	534.0
15	Riau	290.0	325.1	478.6	1,093.8
16	Lampung	207.2	39.6	-	246.9
17	DKI Jakarta	63.1	14.1	46.5	123.7
18	Central Kalimantan	30.0	228.0	28.0	286.0
19	Bangka Belitung	3.2	-	-	3.2
TOTAL		97,985.9	25,070.3	28,275.2	151,331.4

Note: From total 34 Provinces in Indonesia, there are 19 Provinces that have natural gas reserves

Indonesia also has significant resources of non-conventional gas in Coal Bed methane (CBM) and shale gas deposits. Although CBM has higher full-cycle cost, but by optimizing such advantages of lower exploration risk and drilling costs, the government is ready to capitalize the resource potential of CBM which estimated to be 56 TCF[8] in total (Indonesia Infrastructure Initiative, 2013). In addition to CBM, Indonesia is also developing its substantial resources of shale gas in Sumatera, Kalimantan and Papua. Based on data from the Gas Development Master Plan for Indonesia, the potential recoverable resource of Indonesia's shale gas deposits estimated to be 142.5 TCF.

Based on the RUEN, the Indonesian government has established some strategic steps to optimize this substantial natural gas potential, such as by intensifying exploration activities to strengthen national gas reserves. Beside that the government also committed to reduce the exports of natural gas to less than 20% by 2025 and completely stop the exports in 2036 (along with the expiration period of the long-term sales contracts), by also strengthening domestic gas infrastructures and expanding domestic gas market such as the manufacturing industries, power plants, transportation and other sectors.

[8]Trillion Cubic Feet

2.1.3 Coal Resources and Potential

Coal is the most popular energy source in Indonesia, because it is the backbone of national energy supplies and also Indonesia's main export commodity. Indonesia's coal reserves are also considerable and estimated of 32.3 billion tons, which are mostly located at Kalimantan and Sumatera.

Table 3. Coal Reserves in each Province and/or Region in Indonesia

Source: MEMR, 2017

No.	Province / Region	Resources (mill.ton)	Reserves (in million ton)		
			Probable	Proven	Total
1	South Sumatera	50,226.3	9,944.8	2,053.5	11,998.3
2	East Kalimantan	48,180.2	11,918.5	3,188.4	15,106.8
3	South Kalimantan	16,477.0	1,169.9	2,475.3	3,645.3
4	Central Kalimantan	3,426.6	234.3	440.5	674.8
5	Jambi	2,224.9	17.8	76.5	94.3
6	Riau	1,800.1	54.5	633.3	687.8
7	West Sumatera	795.5	-	158.4	158.4
8	West Kalimantan	491.5	-	-	-
9	Aceh	450.6	-	-	-
10	South Sulawesi	231.1	-	0.1	0.1
11	Bengkulu	192.1	-	19.0	19.0
12	Papua and West Papua	135.8	-	-	-
13	Lampung and Banten	126.7	-	-	-
14	North Sumatera	27.2	-	-	-
15	North Maluku	8.2	-	-	-
	TOTAL	124,796.7	23,339.9	9,044.8	32,384.7

Note: From total 34 Provinces in Indonesia, there are 17 Provinces that have coal resources

Indonesia is one of the world's major coal producers and also one of the largest coal exporters in the world, with its main markets being China and India. In addition to export market, domestic coal consumption has also been increasing every year considering that coal has leading role in Indonesia’s long-term energy program that reduces Indonesia’s dependency on petroleum products. Considering the importance of coal's role in the national energy structure as well as the depletion of coal reserves, the government's RUEN projected that the level of coal exports will continue to be reduced in line with increased domestic demand for power generation and industrial sector. Additionally, starting in 2019 coal production will be limited to a maximum level of 400 million ton per year.

However the utilization of coal as the main energy source also yields major problem related to the environmental factor, especially with Indonesia’s commitments to reduce its carbon emission. Hence the government’s agendas are focused on the efficient and effective implementation of clean coal technologies, and also supercritical or ultra-supercritical coal-fired power plants to minimize efficiency losses.

2.1.4 Resources and Potential of Geothermal Energy

Indonesia has the world's largest geothermal potential that represents 40% of the world's potential (ADB, 2015). In 2016, total installed capacity for geothermal energy was 1,653 MW, which represented only 6% of Indonesia's total potential (MEMR, 2017).

Table 4. Geothermal Potential in each Province and/or Region in Indonesia

Source: MEMR, 2017

No.	Province	Resources (in MW)	Reserves (in MW)
1	West, Central and East Java	3,038	6,121
2	Aceh and North Sumatera	1,414	2,648
3	Lampung and South Sumatera	2,161	2,303
4	West Sumatera	801	1,035
5	West and East Nusa Tenggara	635	932
6	Bengkulu and Jambi	1,002	1,401
7	North and Central Sulawesi	513	1,136
8	Maluku and North Maluku	651	800
9	Banten	261	365
10	West and South Sulawesi	661	325
11	Bali	92	262
12	Southeast Sulawesi and Gorontalo	365	208
13	Bangka Belitung and Riau	147	-
14	West Papua	75	-
15	West Kalimantan	65	-
16	North, South and East Kalimantan	118	-
17	Yogyakarta	-	10
	TOTAL	11,998	17,546

Note: There are 30 Provinces that have geothermal potential

Realizing the important role of geothermal energy to ensure Indonesia's sustainable and environmentally friendly energy supply, the government’s RUEN has prioritized the development of geothermal energy as one of the major energy in the future. As the embodiment of this vision, the development of geothermal energy is projected to provide 7.2 GW by 2025 and reaches 17.6 GW by 2050, or aims to utilize 59% of the total geothermal energy potential of 29.5 GW. This total potential can also increase along with the intensive effort of exploration activities and the discovery of new reserves.

2.1.5 Potential of Hydropower Energy

Considering the geographical position of Indonesia that located on the equator and the topographical structure of Indonesia that mountainous with lots of forest, it is no wonder if Indonesia possesses a significant potential of hydropower energy. Total potential of Indonesia’s hydropower energy is estimated to be 75,091 MW with total installed capacity of 4,871 MW in 2016, or it only used 6% of its total potential (MEMR, 2017). By considering its capability and stability of supplying energy at base-load condition and also by looking into the distribution of potential locations of this energy type, hydropower energy can be an appropriate solution to provide energy supply for remote regions that still do not have access to electricity.

Table 5. Hydropower Potential in each Region in Indonesia

Source: MEMR, 2017

No.	Region	Potential (in MW)
1	Papua	22,371
2	South-Central-East Kalimantan,	16,844
3	South-Southeast Sulawesi	6,340
4	Aceh	5,062
5	West Kalimantan	4,737
6	North-Central Sulawesi	3,967
7	North Sumatera	3,808
8	West Sumatera and Riau	3,607
9	South Sumatera, Bengkulu, Jambi and Lampung	3,102
10	West Java	2,861
11	Central Java	813
12	Bali and West-East Nusa Tenggara	624
13	East Java	525
14	Maluku	430
	TOTAL	75,091

Note: From total 34 Provinces in Indonesia, there are 14 regions that have hydropower potential

Government's RUEN has prioritized the development of hydropower for electricity to provide 18 GW in 2025 and 38 GW by 2050, or has capitalized 51% of the total Indonesia's hydropower potential of 75 GW. However main challenge in developing hydropower energy is its massive requirement for areas. This certainly requires a complicated licensing process and involves many parties and government agencies. Therefore, to optimize the utilization of hydropower energy, the government needs to strengthen overall coordination across government units and agencies, and also synchronize their regulations and policies.

2.1.6 Potential of Solar Energy

Given that Indonesia located on the equator with maximum intensity of sunlight throughout the year, this country has substantial potential of solar energy spread throughout Indonesia. Solar energy development is very suitable for Indonesia that has many islands and areas that still don't have grid connections, but unfortunately its total installed capacity only reached 107.8 MW in 2016, or just less than 1%.

Table 6. Solar Energy Potential in each Province and Region in Indonesia

Source: MEMR, 2017

No.	Province	Potential (in MW)
1	West and Central Kalimantan	28,572
2	South Sumatera	17,233
3	East Kalimantan	13,479
4	Aceh and North Sumatera	19,732
5	East Java	10,335
6	West Nusa Tenggara	9,931
7	Banten and West Java	11,560
8	Jambi	8,847
9	Central Java and Yogyakarta	9,749
10	Riau and Riau Islands	8,516
11	South Sulawesi	7,588
12	East Nusa Tenggara	7,272
13	Papua and West Papua	8,342
14	Central Sulawesi	6,187
15	South Kalimantan	6,031
16	West Sumatera	5,898
17	North Kalimantan	4,643
18	Southeast Sulawesi and Gorontalo	5,135
19	Bengkulu	3,475
20	Maluku and North Maluku	5,056
21	Bangka Belitung	2,810
22	Lampung	2,238
23	North Sulawesi	2,113
24	West Sulawesi	1,677
25	Bali	1,254
26	DKI Jakarta	225
	TOTAL	207,898

Note: From total 34 Provinces in Indonesia, all of them have solar energy potential

Government's RUEN has prioritized the development of solar energy by introducing the obligation to utilize rooftop solar cell for at least 30% of total roof area for all government buildings, and at least 25% of total roof area for apartments and private office buildings. Additionally, the government will also continue to develop upstream and downstream industries that provide spare parts and equipment required by solar power plants. With these efforts the government aims to provide 6.5 GW in 2025 and reach 45 GW by 2050, or successfully capitalize 22% of total solar energy potential of 207.8 GW. The prospect of solar energy development is considered ideal, considering that the trends of required investment tend to be cheaper along with technological progress.

2.1.7 Potential of Wind Energy

One of the energy sources that is currently becoming very popular and considered for having good prospect is wind energy. Thousands of islands that owned by Indonesia make the potential of wind energy is very huge in this country. Therefore, RUEN has determined that the development of wind energy potential will only be conducted in the regions with wind speed > 4 m/s.

Table 7. Wind Energy Potential in each Province and Region in Indonesia

Source: MEMR, 2017

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 and North Maluku	3,692
7	West Nusa Tenggara	2,605
8	Bangka Belitung	1,787
9	Banten and DKI Jakarta	1,757
10	Bengkulu	1,513
11	Southeast Sulawesi and Gorontalo	1,551
12	Papua and West Papua	1,848
13	North Sulawesi	1,214
14	Lampung and South Sumatera	1,438
15	Yogyakarta	1,079
16	Bali	1,019
17	South and East Kalimantan	1,218
18	Riau Islands	922
19	Central Sulawesi	908
20	Aceh and North Sumatera	1,250
21	Central Kalimantan	681
22	West Kalimantan	554
23	West Sulawesi	514
24	West Sumatera	428
25	North Kalimantan	73
26	Jambi and Riau	59
	TOTAL	60,647

Note: From total 34 Provinces in Indonesia, all of them have wind energy potential

In addition to the commitment of conducting continuous surveys for improving the wind energy potential's database, the government is also committed to conduct feasibility studies in many potential areas and to build the wind power plants in remote areas and outermost islands. With these efforts, the government projected an additional installed capacity of 1.8 GW in 2025 and 28 GW by 2050, or aims to utilize 46% of the total potential of 60.6 GW (MEMR, 2017).

2.2 Major Challenges in Indonesia's Energy Sector

The government Regulation number 79 of 2014 defined the grand design of Indonesia's energy policy, which was arranged into Kebijakan Energi Nasional (The National Energy Policy) as the guideline of national energy management for the period of 2014 to 2050. But unfortunately, many experts said that this policy was too 'spectacular' because the targets were difficult to achieve and unrealistic. Afterward, the issuance of this policy confirmed the same mistake that have been done by the government in their policy formulation process. Muliadireja (2005) conveyed that there are five main problems that have hampered the policy making process in Indonesia:

a. Cultural Influences

The decision-making process in Indonesia is strongly influenced by the culture and traditions of the past that embrace the royal culture, e.g. long and inefficient procedures. As result there are a famous term 'Asal Bapak Senang' or 'For the Happiness of the Boss' (Nolan, 1999), therefore the policy formulation isn't intended for people's interests.

b. Inadequate and Inaccurate Information and Analysis

Hutagalung (2014) conveyed that accurate analysis using adequate data and information are very important for defining the problems in formulating policy solutions. But however, the policy formulation process in Indonesia often ignores these two key factors, so they can't be properly implemented (Muliadireja, 2005).

c. Substantial Role of Politicians

In Indonesia, most of the time, the Minister is a political figure. Therefore the government's policy is always enriched with political interests. For example, the policy of replacing kerosene with coal briquettes in the household sector was heavily criticized by the public, because it was considered unrealistic and total political maneuver (Muliadireja, 2005).

d. Lack of Implementation

Faludi (1973) argued if there are two main factors that determine successful implementation of public policy, i.e. the ability of policy makers in planning and analyzing, and the willingness of the government to implement it professionally. Abandonment on these factors has affected the government's ability to formulate and implement short-term and long-term energy policies.

e. Limited Bureaucrat Capability

In his study, Lindblom (1993) argued that bureaucrats tend to have short-term visions, rather than setting long-term visions. This is similar to the conditions in Indonesia, where the bureaucrats' ability to analyze the problems is not sufficient (Muliadireja, 2005). According to Lindblom (1993), bureaucrats emphasize the process rather than the outcome, and prioritize personal ambition rather than professionalism.

Hereafter as the consequences of the absence of comprehensive decision-making process in energy planning system, in these following sections we will discuss the current major issues and future challenges faced by the energy sector in Indonesia. This will be the starting base for policy improvement and for establishing a proper energy planning system, in order to ensure sustainable and equitable energy supply in Indonesia.

2.2.1 Energy Resources as Export Commodities

In Indonesia, energy resources (especially natural gas and coal) are one of the main export commodities that accounted for a large share of national state revenue. Export market becomes a more attractive destination for domestic natural gas production because the gas infrastructures are still very limited, therefore the multiplier effect from natural gas industry for the domestic economy can't be maximized. In coal industry, in 2015 there was only 20.7% from total Indonesia's coal production of 461.6 million ton that was supplied to the domestic market, while the rest was exported to various countries. Ironically this substantial export volume makes Indonesia as the largest coal exporting country in the world, whereas Indonesia's coal reserves are only 3.1% of the world's total reserves (BP[9], 2016).

2.2.2 Depleted Oil Reserves

Indonesia is one of the oldest oil producing countries in the world, but currently the amount of Indonesia's oil reserves estimated only 0.2% of the world's oil reserves. Since 1995 domestic oil production has continued to decline from 1.6 million BOPD[10] to only 786,000 BOPD by 2015. Moreover, in the last 5 years the Reserve Replacement Ratio[11] (RRR) is only 65% and far from ideal of 100% RRR. This means for every extraction of 1 barrel of oil, they can only replace with the new oil reserve discovery of 0.65 barrel of oil (MEMR, 2017).

---

[9] BP Statistical Review of World Energy

[10] Barrels of Oil per Day

[11] Rate of the discovery of new oil reserve compared to oil production rate

These low RRR and declining production are caused by several key factors, specifically low investor’s interest in new exploration activities and also low success rates of exploration by oil companies. Moreover the implementation of Enhanced Oil Recovery (EOR) technology in old oil fields in Indonesia also not optimal. This failure is triggered by the lack of active government’s involvement in exploration activities, so that the initial data and information that required during the initial exploration stages can’t be properly provided. Furthermore, the cases of overlapping land, the complicated licensing procedures, spatial conflict issues, and also social acceptance social issues toward the project also make upstream oil investment in Indonesia become less attractive for investors.

2.2.3 Limited Energy Access and Infrastructure

As the largest archipelago country in the world with more than 17,000 islands, Indonesia is still not able to provide adequate energy infrastructure in order to ensure sustainable energy supplies that evenly distributed throughout Indonesia, for example oil refineries and pipelines distribution, which are vital in terms of production and distribution factors. The limited capacity of Indonesia’s refineries makes this country very dependent on imports of crude oil and petroleum products. While in the natural gas industry, inter-island gas distribution systems among Sumatra, Java, Kalimantan, Sulawesi and Papua haven't been well integrated, so that domestic gas products can't be distributed to the industrial centers and power plants with reasonable prices. Moreover, this condition also makes fuel oil and LPG's[12] scarcity occurs in some areas (especially in eastern Indonesia), which also contributes to the very high disparities in energy prices among all regions in Indonesia.

In the electricity sector, the electricity transmission and distribution in Sumatera, Kalimantan, Sulawesi and Papua areas still haven't been fully integrated, so the national electrification ratio is only 91%. In 2015, Indonesia's installed capacity per capita reached about 218 watts/capita, because the total installed capacity at that time only reached about 55 GW (MEMR, 2016). This condition can certainly hamper the optimal utilization of electricity to increase productivity and also hinder the economic development in Indonesia.

[12]Liquefied Petroleum Gas

2.2.4 Import Dependence on Fuel Oil and LPG

Since 2004 Indonesia has been becoming a net oil importer, because the demand level for petroleum products keep increasing due to its rapid economic and population growth, while domestic production of crude oil and petroleum products continues to decline. The increase in domestic fuel consumption is also caused by inefficient consumption, due to the subsidies that was provided by the government on the fuel prices in Indonesia. The indicator of energy elasticity[13] can reflect this inefficient consumption behavior, and in the last 5 years Indonesia's energy elasticity exceeds 1, whereas ideally this ratio should be less than 1.

This condition has also been aggravated by the limited capacity of domestic oil refineries, which hasn't been significantly increased since the construction of the Balongan refinery in 1994. Currently, Indonesia has seven refineries that owned by PT Pertamina and four non-Pertamina refineries, with total production capacity of 681.000 BOPD (MEMR, 2017).

[13]The ratio between the growth of energy consumption and economic growth

Table 8. Fuel Import to Fulfill Domestic Demand (in 000 BOPD)

Source: MEMR, 2017

Year	Fuel Consumption	Refineries Production		Fuel Import
		Fuel Oil	Non-Fuel Oil	
2010	1,094	646	235	448
2011	1,187	650	285	537
2012	1,206	657	306	549
2013	1,234	671	233	563
2014	1,339	673	266	666
2015	1,229	681	204	548

In addition to fuel oil, the successful implementation of the kerosene-to-LPG conversion program turned out to have significantly increased LPG consumption when the ability of domestic LPG refineries is still very limited. As a result, about 60% of domestic LPG consumption must be fulfilled through imports. The government has tried to control the growth of LPG consumption by expanding the city gas network, but this effort is still not optimal.

2.2.5 Renewable Energy Sources versus Fossil Fuels

In addition to the implementation of renewable energy technologies that requires substantial investment, the economic level of the project itself also isn’t too competitive, considering that fuel subsidies for industry and electricity are still provided by the government.

Table 9. The Cost of Electricity in 2015 (in Rupiah/kWh)

Source: MEMR, 2017

No.	Renewable Energy Sources	
1	Solar Energy	8,786
2	Geothermal	1,058
3	Hydropower	388

No.	Fossil-based Sources	
1	Oil (Diesel)	3,992
2	Gas	806
3	Coal	661

For that reason, the development and utilization of renewable energy sources are always constrained, so that the energy diversification process is also disrupted and provide negative impacts on environment and higher dependence on imports. The government then seeks to increase the utilization of renewable energy by providing subsidy for renewable energy, but this policy is still not fully effective because this energy subsidy (for both fossil fuels and renewable energy sources) burdened the state budget with total subsidy of 2,182 trillion Rupiah over the period of 2004-2015. It was later found that the government's subsidy was not well targeted, as most of the subsidy was actually acquired by high-income groups. Then in 2015 the government gradually changed the fuel and electricity price mechanisms, so that the energy subsidy was successfully decreased to 119.1 trillion Rupiah and became more targeted (MEMR, 2017).

Basically the subsidy policy and pricing mechanism in government policies have not been fully targeted to cut the electricity price from renewable energy, because the required renewable energy technologies also have to be supported by adequate infrastructures, which Indonesia is still also struggling with this particular issue.

2.2.6 Unexplored Potential of Renewable Energy

The potential of renewable energy in Indonesia are very substantial. With hundreds of volcanoes and tropical forest areas that covering for more than 120 million hectares, these great potential are ready to be utilized. But it is unfortunate that renewable energy's utilization level is still very low, where in 2016 the share of fossil energy still dominated the primary energy mix by 90%, while renewable energy only accounted for 10%.

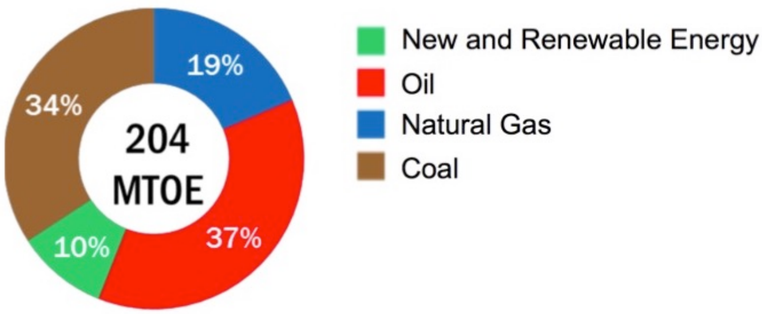


Figure 4. Primary Energy Mix

Source: Ministry of Energy and Mineral Resources, 2016

In 2015 the portion of renewable energy in the national energy mix for electricity sector was only at 10.5% of total installed capacity. The remaining fossil fuels composition of the energy mix in the power plant was 56.1% of coal, followed by natural gas of 24.9% and fuel oil of 8.6% (MEMR, 2017). The low renewable energy utilization in the national power plant composition is due to various factors, such as:

a. Unclear implementation on pricing mechanisms;
b. The existing regulations haven't been able to increase the competitiveness of renewable energy projects that able to attract investment;
c. Financing instruments that prepared for various investments in renewable energy are still inadequate;
d. Complicated and time-consuming licensing process;
e. Land and spatial issues.

For example, Indonesia has the largest potential of geothermal energy in the world, and it has been developed since 1972. However most of the geothermal potentials are located in protected and conservation forest areas, so the utilization of such potentials is constrained by special permits and forest conservation issues. Another obstacle in this project is the high risk of geothermal exploration since the drilling success ratio is quite low. Consequently, Indonesian government must really establish the regulatory instruments that able to facilitate the problems mentioned above, so that the development of geothermal potential and other renewable energy potentials can be well optimized.

Table 10. Utilization Level of Renewable Energy Potential (year 2015)

Source: MEMR, 2017

No.	Energy Type	Potential (MW)	Installed Capacity (MW)	Utilization Rate
1	Geothermal	29,544	1,438.5	4.9%
2	Hydropower	75,091	4,826.7	6.4%
3	Mini/Micro Hydro	19,385	197.4	1.0%
4	Bioenergy	32,654	1,671.0	5.1%
5	Solar Power (4.80 kWh/m^2/day)	207,898	78.5	0.04%
6	Wind Power (≥ 4 m/s)	60,647	3.1	0.01%
	TOTAL	443,208	8,215.5	1.9%

2.2.7 Low Awareness of Energy Conservation

As mentioned before that inefficient energy use can be reflected through an energy intensity indicator which reached 543 TOE/US$, and also through an average level of energy elasticity which exceeding 1 over the past 5 years (MEMR, 2017).

This condition can occur due to various factors, such as:

a. The obligation for energy conservation, which mandated by government Regulation number 70 of 2009 haven't been implemented consistently;
b. The availability of national standards and labeling haven't covered all the products in the domestic market;
c. The restructuring program for industrial machinery and equipment hasn't been widely implemented to the energy intensive industry;
d. The mass transportation system hasn't been optimally implemented by the government;
e. Incentives for energy efficiency and energy conservation programs are still limited, while disincentives for energy users that ignore the energy efficiency and conservation programs are also inconsistent;
f. The subsidy mechanism for energy prices becomes a disincentive for conservation program;
g. The price of energy-efficient equipment is still expensive;
h. Energy Service Company (ESCO) for industrial sector and commercial buildings hasn't been effectively implemented;
i. The people's awareness and industry's awareness of the benefits of energy efficiency and conservation programs are still limited.

2.3 Indonesia's Future Energy Scenario

Energy plays an important and strategic role for the achievement of social, economic and environmental goals in sustainable national development. Energy demand is expected to continue to increase as a consequence of economic growth and population growth, so that a proper energy planning system must be properly established in order to meet current and future energy demand.

Currently, Indonesia's energy planning and management hasn't been optimally arranged to fulfill domestic energy demand, in fact poor energy planning has resulted that most of strategic energy sources are being exported for state revenue. As a result domestic energy demand can't be well fulfilled, which also bring in other complicated problems in the energy sector.

Responding to these conditions, through government Regulation Number 79 of 2014, the government has established a general framework related to the national energy development plan. Through this policy, government wants to assert that the paradigm of energy management must be changed, by making energy as the foundation of national development.

Table 11. Targets that are mandated in GR Number 79 of 2014

Source: MEMR, 2017

No.	Target	Unit	2015	2020	2025	2050
1	Primary Energy Supply	MTOE			> 400	> 1,000
2	Target for Primary Energy Mix					
	Renewable Energy	%			> 23	> 31
	Oil	%			< 25	< 20
	Coal	%			> 30	> 25
	Natural Gas	%			> 22	> 24
3	Installed Capacity	GW			> 115	> 430
4	Electrification Ratio	%	85	100		
5	Primary Energy Consumption per Capita	TOE			1.4	3.2
6	Electricity Consumption per Capita	kWh			2,500	7,000
7	Energy Elasticity				< 1	
8	Reduction of Final Energy Intensity	%	1% each year			
9	Ratio of Gas Consumption in Household Sector	%	85			

Based on the targets in the above table, we can conclude that the utilization of renewable energy becomes the main focus of Indonesia's future energy planning. The government is committed to achieve the renewable energy portion of at least 23% by 2025 and continues to increase to at least 31% by 2050. As confirmed by the government through the RUEN, the economic viability of renewable energy projects should be assessed not only from its profitability, but also through its impact on another aspects such as environmental aspects, increased economic activity, and employment. Thus, the development of renewable energy in the future must remain as top priority by not only considering its economic profitability.

The government is also committed to continue to reduce the use of oil as energy source and optimize the role of natural gas, because national demand for petroleum products is greater than its production level, while the reserves are also depleted. Thus minimizing the utilization of oil will reduce dependence on imports. In addition to that, utilization of natural gas should be optimized to fulfill domestic demands from power plants, transportation sector, household sector and industrial sector. The development of other gas potentials and non-conventional gas deposits such as hydrogen, CBM, liquefied coal and gasified coal are also very promising.

The future portion of coal utilization level will be adjusted to the energy conditions at certain time, which means that if renewable energy and natural gas consumption have been pushed to the maximum level and oil consumption has been reduced to minimum level, then the shortage of energy supplies will be provided from coal energy.

But regardless of all the above-mentioned corridors, by considering that Indonesia is an archipelagic country, hence the energy demands in each island or region or area must be fulfilled by prioritizing the utilization of local energy resources potential (MEMR, 2017).

On the other hand, government's commitment to change the paradigm of national energy planning will also have an impact on the reduction of GHG emission levels. Four factors that must be appreciated from this effort are: the energy diversification program by increasing the portion of renewable energy and reducing the portion of fossil energy, increasing the utilization of clean coal technology, the substitution of fuel oil to natural gas and the improvement of the implementation of energy conservation program. The target of GHG emission reductions that described in the RUEN are also considered to be in line with Indonesia's INDC[14] of 29% by 2030, which is part of Indonesia's commitment to support global efforts to control average temperature rise below 2°C.

As the end of this chapter, it is clear that the government's vision in reforming the paradigm of national energy management are still very general and need to be translated in more detail framework to make it

[14]Intended Nationally Determined Contributions

easier to be implemented. Therefore by taking into account all the issues and challenges that exist, and with the intention to achieve the targets that have been set, this study becomes significant to simplify the government's vision into a more practical framework by identifying which criteria and factors that is considered to be important and substantial for energy planning in Indonesia.

The next chapter describes the review on previous relevant literatures to complete the initial discussion in chapter 2. Through a comprehensive literature review, as well as through a complete analysis of the main issues and future energy scenarios in Indonesia, we hope the results and findings from this study can provide significant contribution to existing literatures and also can generate a tailor-made framework with actual conditions of Indonesia.

3. Literature Review

3.1 Multi Criteria Decision Analysis

The decision-making process is a very natural event that will always be faced by every human in his or her life. For example a Technical Director should evaluate the most appropriate technology selection for his company. A mother should choose the best baby food product for her child. A university fresh graduate should choose the most appropriate job for himself. All these decision-making processes will always require a method and framework to evaluate all the options. In this evaluation method and framework sometimes they involve some criteria and factors, and afterward there will be a ranking process based on the evaluation results to determine the best choice that we should take. For example, when we're in a supermarket and want to buy soap, we don’t only consider the price factor, but we also consider its effect on our skin, its fragrance, its size, its health standardization, and other related factors. With the increasing standards of human life, we become increasingly aware that the right decision-making process always considers multiple criteria and factors in it.

3.1.1 Introduction

In the decision-making analysis, it's difficult to get an ideal result that can fulfill all the established evaluation criteria, therefore a compromise must be made. For that reason, the Multi-Criteria Decision Analysis (MCDA) is developed to overcome this issue by providing some methods and techniques that can be used to find a compromise solution, with incorporating subjective information derived from the decision maker himself. MCDA is a scientific discipline that includes mathematics, management, informatics, psychology, social sciences and economics, and it can be applied toward any fields because of its versatility to solve any strategic decision making process in many areas. As seen from the increasing number of academic publications that implement this method, then we can conclude that this MCDA methods are keep being developed and adjusted to solve current problems that involve multiple confliction criteria (Wallenius et al., 2008).

Roy (1981) posited that there are four main categories of decision:

a. The choice problem. The purpose of this category is to choose one best options, for example when someone is at a car dealer and wants to choose the right vehicle for his family;

b. The sorting problem. In this category, alternative options will be sorted into several criteria that have been established based on characteristics similarity. For example, the selection of shoes can be evaluated and classified into different criteria such as running shoes, soccer shoes and formal shoes. This sorting category is used as an initial selection that able to reduce the number of options that will be considered in the next evaluation step;

c. The ranking problem. All available alternatives will be evaluated and sorted from the best to the worst by using some scales or pairwise comparisons. For example, we can evaluate the selection of the best public transportation method for an area, based on its transport capacity, its technological maturity, its environmental impact and the investment that required to build the facilities;

d. The description problem. In this category each alternative will be qualitatively described to provide detail descriptions and consequences. This category is usually conducted in the early stages of decision making to provide a thorough understanding of the problem that is going to be solved.

Apart from the above four categories, the development of MCDA also generates other decision categories, such as for example Bana e Costa (1996) proposed the Elimination Problem which is a more specific classification than the Sorting Problem. Furthermore, Keeney (1992) also suggested that there is the Design Problem, which identifies the actions that have to be taken in order to achieve the desired purpose.

By focusing on the four main categories of decisions which proposed by Roy (1981) in the preceding paragraph, various MCDA methods can be applied to each desired decision category:

Table 12. Various MCDA Methods

Source: Ishizaka and Nemery, 2013

The Choice Problem	The Sorting Problem	The Ranking Problem	The Description Problem
AHP, ANP, MAUT/UTA, MACBETH, PROMETHEE, ELECTRE I, TOPSIS, Goal Programming, DEA, etc.	AHPSort, UTADIS, FlowSort, ELECTRE-Tri, etc.	AHP, ANP, MAUT/UTA, MACBETH, PROMETHEE, ELECTRE III, TOPSIS, DEA, etc.	GAIA, FS-Gaia, etc.

Based on above table, given the number of available MCDA methods are varied for each desired decision category, the process of selecting the most appropriate method can become a dilemma for decision makers. Basically, there's no perfect method that can be applied to any type of problem, because each method has its own limitations, has its own characteristics and also perspectives (Ishizaka & Nemery, 2013). In addition, Roy and Bouyssou (1993) also said that there is no possibility of determining the best method over other methods, so that a systematic axiomatic analysis must be performed.

Table 13. Characteristics of Input and Output (The Ranking Problem)

Source: Ishizaka and Nemery, 2013

Input	MCDA Method	Output
Utility function	MAUT	Complete ranking with scores
Pairwise comparisons on a ratio scale and interdependencies	ANP	
Pairwise comparisons on an interval scale	MACBETH	
Pairwise comparisons on a ratio scale	AHP	
Indifference, preference and veto thresholds	ELECTRE	Partial and complete ranking (pairwise outranking degrees)
Indifference and preference thresholds	PROMETHEE	Partial and complete ranking (pairwise preference degrees and scores)
Ideal option and constraints	Goal Programming	Feasible solution with deviation score
Ideal and anti-ideal option	TOPSIS	Complete ranking with closeness score
No subjective inputs required	DEA	Partial ranking with effectiveness score

Experts in this field propose several ways to select the most appropriate MCDA method for each particular problem. One of them was proposed by Guitouni et al. (1999), which said that the selection of MCDA method could be based on the characteristic of the required input information as well as the desired output. For example as shown in table 13, the Analytic Hierarchy Process (AHP) method would be an appropriate choice if inputs of data and information will be obtained through pairwise comparisons on a ratio scale, and the output will be presented in the complete ranking with scores.

3.1.2 Why Analytic Hierarchy Process?

As shown in table 13, the implementation of the AHP method would be appropriate if input data and information were obtained through pairwise comparisons technique on a ratio scale, while the output wanted to be presented in a complete ranking with scores. Additionally, AHP also has a very long history and its validity has been tested for decades, thus making this method has many advantages over the other methods.

The history of the Analytic Hierarchy Process (AHP) development began in 1860 when Fechner first introduced a pairwise comparison technique, which was then re-developed by Thurstone in 1927. Then, based on this pairwise comparison technique, Saaty (1980) first introduced AHP as a valid approach to solve economic, technological, socio-political and other complex problems that often involve a lot of criteria conflictions and uncertainty. The key feature of AHP that Saaty introduced is its inherent ability to systematically handle large number of intangible and non-quantitative attributes, and afterward synthesize them into multi-criteria evaluation framework. The AHP method incorporates subjective judgment and user intuition into the decision-making process, resulting a valid decision-making basis (Shapira & Goldenberg, 2005). Moreover, Saaty (1987) also conveyed that different experts have different opinions and perspectives, hence their views must be integrated to conclude one result for the decision-making process.

In the early days of AHP's introduction, its increasing popularity attracted some criticism toward the method. The main issues that were being criticized include:

a. The possibility of results' changes when some parameters are changed (Belton & Gear, 1983; Dyer, 1990);
b. The inaccurate objective information's interpretation on the numerical scale in pairwise comparison, caused by limited range of ratio scale of 1 to 9 (Belton, 1986; Belton & Goodwin, 1996); and
c. The minimum variation of objective evaluation in the pairwise comparison, due to the permanent establishment of criteria and factors that are being evaluated (Poyhonen et al., 1995).

In response to these criticisms, Saaty (1990); Saaty and Vargas (1991); and Perez (1995) showed that the principle and ratio scale of AHP has a solid theoretical and practical basis. Saaty and Vargas (1991) showed that in certain applications, changes in ranking results are completely normal and are sometimes required as parameters for sensitivity analysis. The discussions then were ended with a statement from Belton and Goodwin (1996), which concluded that a proper AHP implementation requires a thorough respondents' understanding on the questions that posed in pairwise comparison.

Additionally, Saaty also proposed that the AHP results are very robust because this method is able to simplify a complex decision-making process into a hierarchy structure and a series of pairwise comparisons, with a special technique that able to check the consistency level of the evaluations performed, in order to reduce the bias that may occur during the decision-making process (Saaty, 1980). Supporting this statement, Alonso and Lamata (2006) also suggested that the validity of this method has been applied and tested for decades in many decision-making situations in various fields.

The implementation of AHP in a decision-making process requires two conditions, hierarchy design and evaluation. In structuring the

AHP's model hierarchy, it doesn't matter if the hierarchy is arranged in top-down or bottom-up approach, because the validity of the results depends on the information's availability and the knowledge level from each of the respondent toward the criteria, factors and alternatives (Chatzimouratidis & Pilavachi, 2008). Afterward, the evaluation is conducted by the concept of pair-wise comparison, and the elements in the same hierarchical level are compared relative to their importance or contribution to certain criteria (Vargas, 1990). Besides that, Saaty (1980) conveyed that there are four steps that need to be conducted in order to produce results and priorities:

a. Determine the goal of the decision-making process;
b. Establish a hierarchy structure that describes every related criteria, factors and alternatives;
c. Make a set of pairwise matrix comparisons;
d. Evaluate the calculations that obtained from the pairwise comparison matrices to weigh the priority, and do this for each level until local and global priorities can be obtained.

3.2 Previous Studies

Proper energy planning system and thorough policy implementation are two main keys that able to ensure the sustainable energy for a country. Therefore, the study about designing proper policy and energy planning has long been a very popular topic among energy experts, for both developed and developing countries.

One of the methods that are often being implemented in this field is the multi-criteria decision analysis (MCDA), moreover this method has attracted the attention of decision makers for a long time (Kaya & Kahraman, 2010). Implementation of MCDA method is considered suitable with the purpose of designing a comprehensive energy planning, so that the policy can be applied well to meet the needs and demands of energy from all stakeholders (Beccali et al., 2003; Hiremath et al., 2007). By considering the multi-criteria conflictions that often arise in energy planning and policy-making processes, this MCDA method facilitates the efforts of resolving all that conflictions and balancing ecological factor, social factor, technical factor and economic factor. In addition, Talinli et al. (2010) conveyed that policy formulation should be conducted as a balancing act for various factors such as social, economic, political, legal, technical and scientific issues.

The implementation of MCDA method in energy sector then became more popular after the 1980s, when the awareness toward environmental issues became a global trend. In fact, in 1987 UN WCED[15] also asserted the concept of energy sustainability, in which current economic practices should be carefully oriented toward the future, without diminishing the ability of future generations to meet their own needs (Burton, 1987). Afterward, the global trend that requires the involvement of environmental sustainability and social factors in energy planning, makes the MCDA method a valid decision-making tool and is more widely used by the energy experts (Samouilidis & Mitropoulos, 1982; Meirer & Mubayi, 1983; Pohekar & Ramachandran, 2004).

In accordance with the objective of this study, where a set of assessment factors will be evaluated in order to determine their rank of importance for energy planning in Indonesia, hence a set of criteria and factors is certainly required as an evaluation indicator. As discussed in the previous chapter, each criterion and factor has its own weight that indicates their relative importance, so that we will be able to determine which criterion and factor that have the most substantial value.

[15]United Nations - World Commission on Environment and Development

The weighting evaluation of criteria and factors in this study is conducted by implementing the Analytic Hierarchy Process (AHP) method which introduced by Saaty (1980). In addition to what's been conveyed in the previous chapter, the selection of the AHP method for this study is also because of its high popularity in solving various problems in the energy sector, as described by Ramathan and Ganesh (1995); Kagazyo et al. (1997); Kablan (2004); Wang et al. (2008).

Keeney et al. (1987) implemented AHP by synthesizing the criteria into a hierarchical structure to evaluate the future energy system of West Germany. Additionally, Hamalainen and Karjalainen (1992) used AHP to determine which criteria that have substantial role in the evaluation of Finland's energy policy. Similar with them, by using energy resources factor, environmental factor, social factor and economic factor, Mavrotas et al. (1999) evaluated the electricity sector and its policies in Greece. By using the same criteria of energy sources indicator, environmental indicator, social indicator and economic indicator, Afgan and Carvalho (2002) established an analysis on assessment factors in renewable energy power plants.

Kabir and Shihan (2003) also implemented AHP methodology for selecting the most appropriate renewable energy sources and technology for Bangladesh, among three options: solar energy, wind energy and biogas. They used five criteria and twelve sub-criteria for their evaluation, which includes the indicator of cost per unit of power, social impact, technical, location and environment. The results show that solar energy is the best choice for Bangladesh, followed by biogas and wind energy. But regardless of these results, some experts argue that in the future biogas will have a better social acceptability, especially for people in rural areas.

Nigim et al. (2004) performed an experts survey to support their AHP methodology in evaluating the assessment factors to prioritize local energy sources, in order to minimize the dependence on imported energy sources. Six criteria were used for this study: ecological impact, social and economic benefits, educational potential, resources availability, technical feasibility and financial viability. By evaluating these criteria, Nigim et al. found that the local energy sources are viable to be developed and they also concluded that AHP method is effective for facilitating the decision-making process in both transparent and scientific manner (Nigim et al., 2004).

By implementing a sensitivity analysis to four scenarios that used in their study, Chatzimouratidis and Pilavachi (2008) compared different types of renewable energy power plants based on their each advancement of the technology, economic feasibility, and their role in sustainable development. Related to the role of technology category, Gallego-Carrera and Mack (2010) conducted an analysis on sustainability assessment of energy technology, by evaluating nine factors in four criteria: security and reliability of energy supply, political stability and legitimacy, social and individual risks and quality of life. With a similar purpose, Cowan et al. (2010) conducted a study on the assessment of the impact of technology adoption on hydroelectric power plants in the Pacific Northwest United States, by using four criteria: technological indicator, economic indicator, social indicator and environmental indicator. In 2010, Kaya and Kahraman also conducted a study by using these four criteria, to establish a multi-criteria assessment framework on renewable energy planning in Istanbul. By implementing the result of their framework, they found that wind energy is the most appropriate renewable energy source for Istanbul (Kaya & Kahraman, 2010).

In regards to existing literature, we can notice that most of the studies use four major indicators in applying AHP in the energy sector: technical, economic, environmental and social criteria (Wang et al., 2009). Kaya and Kahraman (2010) also conveyed that these four criteria are the most frequently used indicator in most of the studies. Additionally, they also stated that technical efficiency, investment cost, operation and maintenance cost, GHG emissions level, land use, social acceptability and job creation are seven sub-criteria that are the most frequently used by many experts in conducting their AHP studies in energy field.

Different approaches can be seen in a study that discusses the analysis of the assessment factors for renewable energy dissemination programs in Korea. Heo et al. (2010) used technological criteria, market criteria, economic criteria, environmental criteria and policy criteria for the study. The market criterion was included to evaluate the readiness and competitiveness of Korea's domestic market and its existing technology. From this study they found that the economic feasibility of the project and the advancement of the target technology in the global market are two substantial indicators that have to be considered when creating a renewable energy dissemination program in Korea.

A slightly different approach was also conducted by Tasri and Susilawati (2014). They stated that most of the criteria used by authors are economic, political, social, and environmental, for example: Becalli et al. (2003), Goletsis et al. (2003), Nigim et al. (2004), Kahraman et al. (2009), Heo et al. (2010), and Amer and Daim (2011). They said that in Indonesia, political factors have a stronger influence than technological factors. In their study of selecting the most appropriate renewable energy source in Indonesia, they also added 'the quality of energy sources' as an additional criterion. They argued that this criterion is needed to measure the quality of energy that will be provided to the customers, as well as a guarantee for the investment. From this study, they concluded that hydropower is the most appropriate renewable energy source for Indonesia.

Tasri and Susilawati (2014) also conveyed an interesting statement in this study. They stated that multi-criteria study in the field of Indonesian energy has not attracted much attention from researchers. The only reference they found was the study by Rumbayan and Nagasaka (2012) on the determination of the locations for the development of renewable energies in Indonesia: solar, wind and geothermal. The same thing was also expressed by Luthra et al. (2015), through their implementation of AHP for prioritizing the indicators of an integrated sustainability assessment framework for energy planning systems. They stated that the multi-criteria studies for sustainability assessment and energy planning in developing countries are still very few.

In conclusion, the sustainability of Indonesia's energy sector is not good due to its high dependence of fossil fuels, which also provide impacts on poor environmental conditions and high dependence on imports. Consequently, the establishment of a proper decision making framework will provide a better basis for energy planning and policy formulation. At last, considering the number of studies on this topic is very rare, then this study will be the first in this particular topic, which can also provide significant contribution to the existing literature and also able to provide substantial input to the policy makers in Indonesia.

3.3 Important Criteria and Factors in Energy Planning

In order to establish an assessment framework that can be properly implemented for energy planning in Indonesia, extensive literature reviews were conducted to formulate a draft which contains of substantial categories and factors in energy planning. This draft was also adjusted to the current conditions and the future energy scenario of Indonesia, as discussed in previous chapter. Afterward, the draft was reviewed by energy experts in Indonesia for formulating the final framework of the criteria and factors that are used in this study.

The existing literatures that were used as references for determining each final criterion and factor in this study are described in table 14. As for descriptive explanations for the hierarchy, and also for each criterion and factor will be discussed in the next chapter.

Table 14. Summary of Literature Review for Final Criteria and Factors in Indonesia's Energy Planning

Criteria	Factor	References
Energy Resources	Resources Availability	(Nigim et al., 2004; Rumbayan and Nagasaka, 2012)
	Resources Durability	(Heo et al., 2010; Gallego-Carrera and Mack, 2010; Tasri and Susilawati, 2014)
	Distance to User	(Janke, 2010; Sanchez-Lozano et al., 2013; Tasri and Susilawati, 2014; Mentis et al., 2015; Garni and Awasthi, 2017)
Economic	Capital Cost	(Cavallaro and Ciraolo, 2005; Adhikari et al., 2008; Talinli et al., 2010; Kaya and Kahraman, 2010; Kengpol et al., 2012; Tasri and Susilawati, 2014; Ghimire, 2016; Garni and Awasthi, 2017)
	Operation and Maintenance Cost	(Kabir and Shihan, 2003; Cavallaro and Ciraolo, 2005; Talinli et al., 2010; Kaya and Kahraman, 2010)
	Profitability	(Nigim et al., 2004; Chatzimouratidis and Pilavachi, 2008; Heo et al., 2010; Kaya and Kahraman, 2010; Tasri and Susilawati, 2014; Luthra et al., 2015)
	Volatility of Energy Prices	(Cavallaro and Ciraolo, 2005; Kaya and Kahraman, 2010; Talinli et al., 2010)

Criteria	Factor	References
Technical	Maturity of Technology	(Cavallaro and Ciraolo, 2005; Chatzimouratidis and Pilavachi, 2008; Talinli et al., 2010; Heo et al., 2010; Kaya and Kahraman, 2010)
	Technology Performance	(Nigim et al., 2004; Talinli et al., 2010; Heo et al., 2010; Kaya and Kahraman, 2010; Tasri and Susilawati, 2014)
	Training Requirement	(Kabir and Shihan, 2003; Kahraman et al., 2009; Amer and Daim, 2011; Yadoo and Cruickshank, 2012; Singh, 2013; Dulal et al., 2013; Darmani et al., 2014; Tasri and Susilawati, 2014; Kumar and Katoch, 2015)
	Availability of Equipment and Parts	(Kabir and Shihan, 2003)
Environmental	Pollutant and Emission	(Cavallaro and Ciraolo, 2005; Talinli et al., 2010; Heo et al., 2010; Kaya and Kahraman, 2010; Tasri and Susilawati, 2014; Luthra et al., 2015)
	Area Required	(Carrion et al., 2007; Kaya and Kahraman, 2010; Uyan, 2013; Tasri and Susilawati, 2014; Wang et al., 2014; Massimo et al., 2014; Luthra et al., 2015; Garni and Awasthi, 2017; Sabo et al., 2017)
	Noise	(Kabir and Shihan, 2003; Cavallaro and Ciraolo, 2005; Kaya and Kahraman, 2010)

Criteria	Factor	References
Socio-Political	Population	(Janke, 2010; Kengpol et al., 2012; Massimo et al., 2014; Sabo et al., 2017; Garni and Awasthi, 2017)
	Social Acceptability	(Kabir and Shihan, 2003; Cavallaro and Ciraolo, 2005; Chatzimouratidis & Pilavachi, 2008; Heo et al., 2010; Talinli et al., 2010; Kaya and Kahraman, 2010; Tasri and Susilawati, 2014; Luthra et al., 2015; Ghimire, 2016)
	Job Creation	(Kabir and Shihan, 2003; Gallego-Carrera and Mack, 2010; Kaya and Kahraman, 2010; Tasri and Susilawati, 2014; Luthra et al., 2015)
	Contribution to Support Government Policy	(Heo et al., 2010; Tasri and Susilawati, 2014)

4. Methodology

4.1 Analytic Hierarchy Process

The implementation of Analytic Hierarchy Process (AHP) becomes very popular among the researchers and policy makers, because of its ease in the application, and also its versatility for various fields of study in incorporating various criteria and factors both in quantitative and qualitative data (Sangwook, 2016). The AHP method was first introduced by Thomas Saaty (1980) as an effective method for sorting out a complicated decision-making process, through the evaluation of the priority scale of each indicator in order to generate the best option. AHP is considered as basic methodology for subjective evaluation and the most popular methodology to establish the weights through the pairwise comparison of certain criteria or factors (Ghimire, 2016). As conveyed in previous chapter, this method examines a set of evaluation criteria and alternative options, with its advantages stand on its main features: the hierarchy design and the evaluation of each criterion and factor (Vargas, 1990).

As with the other Multi-Criteria Decision Analysis (MCDA) method, the main research problem has to be structured and afterward the priority of each criterion and factor can be obtained based on the pairwise comparisons that are provided by the decision makers. The research subject is structured into a hierarchy form, where the topmost level is the main objective of the decision-making process. Afterward, the next level of the hierarchy represents the criteria, and subsequently the lowest level represents the alternatives (Ishizaka & Nemery, 2013). This hierarchy structure describes the relationships between various decision factors and criteria (Shapira & Goldberg, 2005).

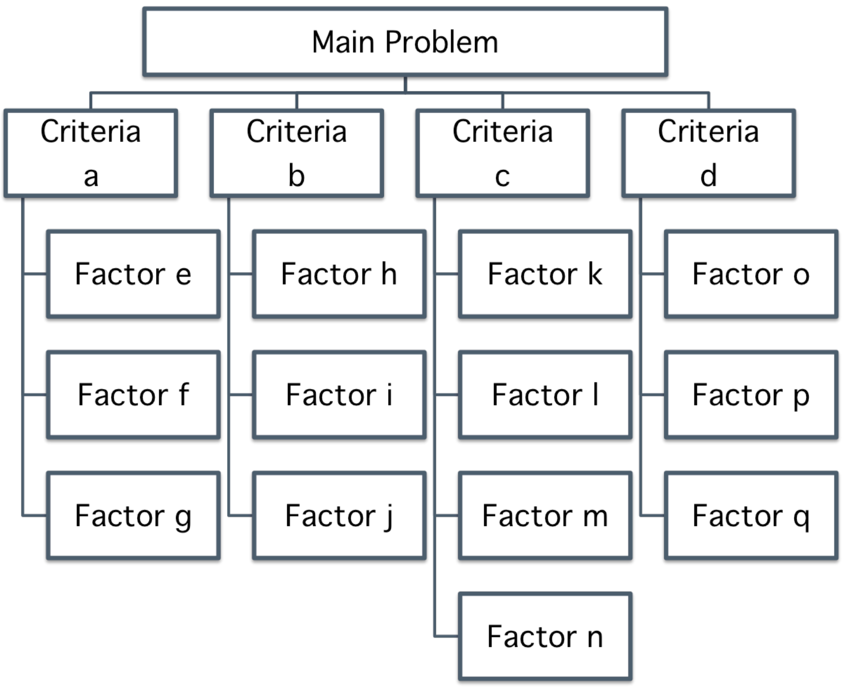


Figure 5. Example of Hierarchy Structure

When the relationships among the indicators have been structured in the form of hierarchy, then we can determine the relative weights of each indicator by making a pairwise comparison for each level in the hierarchy. Shapira and Goldberg (2005) stated that in structuring the pairwise comparison between two indicators, the policy makers must ensure that the questions given in the questionnaire meet these following requirements:

a. Which criterion that is more important or has greater impact to determine the main research problem? For example by using the hierarchy in figure 5, we have to determine which criterion between criterion a and criterion b, that is more important or has greater impact with respect to the main problem;
b. Which factor that is more important or has greater impact to the following criterion? For example by using the hierarchy in figure 5, we have to determine which factor between factor e and factor f, that is more important or has greater impact with respect to the criteria a;
c. By using ratio scale, what is the appraisal of that importance? For example, we have to appraise on what scale of the ratio should we decide if the factor e is more important than the factor f.

As conveyed in the previous chapter, one of the advantages of AHP is its ability to translate qualitative information into quantitative measurement in ratio scale (Kainulainen et al., 2009), because a scale of numbers can indicate how many times more important the factor is over another factor with respect to the criterion (Saaty, 2008). Beside that, the pairwise comparison between two indicators is also considered as the key feature of AHP methodology, since this mechanism allows the decision makers to determine the magnitude of the relationship between all indicators in a hierarchy structure (Saaty, 1980). Ishizaka and Nemery (2013) asserted that this pairwise comparison mechanism is easier to be implemented, and gives more accurate results in indicating the preference between two alternatives.

Table 15. AHP Ratio Scale of Importance
Source: Sangwook, 2016

Intensity of Importance	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

Saaty (1980) conveyed that the conversion of qualitative information to the quantitative information is expressed in the integers of 1 – 9, as expressed in table 15. Basically, there is no restriction to use this Saaty's numerical scale, since there were also other numerical scales that have been used by the experts. The first refutation was expressed by Harker and Vargas (1987), who used a quadratic and a square root scale in their analysis. Lootsma (1989) also argued that the geometric scale is more appropriate to be implemented. Salo and Hamalainen (1997) argued that the Saaty's numerical scale produce the priority weights that unevenly dispersed and lack of sensitivity. They proposed a balanced scale, which was claimed by them to be more evenly dispersed over the weight range. Beside that, Donegan et al. (1992) also preferred to use an asymptotic scale, while Ji and Jiang (2003) preferred to use the combination between the verbal scale and geometric scale. Despite of all the disputes among the experts, however the Saaty's numerical scale with the integers 1 – 9 and its reciprocal numbers is the most popular for this AHP methodology. Saaty (1980, 1991) asserted that his numerical scale is the most appropriate scale to represent the preference between two alternatives, based on its validity as well as the robustness of the results.

Afterward, the results of these pairwise comparisons should be arranged in a comparison matrix as expressed in table 16. This comparison matrix compiles the results of all pairwise comparisons between all given criteria (from figure 5). The main principle of this matrix is the reciprocal system. For example, criterion a is 1/5 as important as criterion c, hence criterion c is 5 times as important as criterion a. Additionally, the importance scales on the main diagonal have a value of 1, because each criterion is compared with itself.

Table 16. Example of Comparison Matrix (from Hierarchy in figure 5)

Criterion	a	b	c	d
a	1	1/3	3	1
b	3	1	3	3
c	1/3	1/3	1	1/3
d	1	1/3	3	1
sum	5.33	2	10	5.33

Thereafter, we are able to obtain the normalized-comparison matrix by using the formula expressed in Eq. (1) to make all the sum of each row in the matrix to have an amount of 1.

$$\bar{a}_{jk} = \frac{a_{jk}}{\sum_{l=1}^{m} a_{lk}} \quad \text{..............................Eq. (1)}$$

Table 17. Example of Normalized Matrix

Criterion	a	b	c	d
a	0.1875	0.1666	0.3000	0.1875
b	0.5625	0.5000	0.3000	0.5625
c	0.0625	0.1666	0.1000	0.0625
d	0.1875	0.1666	0.3000	0.1875
sum	1	1	1	1

Afterward, we can calculate the normalized eigenvector for each row in the decision matrix by using the formula expressed in Eq. (2). This normalized eigenvector represents final relative weights of each criterion with respect to the main problem, and final relative weights of each factor with respect to the following criteria (Saaty, 1980).

$$w_j = \frac{\sum_{l=1}^{m} \bar{a}_{jl}}{m} \qquad \text{......Eq. (2)}$$

Table 18. Example of Normalized Eigenvector

Criterion	Normalized Eigenvector or Priority Vector
a	0.2104
b	0.4813
c	0.0979
d	0.2104
sum	1

Finally from table 18 we can conclude that within the hierarchy structure in figure 5, criterion b is the most important criterion and also has the greatest impact to determine the main problem. Additionally, we can also arrange a ranking system on the scale of importance for all given criteria: (1) criterion b; (2) criterion a, and criterion d; and (3) criterion c.

Saaty (1989) asserted that this AHP methodology can also be applied to group decision problems, in wider applications and more complex issues. Saaty conveyed that there are at least two methods that can be applied in AHP for aggregating individual opinions into a group opinion. Saaty and Vargas (2005) also suggested that two aggregation methods can be used to determine group priorities. The first method is the geometric mean method (GMM), which averaging every individual opinion in a comparison matrix to compute group priorities. The second method is the weighted arithmetic mean (WAM), where the priorities of each respondent is determined, and afterward combined to determine group priorities.

But however, Ramanathan and Ganesh (1994) found that the GMM is the most popular technique in AHP for aggregating individual opinions into group opinion. Additionally, Ishizaka and Nemery (2013) also emphasized that the GMM must be implemented for aggregation of group opinions to maintain the reciprocal system. For example, if person A gives the comparison scale of 3 and person B gives the comparison scale of 1/3, hence the GMM determines the consensus as: $\sqrt{(3 * 1/3)} = 1$, which corresponds to mathematical logic. But if we use the WAM, the group consensus will be determined as: $(3 + 1/3)/2 = 1.667$, which is incompatible with mathematical logic. For this reason, the GMM will be used in this study for aggregating individual opinions into a group opinion.

One of the advantages of AHP is its ability to analyze a subjective assessment of its respondents. But however we also have to admit that this assessment is strongly influenced by the intuition and subjectivity of each respondent, therefore inconsistency may arise in AHP analysis. For example, if one concludes that A is more important than B with ratio scale 2, and B is more important than C with ratio scale 3, then the Absolute Consistency principle requires that A is more important than C with ratio scale 6. Nevertheless, by considering that the Absolute Consistency is very difficult to achieve, then Saaty (1980) conveyed that the inconsistency level can still be tolerated if the Consistency Ratio (CR) is less than or equal to 0.10.

To obtain the value of Consistency Ratio, we must first determine another two variables:

a. Calculate the Consistency Index (CI);

$$CI = \frac{x - m}{m - 1} \qquad \text{……………………………Eq. (3)}$$

b. Determine the Random Index (RI);

Table 19. Random Index

Source: 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

c. Calculate the Consistency Ratio (CR).

$$\text{CR} = \frac{CI}{RI} < 0.1 \qquad \text{…………………………Eq. (4)}$$

4.2 Methodological Framework

The AHP model that is used in this study can be defined in two general aspects. First, in the previous chapter we have discussed about the extensive literature reviews and also the input from the energy experts that used to establish the final criteria and factors for this study. Secondly, we will group these criteria and factors into a hierarchical structure that is needed to perform the pairwise comparisons in this analysis.

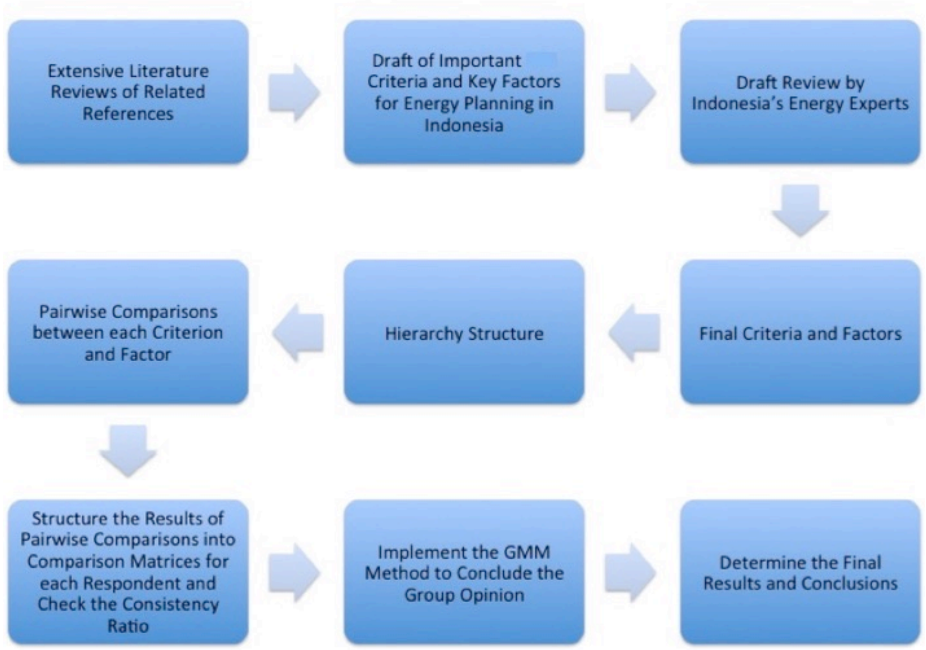


Figure 6. Research Methodology

As presented in figure 6, nine main steps are conducted to attain the results and conclusions of this study, in order to establish the assessment framework for energy planning in Indonesia. Additionally, five important criteria and eighteen key factors are arranged in one hierarchical structure.

According to AHP methodology, the top level of the hierarchy represents the main issue that becomes the purpose of the decision-making process. Then the next level of hierarchy represents the important criteria that able to determine the main issue at the previous level. Afterward, the lowest level in the hierarchical structure represents the sub-criteria or factors or alternatives, which are parts of the criteria at the previous level (Ishizaka & Nemery, 2013). The description of this hierarchical structure illustrates the relationship between the various factors and the criteria underlying in a decision-making process (Shapira & Goldberg, 2005). The hierarchical structure used in this study is presented in figure 7.

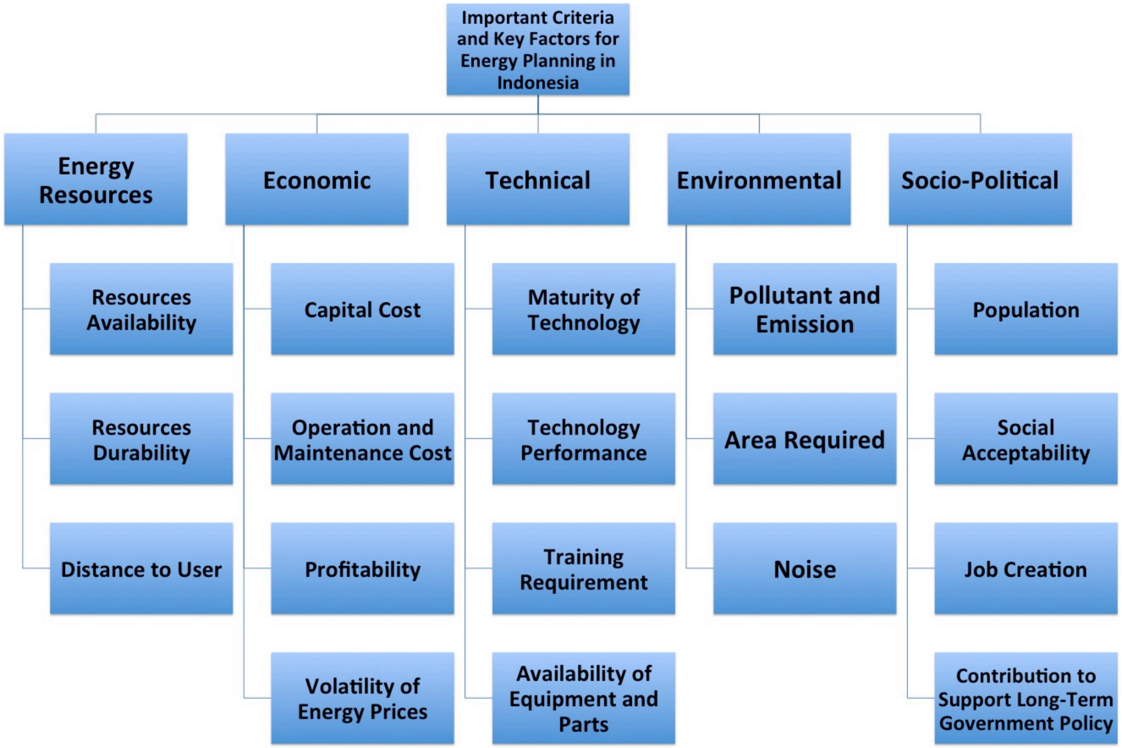


Figure 7. Hierarchy Structure

As presented in figure 7, five criteria and eighteen factors are selected. We consider that the criteria of energy resources, economic, technical, environmental and socio-political are five most substantial criteria for energy planning in Indonesia. Additionally, the description of each factor is as follows:

- Resources Availability

  The factor used to measure the quantitative availability of the energy resources and energy potential in certain area. For example when the Government plans to build a coal-fired power plant in certain area, they have to consider the availability of the coal reserves in that area to supply the power plant.

- Resources Durability

  The factor used to determine the length of period for the energy sources to be capitalized. For example when the Government plans to build an oil refinery in certain area, they have to consider the durability of the reserves in that area to continuously supply the crude oil during the project. Particularly in Indonesia, the overlap between resources area and conservation forests area or residential area may reduce the durability.

- Distance to User

  The factor used to consider the maximum distribution distance that can be tolerated when capitalizing the energy sources. For example when the Government plans to determine the most appropriate location for LNG storage project, they have to consider the distance between the locations of the gas reserves, gas processing plant, and also the location of the LNG consumers.

- Capital Cost

  The factor used to consider the required initial investment for the energy plan. For example when the Government has to choose between delivering the natural gas from Kalimantan to Sulawesi through the construction of submarine gas pipelines, or by using LNG carrier and building the gas terminals, they have to consider the total required capital costs for these two options.

- Operation and Maintenance Cost

  The factor used to consider the cost structure of the energy plan, particularly its operation and maintenance cost. For example when the Government plans to select the most appropriate renewable energy sources for a certain area, they have to consider the diverse levels of the cost variables provided by different energy sources.

- Profitability

The factor used to consider the economic profitability of the energy plan. For example in 2016 the Government had to decide the most appropriate scheme to process the natural gas from Masela offshore gas project. The first option was the onshore gas processing plant, which located very far from the project location. Secondly, the offshore gas processing plant by constructing Floating Storage Regasification Unit (FSRU). One of the main considerations is the profitability of each option, in order to make the Masela offshore gas project can run well and provide benefits to all stakeholders.

- Volatility of Energy Prices

The factor used to consider the fluctuation of the energy prices around its average value. For example when the Government plans to choose between coal-fired power plant or diesel power plant for supplying electricity in a certain area, they have to consider the volatility of the coal and diesel prices, which can affect the long-term cost structure of the project.

- Maturity of Technology

The factor used to consider the development rate of the technology, because the more it advances then its initial faults and inherent problems have been removed or reduced by previous development. For example when the Government assess the project's feasibility of a solar power plant in certain area, this factor is one of the main factors that have to be prioritized.

- Technology Performance

  The factor used to consider the performance of the technologies, whether it can be well operated within the desired time on various working conditions, or not. For example when the Government plans to popularize the utilization of electric vehicle by starting the imports-trade on this vehicle, first they have to consider whether it can be ideally suited and well operated in Indonesia or not.

- Training Requirement

  The factor used to consider the people's comprehension and understanding toward the desired technology. For example when the Government plans to build a power plant with sophisticated technology in a remote area, this factor has to be considered to ensure the sustainability of the project.

- Availability of Equipment and Parts

  The factor used to consider the availability of different equipment and parts therein for different choices of energy sources and technologies. For example when the Government plans to build a wind power plant with rare new technology in a remote area, this factor has to be considered to ensure the sustainability of the project. Because, the inability to handle this problem will create ineffective maintenance system, that lead to more serious problems.

- Pollutant and Emission

  The factor used to consider the different amount of pollutant, emission and also waste that produced from different energy sources, such as the greenhouse gases, liquid waste and solid waste. For example when the Government plans to maximize the potential of Indonesia’s coal reserves as the backbone of Indonesia's energy supply in the future, they have to consider the adverse impacts arising from this scenario toward the environmental conditions.

- Area Required

  The factor used to consider the measurement of the site choices, required land acquisition, and also to consider the impacts toward the change of ecosystem. For example when the Government plans to start a new coal-mining project to enhance coal domestic supplies in Sumatera region, they have to consider how much area required for this project and also its impacts for the ecosystem.

- Noise

  The factor used to consider the noise-pollution impact caused by the energy project to nearby residences. For example according to the Government plan of increasing the utilization of wind power as one of the renewable energy sources for electricity, this may have some impacts toward the noise pollution issue. The level of sound or noise that is produced by one-single-unit of wind turbine can reach 80 – 100 dB at 100 meters distance.

- Population

  The factor used to consider the demand level and impacts measurement from the energy plan in a certain area. For example when the Government plans to develop the city gas distribution system in Jakarta, they have to consider the number of population that will use this services.

- Social Acceptability

  The factor used to consider the social supports and acceptance from the people who are likely to be impacted by the energy plan. For example when the Government plans to build a new hydroelectric power plant, they have to consider all possibilities of rejection and harsh challenges from the local people and environmental community, considering the massive changes in ecosystem and also the local people's relocation that required for dam construction.

- Job Creation

  The factor used to measure the direct and indirect impacts of the energy plan on the employment condition, which can change the life's quality of the people. For example when the Government plans to start a new oil project in Eastern Indonesia, they have to consider the employment opportunities for the local people so that they can enhance their life's quality.

- Contribution to Support Long-Term Government Policy

  The factor used to determine whether an energy plan is in line with the long-term Government policy on sustainable development, or not. For example when the Government plans to convert the utilization of fuel oil to gas for transportation, then this plan is considered as an effort that supports Indonesia's long-term policy in reducing its dependence on imports of petroleum products.

4.1 Survey on AHP Pairwise Comparisons

As mentioned before that the implementation of AHP methodology requires the pairwise comparisons, which are organized in a questionnaire through the experts in the related fields (Wind & Saaty, 1980). The AHP methodology is chosen because it's considered as the best MCDA procedure for establishing the assessment framework for energy planning in Indonesia, therefore the hierarchy structure in figure 7 is the basis for the pairwise comparisons that are presented in the questionnaire.

The questionnaire in this study was conducted via Google Forms and divided into three main parts. The first part was the introduction and explanation of the background of the study. Additionally, an explanation about how to answer the questions was also described in this section. The second section contained thirty-four pairwise comparison questions for five criteria and eighteen factors, while the last section contained information related to the respondents and their expertise.

The survey involved the energy experts with diverse backgrounds and expertise, from Government agencies and energy companies in Indonesia, both in the stage of draft review and also the final survey stage. Accordingly, the data and information in this study has represented the preparation of energy plan and policy formulation in Indonesia, and can be used as a valid reference for the basis of analysis.

In the stage of draft review, a small group of energy experts was formed to review and evaluate the draft in order to establish the final criteria and factors for the analysis. Afterward in the final survey stage, more energy experts were involved from 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 ESDM, State-owned Enterprises in the Energy Sector, Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas), Secretariat General of the Ministry of Energy and Mineral Resources, Inspectorate General of the Ministry of Energy and Mineral Resources and other Government agencies and energy companies.

The final survey was conducted in October 2017 and targeted 82 energy experts from various Government agencies and energy companies. But unfortunately only 60 energy experts provided their responses, which made 73.1% response rate. After that by implementing the Consistency Ratio (CR) proposed by Saaty (1980), we checked the consistency of each respondent's answers. Therefore from a total of 60 responses, there were 14 responses that have CR higher than 0.10, and these responses were excluded from this study. For more details, the results of the calculation are presented in the next chapter.

5. Results and Discussion

5.1 Empirical Results

As presented in figure 6, nine main steps of the research methodology were conducted to attain the results and conclusions of this study. Based on the establishment of the AHP model, a hierarchy structure was formed as the basis for the pairwise comparisons that are presented in the questionnaire. Afterward, all the pairwise comparisons results from the energy experts were collected to calculate and synthesize the results.

5.1.1 Consistency Analysis

As discussed before that one of the benefits of AHP is its flexibility in analyzing subjective judgments of respondents. But as we know that these judgments are strongly influenced by the intuition and subjectivity of each respondent, so there can be inconsistencies in the AHP analysis. However, realizing that an absolute consistency is very difficult to achieve, Saaty (1980) emphasized that inconsistencies in the subjective judgment of respondents can still be tolerated if the Consistency Ratio (CR) is less than or equal to 0.10.

The consistency of pairwise comparisons results was checked using the Consistency Ratio (CR) proposed by Saaty (1980). The distribution of the CR value is presented in figure 8, where from a total of 60 responses, there were 14 responses that have CR higher than 0.10, and these responses were excluded from this study.

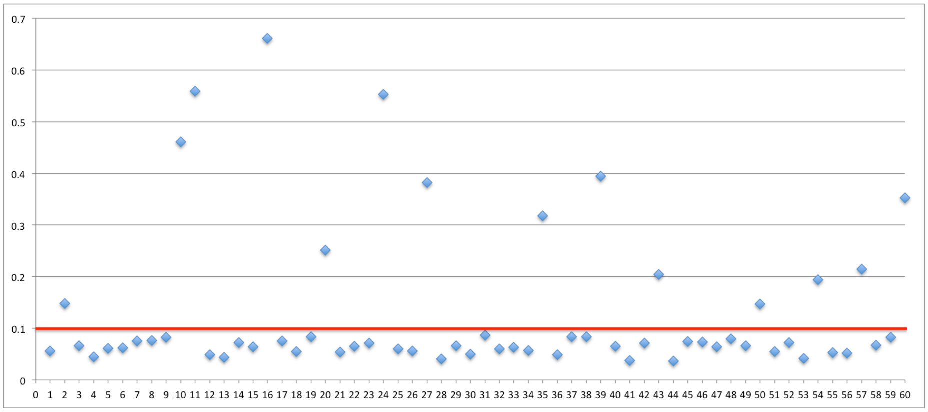


Figure 8. Distribution of CR Value

5.1.2 Estimated Weights of Criteria

This section discusses the calculation results of pairwise comparisons toward five criteria using AHP methodology. The aggregated results from experts' opinions show that the importance of the socio-political and technical criteria was relatively low. Additionally, they assessed the importance of economic and environmental criteria as high, while the energy resources criterion was estimated to have the highest importance weight. For more details, the calculation results that determine the estimated weights of five criteria (parent level) are shown in table 20 and figure 9.

Table 20. Estimated Weights of Five Criteria

Criterion	Priority Weight	Priority Weight (%)	Rank
Energy Resources	0.2598	25.98	1
Economic	0.2344	23.44	3
Technical	0.1403	14.03	4
Environmental	0.2370	23.70	2
Socio-Political	0.1283	12.83	5

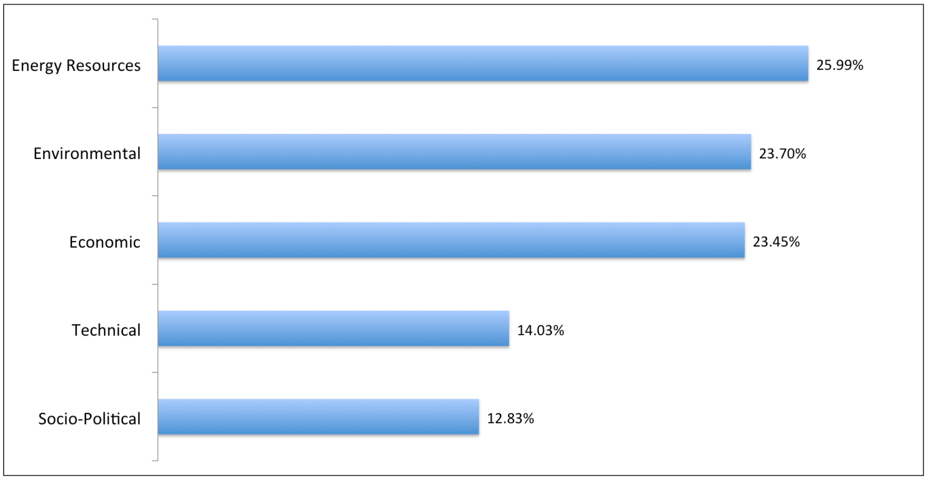


Figure 9. Estimated Weights of Five Criteria

5.1.3 Estimated Weights of Factors

This section discusses the calculation results of pairwise comparisons in determining the weights of each factor within their each criterion. Afterward based on the calculation results, all the factors were ranked to determine the local priorities within each criterion.

For energy resources criterion, the aggregated results from experts' opinions estimated the distance to user to have the least importance compared to the other two factors. Additionally, they believed that the utilization period of the energy sources is more important than the quantitative availability of the energy sources itself. For more details, the calculation results that determine the estimated weights of three factors and the local priorities in energy resources criterion are shown in table 21 and figure 10.

Table 21. Estimated Weights of Three Factors in Energy Resources Criterion

Factors	Priority Weight	Priority Weight (%)	Rank
Resources Availability	0.3239	32.39	2
Resources Durability	0.4292	42.92	1
Distance to User	0.2467	24.67	3

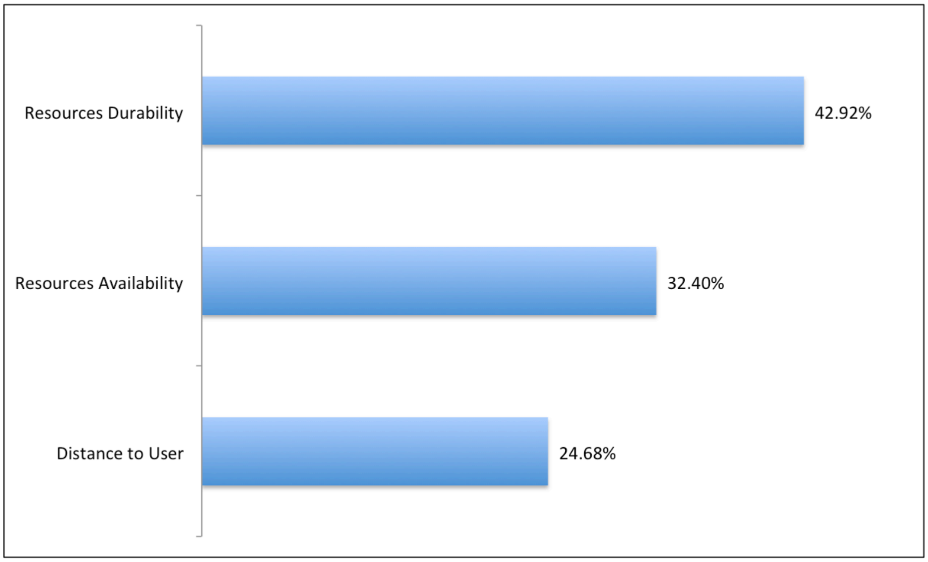


Figure 10. Local Priorities in Energy Resources Criterion

For economic criterion, the aggregated results from experts' opinions estimated the cost elements, particularly the capital cost and operation and maintenance cost, to have the least importance compared to other factors. Additionally, they assessed the importance of economic profitability of the energy plan as high, while the fluctuation of the energy prices was estimated to have the highest importance weight. For more details, the calculation results that determine the estimated weights of four factors and the local priorities in economic criterion are shown in table 22 and figure 11.

Table 22. Estimated Weights of Four Factors in Economic Criterion

Factors	Priority Weight	Priority Weight (%)	Rank
Capital Cost	0.1913	19.13	4
Operation and Maintenance Cost	0.2240	22.40	3
Profitability	0.2553	25.53	2
Volatility of Energy Prices	0.3292	32.92	1

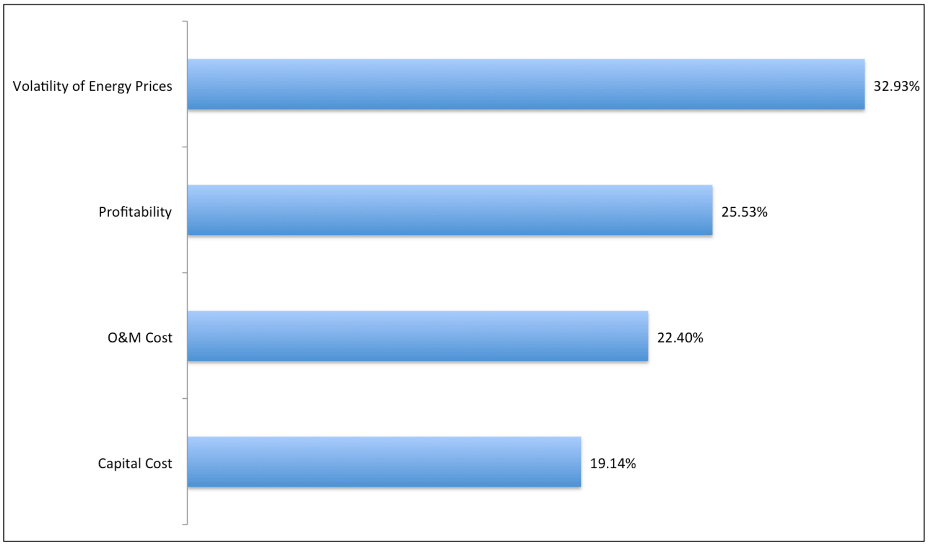


Figure 11. Local Priorities in Economic Criterion

For technical criterion, the aggregated results from experts' opinions estimated that the importance of training requirement factor was relatively low. Additionally, they believed that the availability of the equipment and parts in domestic market is more important than the maturity of the technology, while the technology performance was estimated to have the highest importance weight. For more details, the calculation results that determine the estimated weights of four factors and the local priorities in technical criterion are shown in table 23 and figure 12.

Table 23. Estimated Weights of Four Factors in Technical Criterion

Factors	Priority Weight	Priority Weight (%)	Rank
Maturity of Technology	0.2067	20.67	3
Technology Performance	0.3747	37.47	1
Training Requirement	0.1291	12.91	4
Availability of Equipment and Parts	0.2893	28.93	2

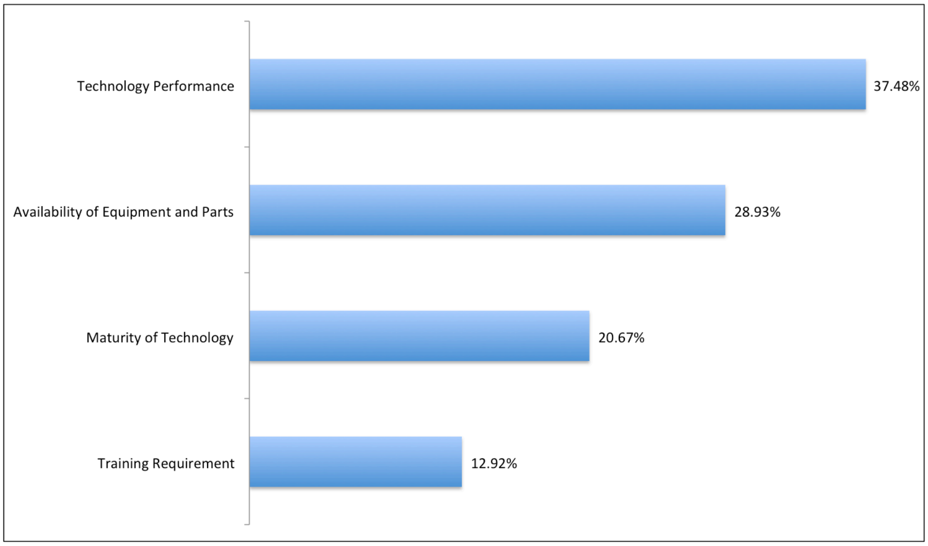


Figure 12. Local Priorities in Technical Criterion

For environmental criterion, the aggregated results from experts' opinions estimated the area-required factor to have the least importance compared to the other two factors. Beside that they also asserted that the pollutant and emission, e.g. the greenhouse gases, liquid waste and solid waste, is almost twice as important as the noise pollution. For more details, the calculation results that determine the estimated weights of three factors and the local priorities in environmental criterion are shown in table 24 and figure 13.

Table 24. Estimated Weights of Three Factors in Environmental Criterion

Factors	Priority Weight	Priority Weight (%)	Rank
Pollutant and Emission	0.5442	54.42	1
Area Required	0.1674	16.74	3
Noise	0.2883	28.83	2

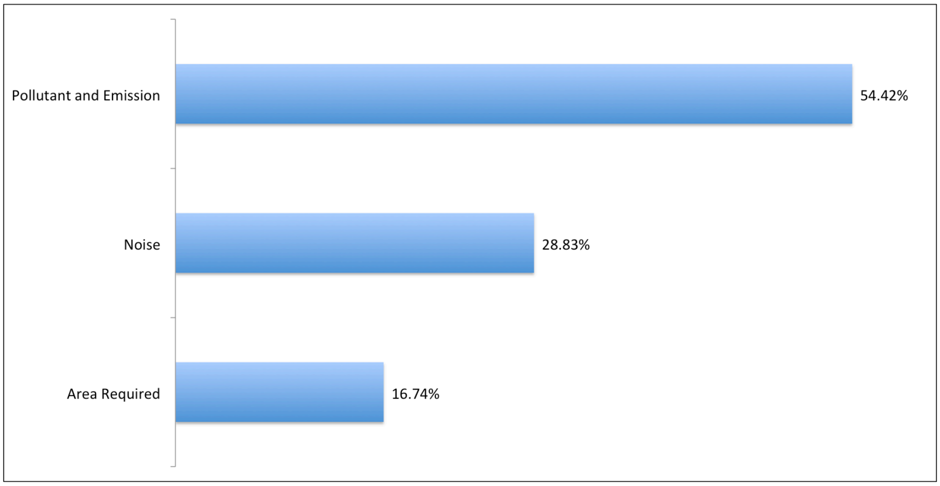


Figure 13. Local Priorities in Environmental Criterion

For socio-political criterion, the aggregated results from experts' opinions estimated that the population level of the area becomes the least important factor that have to be considered by the Government in their energy plans, compared to the other factors. The direct and indirect impact of the energy plan on the employment condition was estimated to be more important than the contribution of the energy plan to support long-term Government policies. Additionally, they confirmed that the social supports and acceptance from the people who are likely to be impacted by the energy plan was estimated to have the highest importance weight. For more details, the calculation results that determine the estimated weights of four factors and the local priorities in socio-political criterion are shown in table 25 and figure 14.

Table 25. Estimated Weights of Four Factors in Socio-Political Criterion

Factors	Priority Weight	Priority Weight (%)	Rank
Population	0.1780	17.80	4
Social Acceptability	0.3023	30.23	1
Job Creation	0.2684	26.84	2
Contribution to Support Long-Term Government Policies	0.2510	25.10	3

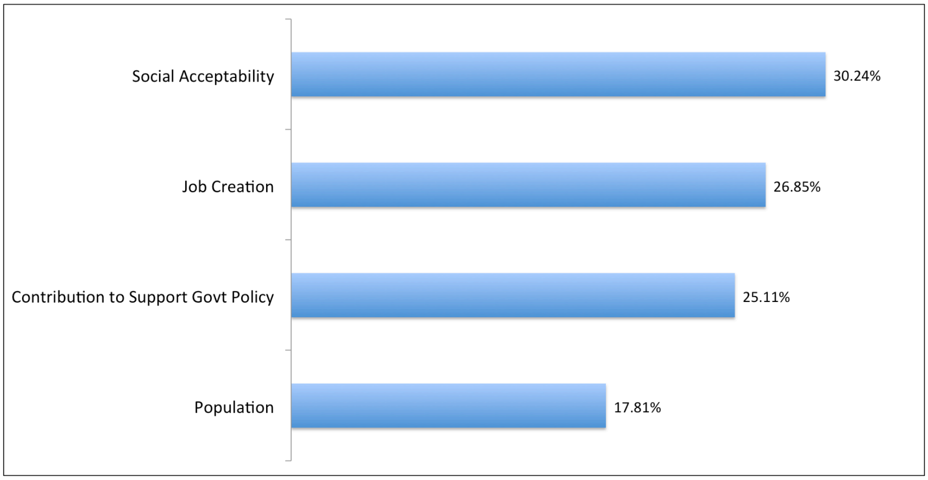


Figure 14. Local Priorities in Socio-Political Criterion

5.1.4 Results of Global Priorities

Heo et al. (2010) conveyed that the results of global priorities are determined by multiplying the weights of the criteria (parent level) to the weights of each factor (sibling level). The calculation results that determine the overall weights of all factors and their global priorities are shown in table 26 and figure 15.

From the aggregated results of experts' opinions, the factor of pollutant and emission was estimated to have the highest weight compared to all the factors in the calculation of the total respondents. Afterward, the durability or the utilization period of the energy sources had the second highest weight, while the quantitative availability of the energy sources was ranked third. Among all the factors, the training requirement and population were considered as two least important factors among the other factors, whereas the economic profitability, the technology performance and social acceptability were ranked seventh, eighth and thirteenth respectively.

Table 26. Results of Global Priorities

Factors	Priority Weight	Priority Weight (%)	Rank
Resources Availability	0.0842	8.42	3
Resources Durability	0.1115	11.15	2
Distance to User	0.0641	6.41	6
Capital Cost	0.0449	4.49	10
Operation and Maintenance Cost	0.0525	5.25	9
Profitability	0.0599	5.99	7
Volatility of Energy Prices	0.0772	7.72	4
Maturity of Technology	0.0290	2.90	16
Technology Performance	0.0526	5.26	8
Training Requirement	0.0181	1.81	18
Availability of Equipment and Parts	0.0406	4.06	11
Pollutant and Emission	0.1290	12.90	1
Area Required	0.0397	3.97	12
Noise	0.0683	6.83	5
Population	0.0228	2.28	17
Social Acceptability	0.0388	3.88	13
Job Creation	0.0344	3.44	14
Contribution to Support Govt. Policy	0.0322	3.22	15

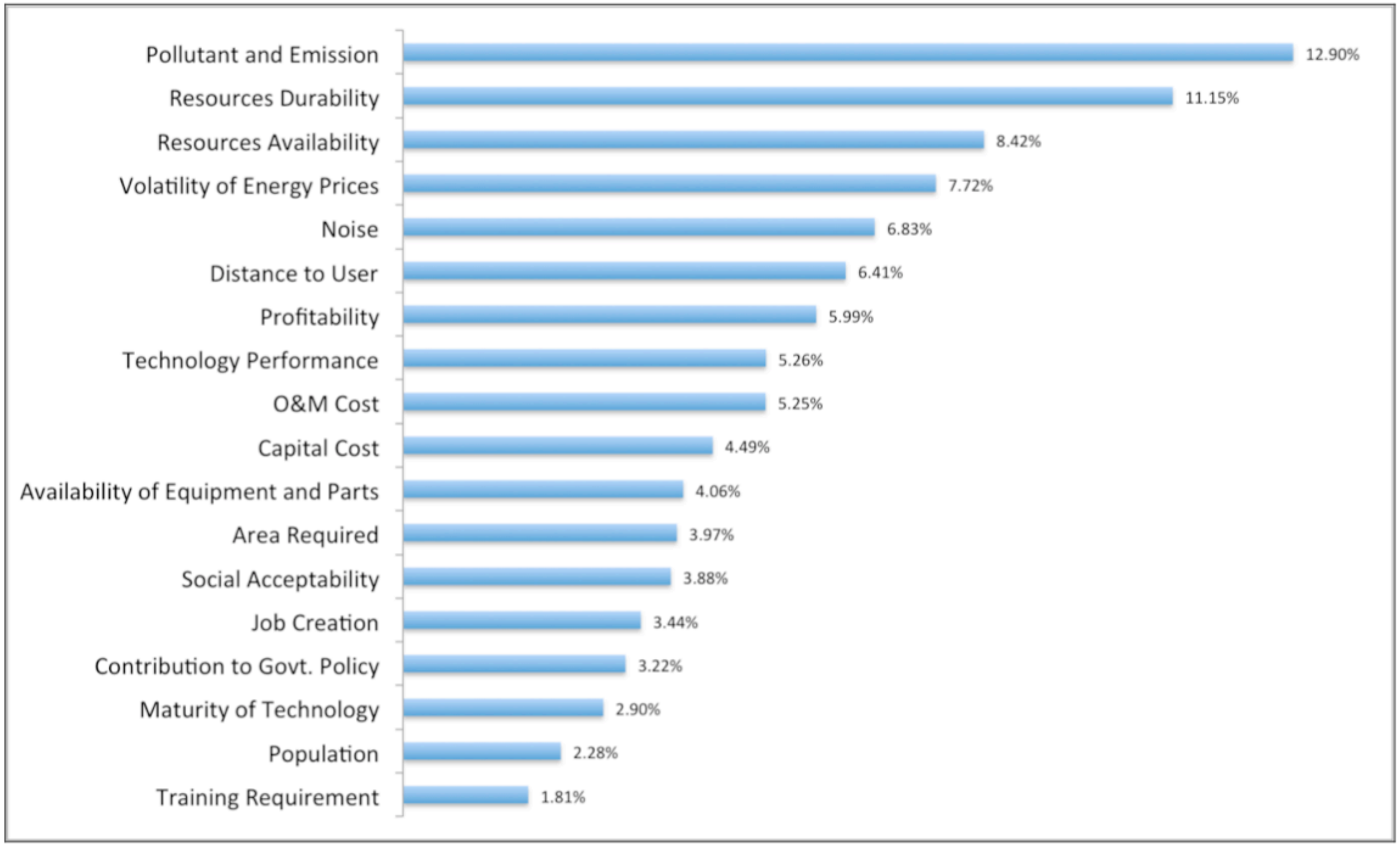


Figure 15. Results of Global Priorities

5.2 Results Discussion

5.2.1 Discussion for Local Priorities

In this section we discuss about the results that we obtained from this study, in order to establish the assessment factors for energy planning in Indonesia. The aggregated results from experts' opinions showed that the most important criterion for energy planning in Indonesia was the energy resources criterion. This finding is similar to those of Tasri and Susilawati (2014), who also conveyed that the energy source's quality criterion was the most important criterion in determining the most appropriate renewable energy sources for Indonesia. The high importance of energy resources criterion for energy planning is also in line with the government's vision as stipulated in Presidential Regulation No. 22 of 2017, which asserted that energy demands in every island or region must first be met by prioritizing the utilization of local energy potential. Afterward this government's vision is also supported by another finding of this study, which showed that the utilization period of the energy sources and quantitative availability of local energy sources were two most important factors in energy resource criterion. In other words, the security of supply from local energy potential has substantial role in formulating an energy plan.

In accordance with global efforts to harmonize the economic growth and environmental sustainability, therefore as expected we found that environmental criterion was the second highest rank for energy planning in Indonesia. In their study, Luthra et al. (2015) found that the environmental indicator was the first rank for establishing the indicators of sustainability assessment in Indian energy planning. Talinli et al. (2010) also found that environmental criterion was ranked second after social factors, in determining sustainable energy futures from Turkey. These examples from different authors show us that the environmental aspect is an inseparable component and is a major part of the sustainability concept. In addition, this finding also shows that the policy makers and energy experts are committed to shift from fossil fuels, to prioritize the utilization of environmentally friendly energy sources. This commitment can also be represented by the aggregated experts' opinion in this study, which concluded that pollutant and emission factor was the most important factor in environmental criteria for energy planning in Indonesia. As one of the world's top emitters, the government of Indonesia has committed to reduce their GHG emissions by 29% compared to Business as Usual (BAU), and optimizing international assistance to improve their target to 41% by 2030 (MEMR, 2017). Moreover through the Presidential Regulation No. 22 of 2017, the government has committed to continuously increasing the utilization of environmentally friendly energy sources while continuing to reduce the portion of fossil fuels consumption in its energy mix composition.

In economic criterion, the fluctuation of the energy prices was considered as the most important factor, because nowadays forecasting the energy prices, especially fossil fuels, are uncertain and unpredictable (Bharat Raj Singh & Onkar Singh, 2012). Additionally by considering that an energy plan and/or energy policy should be able to be implemented over a long period of time, therefore the utilization of energy sources that have more stable price becomes the government's priority for the future. This finding seems to support the Indonesia's Future Energy Scenario that we have discussed in chapter two. The government has confirmed their commitment to continue to reduce the use of fossil fuels and increase the utilization of renewable energy to at least 23% by 2025, and at least 31% by 2050 (MEMR, 2017). Although nowadays fossil fuels are cheaper than renewable energy, but their future market conditions are very difficult to predict, and this condition is not preferable for government's planning system.

In the future, some fossil fuels may become more expensive because of the increasing difficulty of the extraction and refining process, whereas the prices of renewable energy continue to decline and become more competitive along with technological developments and increased global utilization (BP, 2015).

By implementing the AHP methodology, we found that technical criterion was the fourth most important criterion for energy planning in Indonesia. Similarly, the technological criterion was also ranked fourth by Luthra et al. (2015) for establishing the indicators of sustainability assessment in Indian energy planning. While in their study, Heo et al. (2010) found that the technological criterion had the highest importance in the specialist group, when determining the criteria and factors for renewable energy dissemination program. These examples from different authors seem to confirm that the energy planning process has its own different criteria and factors for each country, particularly for technical criterion. For a developing country like Indonesia where technological developments are not yet advanced, the most important factors in technical criterion are technology performance factor and the factor of equipment and parts availability, as indicated by the results obtained in this study. It is vital for the government to always choose more proven technology with good performance, because reliable technology performance will minimize damage and failure when the technology is applied, which also will make the projects more sustainable and maintenance activities more effective and efficient. Additionally, the selection of technology with good availability of equipment and parts in the domestic market should be the main focus of the government. This should be done because in the future, the national energy development will be focused in many remote areas in Indonesia, therefore effective and efficient maintenance processes become mandatory.

Finally we found that the importance of the socio-political criterion was the lowest among the other criteria. We didn’t expect before if this criterion will be the lowest rank, because oftentimes the socio-political criterion becomes a key determinant of the government program, moreover the social acceptability factor found to be the most significant factor within this criterion. We first expected this criterion would have a higher priority weight by reflecting on what’s been happening in Indonesia, especially in renewable energy projects. For example, some hydropower projects were constrained by land acquisition problems and protests from several Non-Governmental Organizations (NGO) and community groups. Additionally, some geothermal projects were also constrained by forestry's permit issues and have been protested by several community groups. For that reason, we conducted further analysis to derive another conclusions that able to explain this particular results. We formed two groups and then compared the aggregated results from these groups: the energy experts in the renewable energy sector, and energy experts in the fossil-energy sector (particularly coal, oil and gas). The discussion of this analysis is presented in the next section of this chapter.

5.2.2 Discussion for Global Priorities

Similar to the frameworks of Ghimire (2016), in this section we classified all the factors based on its each global priorities to establish three groups of factors: high important factors for energy planning, medium important factors for energy planning, and least important factors for energy planning. The factors that have more than 6% importance weight in global priorities were classified into "high important factors" group.

Table 27. High Important Factors

Factors	Priority Weight	Priority Weight (%)	Rank
Pollutant and Emission	0.1290	12.90	1
Resources Durability	0.1115	11.15	2
Resources Availability	0.0842	8.42	3
Volatility of Energy Prices	0.0772	7.72	4
Noise	0.0683	6.83	5
Distance to User	0.0641	6.41	6

From above table we concluded that these six factors should be the main factors that taken into account for energy planning in Indonesia. The future Indonesia’s energy planning must prioritize the security of supply of local energy potential that are environmentally friendly and have relatively stable prices. Moreover if we synchronize these findings with Indonesia's future energy scenario as stipulated in Presidential Regulation No. 22 of 2017, this framework is very much in line with the government's vision to increase the utilization of local renewable energy sources to support economic and industrial growth, as well as social development.

Table 28. Medium Important Factors

Factors	Priority Weight	Priority Weight (%)	Rank
Profitability	0.0599	5.99	7
Technology Performance	0.0526	5.26	8
O&M Cost	0.0525	5.25	9
Capital Cost	0.0449	4.49	10
Availability of Equipment and Parts	0.0406	4.06	11
Area Required	0.0397	3.97	12
Social Acceptability	0.0388	3.88	13
Job Creation	0.0344	3.44	14
Contribution to Govt. Policy	0.0322	3.22	15

Afterward, the factors that have more than 3% but less than 6% importance weight in global priorities were classified into “medium important factors” group. And finally, the remaining factors were classified into “least important factors” group.

Table 29. Least Important Factors

Factors	Priority Weight	Priority Weight (%)	Rank
Maturity of Technology	0.0290	2.90	16
Population	0.0228	2.28	17
Training Requirement	0.0181	1.81	18

5.2.3 Comparative Analysis

As mentioned before that we conducted further analysis by forming two groups and compared the aggregated results from these groups: the energy experts in the renewable energy sector, and energy experts in the fossil-energy sector.

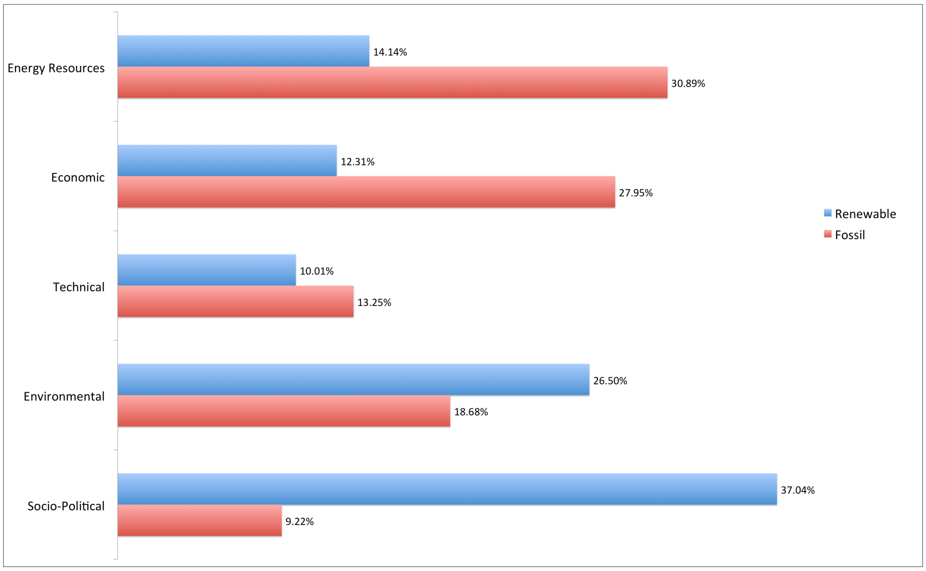


Figure 16. Comparisons for Criteria

As shown in figure 16, we can infer that both groups have different judgments toward each of the criterion. The renewable group considered socio-political criterion as the most important criterion for energy planning, while the fossil group estimated this criterion as the least important. The role of energy resources criterion was ranked as the most important in fossil group, while in renewable group this criterion was ranked as the third. In fossil group, economic criterion was considered more important and ranked as the second, whereas in renewable group this economic criterion was ranked as number fourth. Both groups agreed that technical criterion was estimated to be relatively low importance, since the fossil group ranked this criterion as the fourth and renewable group ranked this criterion as the least important. Additionally, they also both agreed that environmental criterion has substantial role in energy planning, hence the fossil group ranked this criterion as third and renewable group ranked this as the second most important.

These distinctions were caused by different challenges and different working-conditions that were experienced by each group. For example, the energy experts in fossil group often faced with the fact that fossil-energy reserves are depleted, hence it is important to take into account the security of supply and resources availability criteria in their decision making process for energy planning. Another example, the obstacles encountered by energy experts in renewable groups are often related to socio-political aspects, such as the lack of social acceptability to their plans and/or policies, or the complicated licensing processes that involving the other government agencies and other Ministries.

These distinctions were also caused by the different mechanisms of plan and policy formulation in each sector. For example in the Directorate General of New Renewable Energy and Energy Conservation, through the Ministerial Regulation No. 39 of 2017, the formulation of energy plan is based on the bottom-up principle, with considering the input from local communities and local governments. This mechanism was conducted to minimize the potential for social conflicts, so that the plan can be successfully implemented. Another example is what happened at Directorate General of Oil and Gas and Directorate General of Mineral and Coal. The oil and gas sector and mining sector are the main contributors to state revenues, therefore all the programs that are being designed for these sectors classified as National Energy Program. Accordingly, the energy plan and energy policy development process is more top-down approach based on the energy resources and economic criterion.

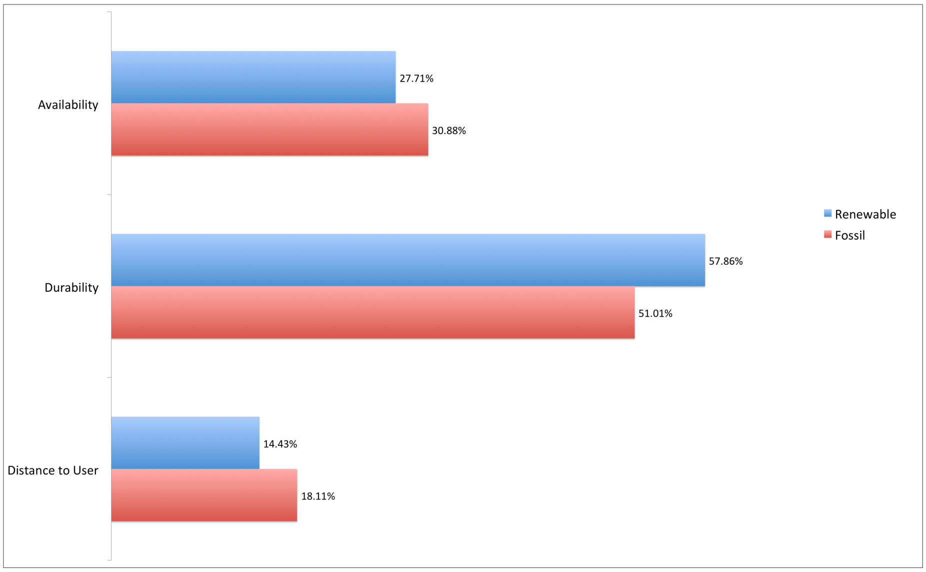


Figure 17. Comparisons for Local Priorities in Energy Resources Criterion

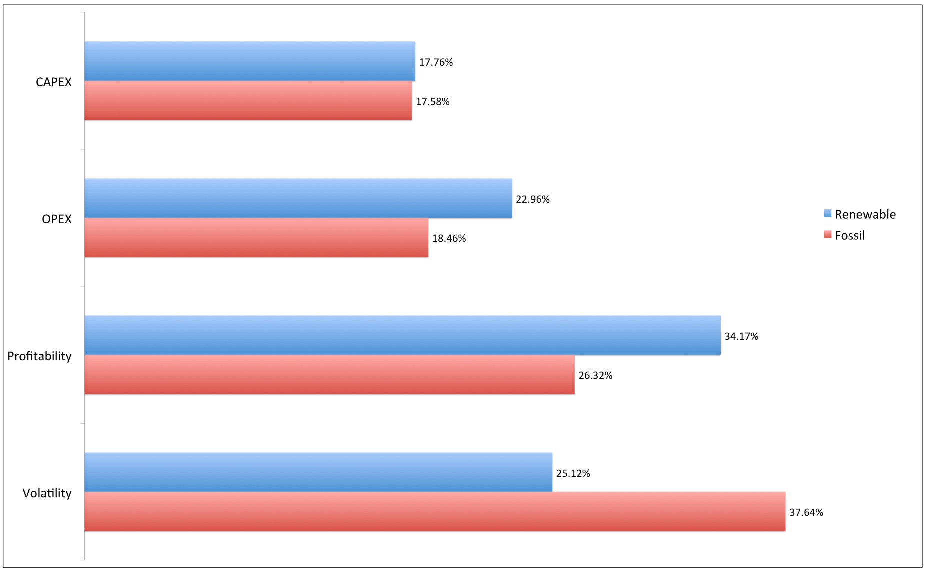


Figure 18. Comparisons for Local Priorities in Economic Criterion

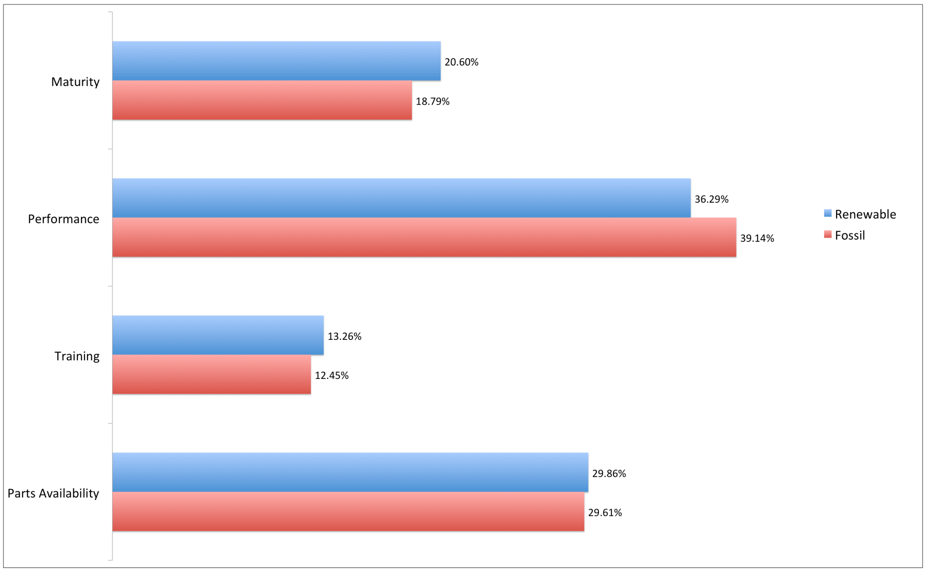


Figure 19. Comparisons for Local Priorities in Technical Criterion

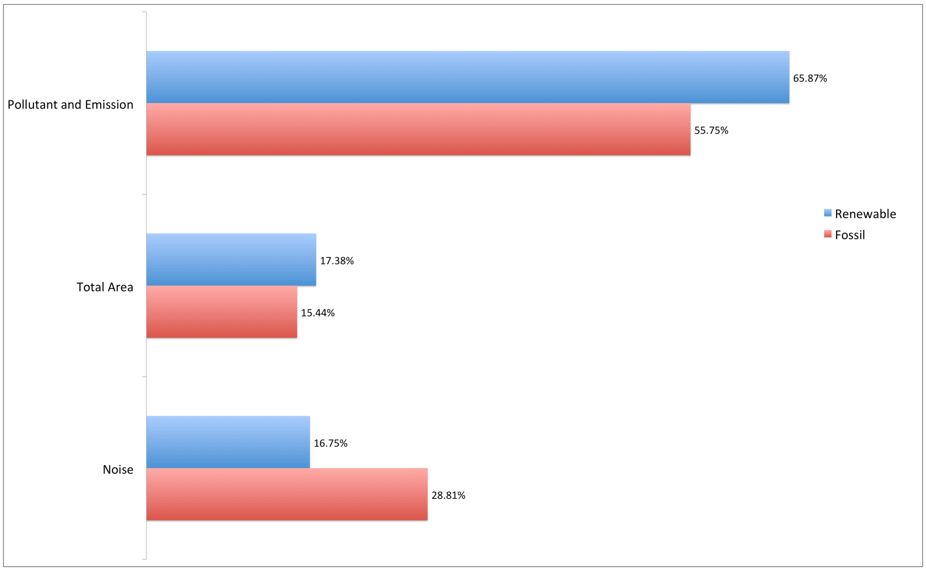


Figure 20. Comparisons for Local Priorities in Environmental Criterion

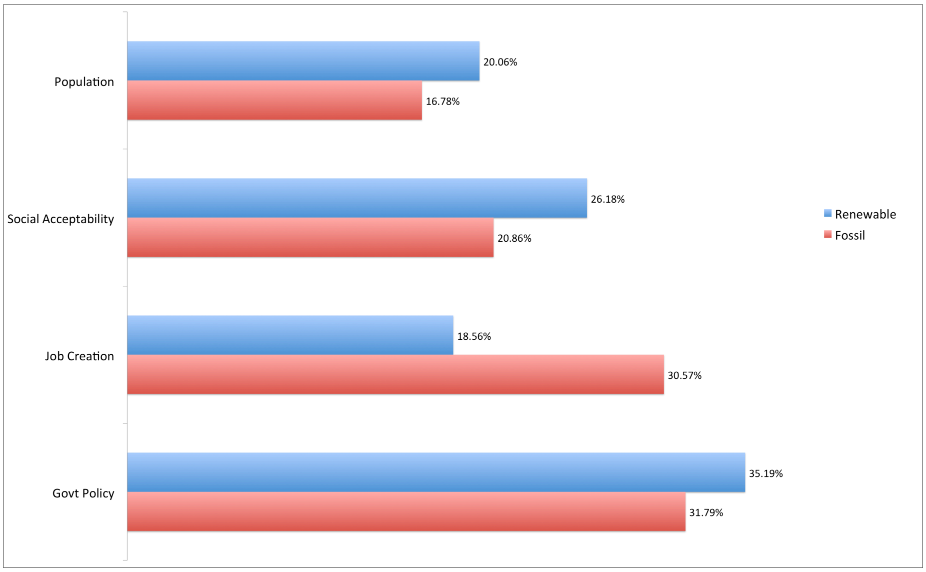


Figure 21. Comparisons for Local Priorities in Socio-Political Criterion

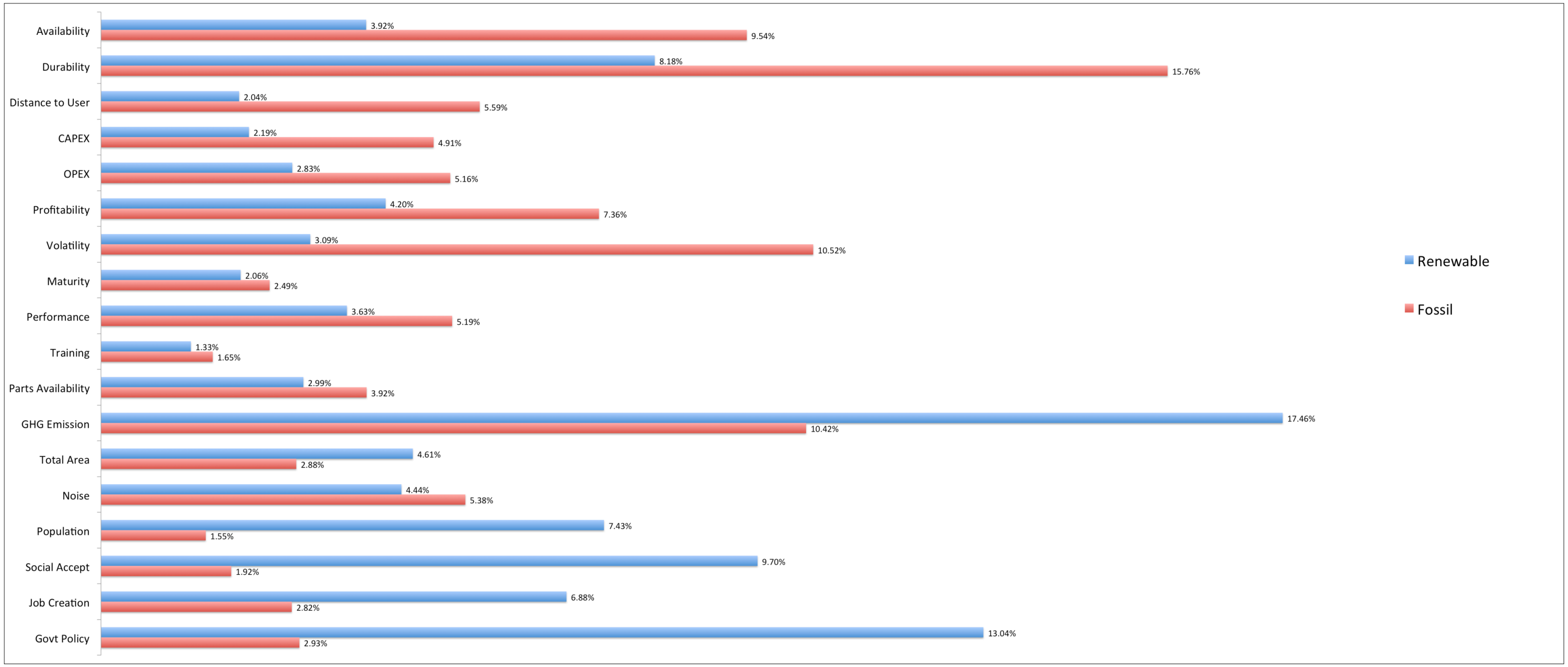


Figure 22. Comparisons for Global Priorities

6. Conclusions

6.1 Overall Conclusions

This study discussed about the current major challenges in Indonesia's energy sector, and also Indonesia's future energy scenario, as the starting base for policy improvement in order to establish a proper energy planning system. It was proposed that the participation of Indonesia's energy experts in this study would be the key factor in collecting different perspectives in determining the criteria and factors that should be taken into account for energy planning in Indonesia. Hereafter, a systematic analysis of the existing literatures and the government's policies were also conducted in previous chapters.

Despite the fact that Indonesia is endowed with abundant energy resources, this country is still not able to cope with the issue of electricity shortage and high dependence on energy imports. The absence of comprehensive decision-making process in Indonesia's energy planning system makes the energy sustainability concept very difficult to be realized by the government. Muliadireja (2005) conveyed that one of the obstacles that have hampered the process of policy making in Indonesia is inadequate and inaccurate information and analysis. For these reasons, this study aims to determine various assessment criteria and factors that should be taken into account for energy planning in Indonesia and compiling those factors into rank and weight based on its importance. From the weights estimation results, four major conclusions can be derived regarding the six highly important factors, substantial role of energy resources criteria, different perspectives between two groups of energy experts, and the application of the results.

The aggregated results from experts' opinions showed that there are six highly important factors that should be taken into account for energy planning in Indonesia: pollutant and emission, resources durability, resources availability, volatility of energy prices, noise, and distance to user. According to this finding, Indonesia's energy planning must prioritize the security of supply of local energy potential that are environmentally friendly and have relatively stable prices. This seems to be in line with the government's vision to increase the utilization of renewable energy and natural gas, which definitely will provide positive impacts on many aspects, such as reducing dependence on imports and also taking part in global efforts to reduce global carbon emissions. However, optimizing the local energy potential is challenging. There are two main keys that must be done by the government, i.e. providing adequate infrastructures that able to accelerate the project's implementation (especially for gas infrastructures), and regulating the fiscal and financial instruments to support the viability of energy projects.

Secondly, this study found that the most important criterion for energy planning in Indonesia was the energy resources criterion. Moreover, the findings of this study also estimated that the utilization period of the energy sources and quantitative availability of local energy sources were the two most important factors in this criterion. Based on these findings, we can draw the conclusion that the security of supply from local energy potentials has substantial role in formulating an energy plan. However, there are some challenges that must be resolved by the government to actualize this concept. For example, the mapping of energy potential and energy resources in each region hasn't been well conducted, therefore it may provide incorrect information during the process of energy plan and energy policy formulation. This is due to the lack of Government's attention to the exploration and survey activities. To address this issue, some efforts must be done by the government in order to fix this situation, e.g. by improving the quantity and quality of exploration data. The government must possess complete and accurate data of energy resources, energy reserves, and energy potential in every region in Indonesia, and for this purpose, government's active participation is absolutely necessary. Accurate mapping of energy potential and resources can result in good planning and decision-making process, so that the government's mission to provide sustainable energy supplies from local energy potentials can be well implemented.

Thirdly, we found significant differences between the importance weights derived from the energy experts in renewable energy group and the ones from the fossil-based energy group. The most distinguishing between these two groups was their assessment of socio-political criterion, in which the assessment of the renewable energy group toward this criterion was four times higher than the estimated weights assigned by fossil energy group. In addition, the fossil energy group estimated the energy resources criterion to be about two times more important than the renewable energy group did. With further analysis, we concluded that these distinctions were caused by different challenges and different working-conditions that are experienced by each group. Beside that, different mechanisms of plan and policy formulation in each sector also make these two groups have different perspectives. In renewable energy sector plan and policy formulations are arranged based on the bottom-up principle, whereas in the oil, gas and mining sector the energy plan and energy policy developments are based on the top-down approach.

The frameworks obtained from this study can be implemented for both purposes, evaluating the existing plan and also for planning the upcoming energy projects. The weights of criteria and factors derived from this paper will help policy-makers to establish an effective assessment framework for energy planning system in Indonesia, especially in breaking down the long-term energy plans into short-term energy plans as the reference for the policy formulation and implementation.

6.2 Study Limitations and Scope for Future Work

This study was conducted for determining the assessment criteria and factors that should be taken into account for energy planning in Indonesia, and compiling those indicators into rank and weight based on its importance. However, the perspectives that used in establishing the criteria and factors in this study were tend to be supply-side approach. Therefore, future development on this study should be focused on both supply-side and demand-side approach, in order to generate more comprehensive results.

Additionally, the frameworks obtained from this study can be further developed into more specific assessment purposes, i.e. evaluating the most appropriate renewable energy sources for a specific region in Indonesia, selecting the best location for oil refineries development in Indonesia, or analyzing the important assessment criteria and factors for nuclear energy development in Indonesia.

Appendix

Questionnaire on the Assessment Factors for Energy Planning in Indonesia

This questionnaire is intended as one of the methodologies for my research entitled "Analysis of The Assessment Factors for Energy Planning in Indonesia using Analytic Hierarchy Process", and your answers here will be analyzed and formulated to determine the key criteria and factors that should be taken into account for energy planning in Indonesia. This questionnaire provides pair-wise comparison questions for the energy experts in Indonesian Government, in order to provide a solid contribution for decision-making process in Indonesia's energy planning system.

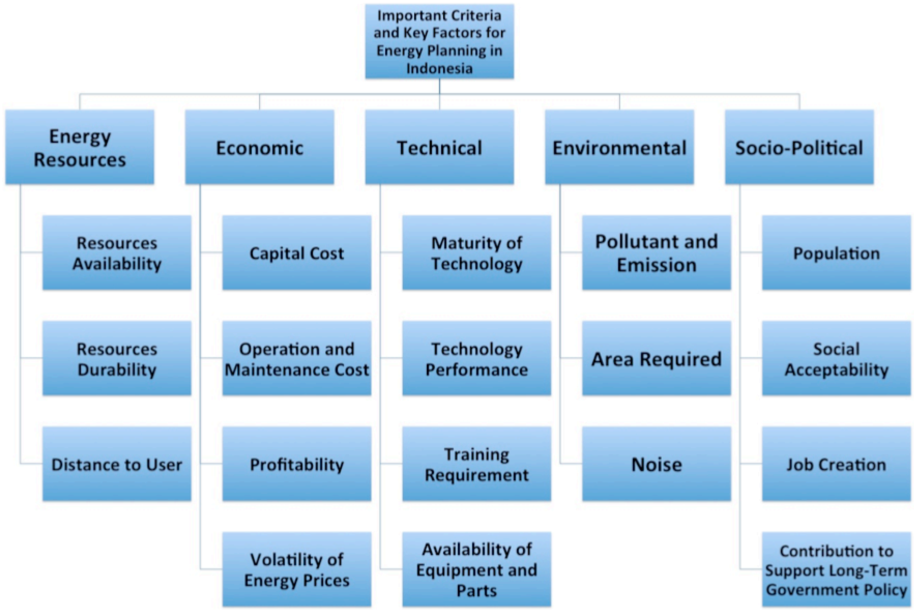
As an affirmation, all your information and your answers to this questionnaire remain confidential, will not be disclosed and used only for academic research purposes. If you have any comment, suggestion or question about this questionnaire, you can reach me through email: ekomahar@snu.ac.kr and eko.diputra@gmail.com.

To attain the research objectives, the Analytic Hierarchy Process (AHP) methodology is implemented to define the main problem in the form of hierarchy structure. As the most important tools, the pair-wise comparison questions in this questionnaire enable the respondents to compare the relative importance between two criteria or two sub-criteria, hence the results from this questionnaire will be significant for this entire research.

Eko Mahar Diputra
Seoul National University

How to Answer this Questionnaire?

The pair-wise comparison questions in this questionnaire are based on this hierarchy (five criteria and eighteen sub-criteria), where the relative importance of each criterion and sub-criterion will be evaluated under quantitative and qualitative methods.



Answering the questions in this questionnaire is very easy! You just need to provide your judgments when comparing the relative importance between two criteria or two sub-criteria within the hierarchy.

Example: You have to compare the relative importance between Orange and Apple for the health of your body. And to answer this question, you can choose ONLY ONE OPTION among all nine options, which strongly represents your view of it.

Orange 1 2 3 4 5 6 7 8 9 Apple

1 : if Orange is EXTREMELY MORE IMPORTANT than Apple
2 : if Orange is VERY STRONGLY MORE IMPORTANT than Apple
3 : if Orange is STRONGLY MORE IMPORTANT than Apple
4 : if Orange is MODERATELY MORE IMPORTANT than Apple
5 : if Orange and Apple are EQUALLY IMPORTANT
6 : if Apple is MODERATELY MORE IMPORTANT than Orange
7 : if Apple is STRONGLY MORE IMPORTANT than Orange
8 : if Apple is VERY STRONGLY MORE IMPORTANT than Orange
9 : if Apple is EXTREMELY MORE IMPORTANT than Orange

Which option that you will choose?

You must keep in mind that THE DEGREE OF IMPORTANCE FOR LEFT-SIDE CRITERION (in this case, Orange) continues to decline from '1' to '4', while THE LEVEL OF IMPORTANCE FOR RIGHT-SIDE CRITERION (in this case, Apple) keeps increasing from '6' to '9'. In addition, if you decide that BOTH CRITERIA ARE EQUALLY IMPORTANT thus option '5' is your answer.

If you already have a thorough understanding of this questionnaire, then let's proceed to the real questions!

SELECTION OF MAIN CRITERIA

Considering that the successful implementation of energy plan and Government's policies require various supportive conditions from multi-sectors, hence in this section you have to provide your professional judgement in comparing the relative importance between two main criteria.

Description of each main criterion:

a. Energy Resources

The criterion used to measure the quantitative availability of energy resources and/or energy potential in an area/city/province/island

b. Economic

The criterion used to determine the economic cost-and-benefit value of the energy plan that is going to be established in certain area/city/province/island.

c. Technical

The criterion used to evaluate the technical aspect of the technologies that will be chosen for the energy plan.

d. Environmental

The criterion used to measure the environmental impact that may arise from a particular energy plan

e. Socio-Political

The criterion used to determine the social and political factors that have to be considered for the energy plan

QUESTION: In decision-making process of formulating an energy plan, which criterion that you consider more important?

	1	2	3	4	5	6	7	8	9	
Energy Resources	○	○	○	○	○	○	○	○	○	Economic

	1	2	3	4	5	6	7	8	9	
Energy Resources	○	○	○	○	○	○	○	○	○	Technical

	1	2	3	4	5	6	7	8	9	
Energy Resources	○	○	○	○	○	○	○	○	○	Environmental

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

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

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

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

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

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

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

SELECTION OF LOCAL PRIORITIES

Considering that the successful implementation of energy plan and Government's policies require various supportive conditions from multi-sectors, hence in this section you have to provide your professional judgement in comparing the relative importance between two factors within the energy resources criterion.

Description of each factor:

a. Resources Availability

The factor used to measure the quantitative availability of the energy reserves and/or energy potential in the area/city/province/island.

b. Resources Durability

The factor used to determine the length of period for the energy sources to be capitalized. Please keep in mind some particular circumstances may reduce the durability, i.e. overlapping resources area, technical constraints, etc.

c. Distance to User

The factor used to consider the maximum distribution distance that can be tolerated when capitalizing the energy sources.

QUESTION: In decision-making process of formulating energy plan, which factor that you consider more important?

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

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

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

SELECTION OF LOCAL PRIORITIES

Considering that the successful implementation of energy plan and Government's policies require various supportive conditions from multi-sectors, hence in this section you have to provide your professional judgement in comparing the relative importance between two factors within the economic criterion.

Description of each factor:

a. Capital Cost

The factor used to consider the required initial investment for the energy plan.

b. Operation and Maintenance Cost

The factor used to consider the cost structure of the energy plan, particularly its operation and maintenance cost.

c. Profitability

The factor used to consider the economic profitability of the energy plan.

d. Volatility of Energy Prices

The factor used to consider the fluctuation of the energy prices around its average value.

QUESTION: In decision-making process of formulating energy plan, which factor that you consider more important?

	1	2	3	4	5	6	7	8	9	
Lower Capital Cost	○	○	○	○	○	○	○	○	○	Lower Operation and Maintenance Cost

	1	2	3	4	5	6	7	8	9	
Lower Capital Cost	○	○	○	○	○	○	○	○	○	Higher Profitability

	1	2	3	4	5	6	7	8	9	
Lower Capital Cost	○	○	○	○	○	○	○	○	○	Lower Volatility (Stable Price)

	1	2	3	4	5	6	7	8	9	
Lower Operation and Maintenance Cost	○	○	○	○	○	○	○	○	○	Higher Profitability

	1	2	3	4	5	6	7	8	9	
Lower Operation and Maintenance Cost	○	○	○	○	○	○	○	○	○	Lower Volatility (Stable Price)

	1	2	3	4	5	6	7	8	9	
Higher Profitability	○	○	○	○	○	○	○	○	○	Lower Volatility (Stable Price)

SELECTION OF LOCAL PRIORITIES

Considering that the successful implementation of energy plan and Government's policies require various supportive conditions from multi-sectors, hence in this section you have to provide your professional judgement in comparing the relative importance between two factors within the technical criterion.

Description of each factor:

a. Maturity of Technology

The factor used to consider the development rate of the technology, because the more it advances then its initial faults and inherent problems have been removed or reduced by previous development.

b. Technology Performance

The factor used to consider the performance of the technologies.

c. Training Requirement

The factor used to consider the people's comprehension and understanding toward the desired technology.

d. Availability of Equipment and Parts

The factor used to consider the availability of different equipment and parts therein for different choices of energy sources and technologies.

QUESTION: In decision-making process of formulating energy plan, which factor that you consider more important?

	1	2	3	4	5	6	7	8	9	
More Mature Technology	○	○	○	○	○	○	○	○	○	Better Performance and Reliability

	1	2	3	4	5	6	7	8	9	
More Mature Technology	○	○	○	○	○	○	○	○	○	Less Training Required (More Familiar Technology)

	1	2	3	4	5	6	7	8	9	
More Mature Technology	○	○	○	○	○	○	○	○	○	Easier-to-Get Equipment and Parts

	1	2	3	4	5	6	7	8	9	
Better Performance and Reliability	○	○	○	○	○	○	○	○	○	Less Training Required (More Familiar Technology)

	1	2	3	4	5	6	7	8	9	
Better Performance and Reliability	○	○	○	○	○	○	○	○	○	Easier-to-Get Equipment and Parts

	1	2	3	4	5	6	7	8	9	
Less Training Required (More Familiar Technology)	○	○	○	○	○	○	○	○	○	Easier-to-Get Equipment and Parts

SELECTION OF LOCAL PRIORITIES

Considering that the successful implementation of energy plan and Government's policies require various supportive conditions from multi-sectors, hence in this section you have to provide your professional judgement in comparing the relative importance between two factors within the environmental criterion.

Description of each factor:

a. Pollutant and Emission

The factor used to consider the different amount of pollutant, emission and also waste that produced from different energy sources, such as the greenhouse gases, liquid waste and solid waste.

b. Area Required

The factor used to consider the measurement of the site choices, required land acquisition, and also to consider the impacts toward the change of ecosystem.

c. Noise

The factor used to consider the noise-pollution impact caused by the energy project to nearby residences.

QUESTION: In decision-making process of formulating energy plan, which factor that you consider more important?

	1	2	3	4	5	6	7	8	9	
Less Pollutant and Emission	○	○	○	○	○	○	○	○	○	Less Area Required

	1	2	3	4	5	6	7	8	9	
Less Pollutant and Emission	○	○	○	○	○	○	○	○	○	Less Noise Pollution

	1	2	3	4	5	6	7	8	9	
Less Area Required	○	○	○	○	○	○	○	○	○	Less Noise Pollution

SELECTION OF LOCAL PRIORITIES

Considering that the successful implementation of energy plan and Government's policies require various supportive conditions from multi-sectors, hence in this section you have to provide your professional judgement in comparing the relative importance between two factors within the socio-political criterion.

Description of each factor:

a. Population

The factor used to consider the demand level and impacts measurement from the energy plan in a certain area.

b. Social Acceptability

The factor used to consider the social supports and acceptance from the people who are likely to be impacted by the energy plan.

c. Job Creation

The factor used to measure the direct and indirect impacts of the energy plan on the employment condition.

d. Contribution to Support Long-Term Government Policy

The factor used to determine whether an energy plan is in line with the long-term Government policy on sustainable development, or not.

QUESTION: In decision-making process of formulating energy plan, which factor that you consider more important?

	1	2	3	4	5	6	7	8	9	
Population Level	○	○	○	○	○	○	○	○	○	Better Social Acceptability

	1	2	3	4	5	6	7	8	9	
Population Level	○	○	○	○	○	○	○	○	○	More Job Creation

	1	2	3	4	5	6	7	8	9	
Population Level	○	○	○	○	○	○	○	○	○	Support Long Term Government Policy

	1	2	3	4	5	6	7	8	9	
Better Social Acceptability	○	○	○	○	○	○	○	○	○	More Job Creation

	1	2	3	4	5	6	7	8	9	
Better Social Acceptability	○	○	○	○	○	○	○	○	○	Support Long Term Government Policy

	1	2	3	4	5	6	7	8	9	
More Job Creation	○	○	○	○	○	○	○	○	○	Support Long Term Government Policy

ADDITIONAL INFORMATION

NAME:

WORKING UNIT:

- ○ Secretariat General
- ○ Inspectorate 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 ESDM
- ○ State-owned Enterprises in the Energy Sector
- ○ Special Task Force for Upstream Oil and Gas Business Activities (SKK Migas)
- ○ Other Ministries
- ○ Other Government Units
- ○ Other: ____________

References

Adhikari, S., Mithulananthan, N., Dutta, A. & Mathias, A. (2008). Potential of Sustainable Energy Technologies under CDM in Thailand. *Renewable Energy*, 33(9): 2122–2133.

Afgan, N. & Carvalho, M. (2002). Multi-criteria Assessment of New and Renewable Energy Power Plants. *Energy*, 27: 739-755.

Alonso, J. & Lamata, T. (2006). Consistency in The Analytic Hierarchy Process: A New Approach. *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, 14(4): 445–459.

Asian Development Bank. (2015). Summary of Indonesia's Energy Sector Assessment. *ADB Papers on Indonesia*. Philippines.

Amer, M. & Daim, T. U. (2011). Selection of Renewable Energy Technologies for A Developing Country: A Case of Pakistan. *Energy Sustainable Development*, 15: 420–435.

Bana e'Costa, C., De Corte, J. M. & Vansnick, J. C. (2005). On the mathematical foundation of MACBETH. In J. Figueira, S. Greco and M. Ehrogott (eds), *Multiple Criteria Decision Analysis: State of the Art Surveys* (pp. 409–437). New York: Springer-Verlag.

Beccali, M., Cellura, M. & Mistretta, M. (2003). Decision-Making in Energy Planning: Application of The ELECTRE Method at Regional Level. *Renewable Energy,* 20: 2063–87.

Belton, V. & Gear, A. (1983). On a shortcoming of Saaty's method of analytical hierarchies. *Omega*, 11(3): 228–230.

Belton, V. (1986). A comparison of the analytic hierarchy process and simple multiattribute value function. *European Journal of Operational Research*, 26(1): 7–21.

Belton, V. & Goodwin, P. (1996). Remarks on the application of the analytic hierarchy process to judgmental forecasting. *International Journal Forecasting*, 12(1): 155–161.

BP. (2015). The Energy Challenge and Climate Change. *BP Sustainability Report 2015*. London: British Petroleum Co.

BP. (2016). *BP Statistical Review of World Energy 2017*. London: British Petroleum Co.

Burton, I. (1987). Report on Reports: Our Common Future: The World Commission on Environment and Development. *Environmental Science Policy and Sustainable Development*, 29(5): 25–9.

Carrion, J. A., Espin, Estrella, A., Aznar, D. F., Ridao, A. R. (2008). The Electricity Production Capacity of Photovoltaic Power Plants and the Selection of Solar Energy Sites in Andalusia (Spain). *Renewable Energy*, 33: 545–552.

Cavallaro, F. & Ciraolo, L. (2005). A Multi Criteria Approach to Evaluate Wind Energy Plants on an Italian Island. Energy Policy, 33: 235-244.

Chatzimouratidis, A. I. & Pilavachi, P. A. (2008). Multicriteria Evaluation of Power Plants Impact on the Living Standard using the Analytic Hierarchy Process. *Energy Policy*, 36: 1074–1089.

Cho, S., Kim, J. & Heo, E. (2015). Application of Fuzzy Analytic Hierarchy Process to Select the Optimal Heating Facility for Korean Horticulture and Stockbreeding Sectors. *Renewable and Sustainable Energy Reviews,* 49: 1075-1083.

Cowan, K., Daim, T. & Anderson, T. (2010). Exploring the Impact of Technology Development and Adoption for Sustainable Hydroelectric Power and Storage Technologies in the Pacific Northwest United States. *Energy*, 35(12): 4771–4779.

Darmani, A., Arvidsson, N., Hidalgo, A. & Albors, J. (2014). What Drives the Development of Renewable Energy Technologies? *Renewable and Sustainable Energy Reviews*, 38: 834–847.

Diputra, E. (2016). Accelerating the Development of Geothermal Energy in Indonesia. International Energy Policy Program.

Diputra, E. (2016). The Assessment of Public-Private Partnership in Indonesia. International Energy Policy Program.

Diputra, E. (2016). The Role of National Steel Industry to Indonesia's Economic Performance. International Energy Policy Program.

Diputra, E. (2016). The Implementation of ISO 50001. International Energy Policy Program.

Diputra, E. (2016). Estimating the Impacts of Oil Price Volatility to Coal Market. International Energy Policy Program.

Diputra, E. (2016). Energy and Mineral Resources Development Cooperation between Indonesia and South Korea. EMRD Symposium.

Diputra, E. (2017). The Analysis of Determinant Factors for Energy-Related CO_2 Emissions in Indonesia. International Energy Policy Program.

Diputra, E. (2017). The Overview of Indonesia's Energy and Mineral Resources Sector and its Investment Opportunities. Energy and Resources Overseas Investment Symposium.

Diputra, E. (2017). The Analysis of Determinant Factors for Food and Beverage Industry in Indonesia using Structure-Conduct-Performance Framework. International Energy Policy Program.

Directorate General of New Renewable Energy and Energy Conservation. (2014). *Rencana Pengembangan EBTKE di Indonesia (The Development Plan of Renewable Energy in Indonesia)*. Internal report.

Donegan, H., Dodd, F. & McMaster, T. (1992). A New Approach to AHP Decision-Making. *The Statician*, 41(3): 295–302.

Dulal, H., Shah, K., Sapkota, C. & Kandel, B. R. (2013). Renewable Energy Diffusion in Asia: Can It Happen Without Government Support. *Energy Policy*, 59: 301–311.

Dyer, J. (1990). Remarks on the analytic hierarchy process. Management Science, 36(3): 249–258.

Faludi, A. (1973). *Planning Theory*. Oxford and New York: Pergamon Press.

Gallego-Carrera, D. & Mack, A. (2010). Sustainability Assessment of Energy Technologies via Social Indicators: Results of a Survey among European Energy Experts. *Energy Policy*, 38(2): 1030–1039.

Garni, H. & Awasthi, A. (2017). Solar PV Power Plant Site Selection using a GIS-AHP based Approach with Application in Saudi Arabia. *Applied Energy*, 206: 1225–1240.

Ghimire, L. P. (2016). *Analysis on Barriers of Renewable Energy Development: Context of Nepal* (Master dissertation). Seoul National University, Seoul, Republic of Korea.

Goletsis, Y., Psarras, J. & Samouilidis, J. E. (2003). Project Ranking in The Armenian Energy Sector Using A Multi Criteria Method For Groups. Annual Operational Research, 20: 135–57.

Government of Indonesia. (2014). Government Regulation Number 79 of 2014 on The National Energy Policy.

Government of Indonesia. (2017). President Regulation Number 22 of 2017 on The National Energy Plan (RUEN).

Guitouni, A., Martel, J. & Vincke, P. (1999). A framework to choose a discrete multicriterion aggregation procedure. Technical Report.

Hamalainen, R. P. & Karjalainen, R. (1992). Decision Support for Risk Analysis in Energy Policy. *European Journal of Operational Research*, 56: 172-183.

Harker, P. & Vargas, L. (1987). The Theory of Ratio Scale Estimation: Saaty's Analytic Hierarchy Process. *Management Science*, 33(11): 1383–1403.

Heo, E., Kim, J. & Boo, K. J. (2010). Analysis of the Assessment Factors for Renewable Energy Dissemination Program Evaluation using Fuzzy AHP. *Renewable and Sustainable Energy Review*, 14(8): 2214-2220.

Heo, E., Kim, J. & Cho, S. (2012). Selecting Hydrogen Production Methods using Fuzzy Analytic Hierarchy Process with Opportunities, Costs, and Risks. *International Journal of Hydrogen Energy*, 37(23): 17655-17662.

Hiremath, R. B., Shikha, S. & Ravindranath, N. H. (2007). Decentralized Energy Planning: Modeling and Application. *Renewable and Sustainable Energy Reviews*, 11: 729-752.

Hutagalung, A. M. (2014). *The Economic Value of Indonesia's Natural Gas: A Quantitative Assessment of Three Gas Policies* (Doctoral dissertation). University of Twente, Enschede, The Netherlands.

Indonesia Infrastructure Initiative. 2013. *Gas Development Master Plan of Indonesia*. Jakarta.

Indonesian Petroleum Association. http://www.ipa.or.id/overview/index/30. Accessed 21 November 2017.

Ishizaka, A. & Nemery, P. (2013). *Multi-Criteria Decision Analysis: Methods and Software*. Chichester, West Sussex: Wiley.

Janke, J. R. (2010). Multicriteria GIS Modeling of Wind and Solar Farms in Colorado. *Renewable Energy*, 35: 2228–2234.

Ji, P. & Jiang, R. (2003). Scale Transitivity in the AHP. *Journal of the Operational Research Society*, 54(8): 896–905.

Kabir, Z. & Shihan, A. (2003). Selection of Renewable Energy Sources using Analytic Hierarchy Process. *Proceedings ISAHP 2003*, 267–276.

Kablan, M. M. (2004). Decision Support for Energy Conservation Promotion: An Analytic Hierarchy Process Approach. *Energy Policy*, 32: 1151–1158.

Kagazyo, T., Kaneko, K., Akai, M. & Hijikata, K. (1997). Methodology and Evaluation of Priorities for Energy and Environmental Research Projects. *Energy,* 22: 121–129.

Kahraman, C., Kaya, I. & Cebi, S. (2009). A Comparative Analysis for Multi Attribute Selection among Renewable Energy Alternatives using Fuzzy Axiomatic Design and Fuzzy Analytic Hierarchy Process. *Energy*, 34: 1603–1616.

Kainulainen, T., Leskinen, P., Korhonen, P., Haara, A. & Hujala, T. (2009). A Statistical Approach to Assessing Interval Scale Preferences in Discrete Choice Problems. *Journal of the Operational Research Society*, 60(2): 252–258.

Kaya, T. & Kahraman, C. (2010). Multiciteria Renewable Energy Planning using an Integrated Fuzzy VIKOR & AHP Methodology. Energy, 35: 2517–2527.

Keeney, R., Renn, O. & Winterfeldt, D. V. (1987). Structuring West Germany's Energy Objectives. *Energy Policy*, 15: 352-362.

Keeney, R. (1992). *Value-Focused Thinking: A Path to Creative Decision Making*. Cambridge, MA: Harvard University Press.

Kengpol, A., Rontlaong, P. & Tuominen, M. (2012). Design of A Decision Support System for Site Selection using Fuzzy AHP: A Case Study of Solar Power Plant in North Eastern Parts of Thailand. *Proc. PICMET'12: Technology Management Emerging Technologies*, 734–743.

Kumar, D. & Katoch, S. S. (2014). Sustainability Indicators for Run of The River (RoR) Hydropower Projects in Hydro Rich Regions of India. *Renewable Sustainable Energy Review*, 35: 101–108.

Lindblom, C.E., & Woodhouse E.J. (1993*). The Policy-Making Process*, third ed. Englewood Cliffs: Prentice Hall.

Lootsma, F. (1989). Conflict Resolution via Pairwise Comparison of Concessions. *European Journal of Operational Research*, 40(1): 109-116.

Luthra, S., Mangla, S. K. & Kharb, R. K. (2015). Sustainable Assessment in Energy Planning and Management in Indian Perspective. *Renewable and Sustainable Energy Reviews*, 47: 58–73.

Massimo, A., Dell'Isola, M., Frattolillo, A. & Ficco, G. (2014). Development of A Geographical Information System (GIS) for the Integration of Solar Energy in the Energy Planning of a Wide Area. *Sustainability*, 6: 5730–5744.

Mavrotas, G., Diakoulaki, D. & Papayannakis, L. (1999). An Energy Planning Approach Based on Mixed 0-1 Multiple Objective Linear Programming. *International Transactions in Operational Research*, 6: 231-244.

Meirer, P. & Mubayi, V. (1983). Modeling Energy-Economic Interactions in Developing Countries-A Linear Programming Approach. *European Journal of Operational Research*, 13: 41-59.

Mentis, D., Welsch, M., Fuso, N. F., Broad, O., Howells, M. & Bazilian, M. (2015). A GIS-based Approach for Electrification Planning: a Case Study on Nigeria. *Energy Sustainable Development*, 29: 142–50.

Ministry of Energy and Mineral Resources. (2014). *Potensi Sumber Daya Energi dan Mineral Indonesia (Energy and Mineral's Potential and Resources of Indonesia)*. Internal report. Geological Agency.

Ministry of Energy and Mineral Resources. (2016a). *Handbook of Energy and Economic Statistics of Indonesia*.

Ministry of Energy and Mineral Resources. (2016b). *Status EBTKE Terkini dan Tantangan Pengembangannya (Current Status of Renewable Energy Development and Its Challenges)*. Internal report. Directorate General of New Renewable Energy and Energy Conservation.

Ministry of Energy and Mineral Resources. (2017a). *Sebaran Potensi Sumber Daya Energi (The Distribution of Potential Energy Resources)*. Internal report. Geological Agency.

Ministry of Energy and Mineral Resources. (2017b). *Membedah Target Energi Jangka Panjang pada RUEN (Discussion on Long-Term Energy Programs in RUEN)*. Internal report. National Energy Council.

Muliadireja, E. P. (2005). *Indonesian Energy Policy Pathways: From Past Trends to Future Alternatives* (Doctoral dissertation). Massey University, Auckland, New Zealand.

Nigim, K., Munier, N. & Green, J. (2004). Pre-Feasibility MCDM Tools to Aid Communities in Prioritizing Local Viable Renewable Energy Sources. *Renewable Energy*, 29: 1775–91.

Nolan, H. (1999). Policy analysis, science and politics: from 'speaking truth to power' to 'making sense together'. *Science and Public Policy*, 26 (3): 201-210.

Perez, J. (1995). Some Comments on Saaty's AHP. *Management Science*, 41(6): 1091–1095.

Pohekar, S. D. & Ramachandran, M. (2004). Application of Multi-Criteria Decision Making to Sustainable Energy Planning. *Renewable and Sustainable Energy Reviews*, 8: 365-381.

Poyhonen, M. A., Hmalainen, R. P. & Salo, A. A. (1995). An experiment on the numerical modeling of verbal ratio statements. *Journal of Multi Criteria Decision Analysis*, 6(1): 1–10.

Ramanathan, R. & Ganesh, L. S. (1994). Group Preference Aggregation Methods Employed in AHP: An Evaluation and an Intrinsic Process for Deriving Members' Weightages. *European Journal of Operational Research*, 79(2): 249–265.

Ramanathan, R. & Ganesh, L. S. (1995). Energy Alternatives for Lighting in Households: An Evaluation using an Integrated Goal Programming-AHP Model. *Energy*, 20: 63–72.

Roy, B. (1981). The Optimisation Problem Formulation: Criticism and Overstepping. *Journal of the Operational Research Society*, 32(6): 427–436.

Roy, B. & Bouyssou, D. (1993). *Aide multicrite`re a` la decision: Me´thodes et cas*. Paris: Economica.

Rumbayan, M., Abudureyimu, A. & Nagasaka, K. (2012). Mapping of Solar Energy Potential in Indonesia using Artificial Neural Network and Geographical Information System. *Renewable and Sustainable Energy Review*, 16: 1437–49.

Saaty, T. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15(3): 234–281.

Saaty, T. (1980). *The Analytic Hierarchy Process*. New York: McGraw-Hill.

Saaty, T. (1986). Axiomatic foundation of the analytic hierarchy process. *Management Science*, 32(7): 841–855.

Saaty, T. (1990). An exposition of the AHP in reply to the paper 'Remarks on the analytic hierarchy process'. *Management Science*, 36(3): 259–268.

Saaty, T. (1991). Response to Holder's comments on the analytic hierarchy process. *Journal of the Operational Research Society,* 42(10): 909–929.

Saaty, T. & Vargas, L. G. (1991). *The Logic of Priorities*. RWS, Pittsburgh, Pa.

Saaty, T. & Vargas, L. G. (2005). The Possibility of Group Welfare Functions. *International Journal of Information Technology & Decision Making*, 4(2): 167–176.

Saaty, T. L. (2008). Decision Making with The Analytic Hierarchy Process. *International Journal of Services Sciences*, 1(1): 83–98.

Sabo, M. L., Mariun, N., Hizam, H., Radzi, M. A. & Zakaria, A. (2017). Spatial Matching of Large-Scale Grid-Connected Photovoltaic Power Generation with Utility Demand in Peninsular Malaysia. *Applied Energy*, 191: 663–688.

Salo, A. & Hamalainen, R. (1997). On The Measurement of Preference in The Analytic Hierarchy Process. *Journal of Multi-Criteria Decision Analysis*, 6(6): 309–319.

Samouilidis, J. & Mitropoulos, C. (1982). Energy Economy Models - A Survey. *European Journal of Operational Research,* 25: 200-215.

Sánchez-Lozano, J. M., Teruel-Solano, J., Soto-Elvira, P. L. & Socorro. (2013). Geographical Information Systems and Multi-Criteria Decision Making Methods for the Evaluation of Solar Farms Locations: Case Study in South-Eastern Spain. *Renewable and Sustainable Energy Review*, 24: 544–556.

Sangwook, L. (2016). Application of AHP and Fuzzy AHP to Decision-Making Problems in Construction. *Proceedings ASC 2016*.

Shapira, A. & Goldenberg, M. (2005). AHP-Based Equipment Selection Model for Construction Projects. *Journal of Construction Engineering and Management*, 131(12): 1263–1273.

Singh, R. K., Murty, H. R., Gupta, S. K. & Dikshit, A. K. (2012). An Overview of Sustainability Assessment Methodologies. *Ecological Indicators*, 15(1): 281–299.

Singh, R. & Singh, O. (2012). Global Trends of Fossil Fuel Reserves and Climate Change in the 21st Century, Fossil Fuel and the Environment, Dr. Shahriar Khan (Ed.), ISBN: 978-953-51-0277-9, InTech, Available from: http://www.intechopen.com/books/fossil-fuel-and-the-environment/global-trends-of-fossil-fuel-reserves-and-climate-change-in-the-21st-century

Singh, B. K. (2013). South Asia Energy Security: Challenges and Opportunities. *Energy Policy*, 63: 458–468.

Talinli, I., Topuz, E. & Akbay, M. (2010). Comparative Analysis for Energy Production Processes, *Energy Policy*, 38: 4479–4488.

Tasri, S. & Susilawati, A. (2014). Selection among Renewable Energy Alternatives based on a Fuzzy Analytic Hierarchy Process in Indonesia. *Sustainable Energy Technologies and Assessments*, 7: 34–44.

Uyan, M. (2013). GIS-based Solar Farms Site Selection using Analytic Hierarchy Process (AHP) in Karapinar Region, Turkey. *Renewable and Sustainable Energy Review*, 28: 11–17.

Vargas, L. G. (1990). An Overview of The Analytic Hierarchy Process and Its Applications. *European Journal of Operational Research*, 48(1): 2-8.

Wallenius, J. D., Dyer, J. S., Fishburn, P. C., Steuer, R. E., Zionts, S. & Deb, K. (2008). Multiple Criteria Decision Making, Multiattribute Utility Theory: Recent Accomplishments and What Lies Ahead. *Management Science*, 54(7): 1336–1349.

Wang, J. J., Jing, Y. Y., Zhang, C. F., Zhang, X. T. & Shi, G. H. (2008). Integrated Evaluation of Distributed Triple-Generation Systems Using Improved Grey Incidence Approach. *Energy,* 33: 1427–1437.

Wang, J., Jing, Y., Zhang, C. & Zhao, J. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews,* 13: 2263-2278.

Wang, Q., M'Ikiugu, M. M. & Kinoshita, I. (2014). A GIS-based Approach in Support of Spatial Planning for Renewable Energy: A Case Study of Fukushima, Japan. *Sustainability*, 6: 2087–2117.

Wind, Y. & Saaty, T. (1980). Marketing Applications of the Analytic Hierarchy Process. *Management Science*, 26(7): 641–658.

Yadoo, A. & Cruickshank, H. (2012). The Role for Low Carbon Electrification Technologies in Poverty Reduction and Climate Change Strategies: A Focus on Renewable Energy Mini-Grids with Case Studies in Nepal, Peru and Kenya. *Energy Policy*, 42: 591-602.

초록

의사결정계층(AHP)분석방법을 이용한 인도네시아의 에너지계획 평가요인 분석

에코 마하 디푸트라
협동과정 기술경영·경제·정책과정
공과대학
서울대학교

꾸준한 경제성장과 높은 인구 증가에도 불구하고 인도네시아의 에너지계획 시스템 및 의사결정과정에 대한 포괄적인 연구가 지난 수십 년간 없었다. 이로 인하여 풍부한 자원을 가지고 있음에도 불구하고 증가하는 에너지 수요를 고려한 지속가능한 에너지

시스템을 만들지 못하고 높아지는 전력 부족 문제와 에너지 수입 의존도 상승에 대하여 대처할 수 없었다고 평가되고 있다.

본 논문에서는 의사결정계측(Analytic Hierarchy Process, AHP) 분석방법론을 이용하여 인도네시아의 에너지정책 결정과정을 구조적으로 분석하고자 한다. 이를 통하여 인도네시아의 에너지 계획 수립시 고려해야 할 다양한 평가 기준과 요인을 분석, 식별하고 우선순위를 확인하고자 한다. 본 논문에서는 인도네시아 정부의 에너지 담당부처 공무원 및 전문가를 대상으로 AHP 설문을 실시함으로써 정책과정에 참여하고 있는 실제 참여자를 대상으로 연구하였으며, 주요 에너지정책 요소들 역시 사전설문을 통하여 발굴하였다.

이러한 목표에 따라 연구는 2 단계로 진행하였다. 첫 번째 단계에서는 포괄적인 문헌 검토와 전문가 설문을 통하여 다섯 분야의 주요기준을 결정하고 에너지계획의 지표로 활용할 18 가지 요인을 설정하였다. 두 번째 단계에서는 전문가 의견 집계 절차로서 의사결정계층(Analytic Hierarchy Process)을 구현하고, 인도네시아 정부의 에너지 담당부처 공무원 및 전문가를 대상으로 설문을

실시하여 18개 요인들의 중요도를 평가하고 에너지계획 시스템을 위한 통합 평가를 실시하였다.

가중치 추정 결과에서 인도네시아의 에너지정책 의사결정과정에 6대 주요 요소가 있음을 확인하였으며, 여섯 가지 주요 요소 중 에너지자원 요소가 실질적인 역할을 함을 확인할 수 있었다. 또한 재생에너지 분야 전문가들의 의사결정구조가 석유 및 가스 등 기존 주력에너지원 분야 전문가들의 의사결정구조와 다르다는 것을 밝혔다. 본 논문에서는 이들을 포함하여 네 가지 결론을 도출하였다. 본 논문은 인도네시아 최초로 에너지정책 수립시스템을 구조적으로 분석하였으며, 이를 통하여 인도네시아의 에너지정책 수립과정에 시사점을 줄 수 있을 것으로 기대한다.

키워드: 의사결정계층, AHP, 인도네시아, 에너지계획, 에너지정책

학생 번호: 2016-22092