Master's Dissertation in Engineering

Decision Making on Power Plant Development in Myanmar using AHP

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이 논문을 공학석사 논문으로 제출함
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Abstract

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Myanmar, one of the countries is facing many difficulties in generating and providing electricity to all needs in the country. Especially in many villages, rural areas, remote areas, and far from the national grid areas do not have electricity access. Even though, Myanmar, an abundant endowment of crude oil and natural gas, and other energy resources compared to other developing countries. To extract those resources at a reasonable production cost in order to fulfill the demand in domestic, Myanmar is not yet. Recently, the possibility to develop lessening production is still low because of the lack of technology and low investment from local and foreign.

This study aims by using Analytic Hierarchy Process (AHP) to find the appropriate power plant development planning for Myanmar by exposing the economic impact, production, and domestic utilization, with those of other natural gas producer countries. This study analyzes the factors that caused significant effects for optimal power plant development among four criteria (technology, economic, socio-political, and environmental) by using Analytical Hierarchy Process (AHP) method. This study also completed a survey to rank the optimal power plant development as the alternatives suggested by the government plans. This study results can be used as a basis of decision-making for electrification in the Government of Myanmar.

Keywords: Electrification, Analytical Hierarchy Process, Multi-Criteria Decision Analysis, Myanmar, Ministry of Electricity and Energy

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Chapter 1. Introduction

1.1 Research Motivation

As of the end of 2019, in Myanmar, the electrification ratio is 50% which is higher than the expectation targeted by the government 47% in 2020. The targeting to achieve 55% in 2021-2022, 75% in 2025-2026, and complete nationwide electrification by 2030.[1] However, there are still many regional areas that do not access fully electrification, such as rural areas, remote areas, and far from the national grid. As of the 2018 statistics Myanmar reported that 31,000 villages are not connected to the national grid and lacking electricity access.[2]

Accordingly, the main objective of Myanmar National Electrification Plan is to achieve full electrification to communities not only in rural but also in urban, and profits on such completion: to improve the Social-Economic Status in terms of health, economics, social, education, to improve the rural communities living standards, to reduce the rural-urban discrimination and to prevent the utilizing of firewood. [3] This key is being applied for electrification to preserve the sustainability of electricity by capitalizing on the effectiveness of natural gas power plant. By applying the natural gas

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[1] https://www.president-office.gov.mm/en/?q=briefing-room/news/2019/12/14/id-9775 (last accessed 12-14-2019)
[2] https://www.rockefellerfoundation.org/blog/accelerating-rural-electrification-myanmar/ (last accessed 30-4-2018)
[3] https://www.moee.gov.mm/en/ignite/contentView/1976 (no date)

power plant for electrification, there will be an increase in the contribution of the total energy mix in Myanmar.

Choosing the natural gas power plant can be the right optimal for electrification if it is well-organized. Nevertheless, it is expensive, it can be the wrong optimal if it is not well-planned. Therefore, the final decision-makers in the development of optimal power plant for electricity generation needed to be considered for several criteria and sub-criteria to certify the successful plan.

1.2 Research Objectives, Questions, Scope, and Structure

This section shows the research objectives, questions, scope, and structure.

1.2.1 Research Objectives

The main objectives of this study are to analyze which factors are the most priority for optimal power plant development in Myanmar with the Analytic Hierarchy Process (AHP) method based on energy expert's viewpoints to achieve full electrification by 2030 according to the National Electrification Project (NEP). The weighting and ranking of the criteria and sub-criteria of optimal power plant development will be helped the decision-makers in planning for future energy development plans. This study analyzes the primary role of the country's economic growth related to the total natural gas production, domestic natural gas consumption, and power plant development for electricity generation and focusing on the analysis of technology, economic, socio-political, and environmental criteria, and finding the appropriate optimal power plant development planning, policy, laws and regulation, and economic impact.

1.2.2 Research Questions

In order to analyze the research objective, the following research questions are considered:

1. Which factors are the main influential for optimal power plant development in Myanmar?
2. Which factors should be given more consideration in the decision-making process for the optimal power plant development?

To answer the research questions, this research conducted widespread literature reviews and survey with electricity and energy experts in Myanmar as respondents.

1.2.3 Research Scope

This study research scope is focused on the analysis of technological, economic, socio-political, and environmental criteria. The Analytic Hierarchy Process (AHP) method is used and experts were selected from the Ministry of Electricity and Energy (MOEE), amongst several available multi-criteria analysis methods.

1.2.4 Research Structure

This study presents six chapters. Chapter 1 introduces the introduction parts which is included research motivation, research objectives, questions, scope, and structure.

Chapter 2 explains the research background which is including electricity development. Chapter 3 describes the previous literature reviews. Chapter 4 is explaining the use of methodology AHP (Analytical Hierarchy Process). Chapter 5 is reported this study's empirical results and discussion based on the result. Final Chapter 6 concludes the result of this study and discussed the study limitations and recommendations for future study.

Table 1. Structure of the research

Chapters	**Chapter Title**	**Contents**
Chapter 1	Introduction	- Research Motivation, Objectives, Questions, Scope, and Structure
Chapter 2	Research Background	- current electricity status, electricity development plan
Chapter 3	Literature Review	- AHP, Multi-criteria decision analysis (MCDA), Previous Study
Chapter 4	Methodology	- Explanation of Methodological Framework and Criteria Description - Progression of the Survey - AHP pairwise comparison
Chapter 5	Research Results	- discussion of empirical results and estimated the weight of main criteria and sub-criteria, Discussion results: Local Priorities and Global priorities
Chapter 6	Conclusion	- Main conclusion and study limitations and recommendations for future study

Chapter 2. Myanmar Power System Background

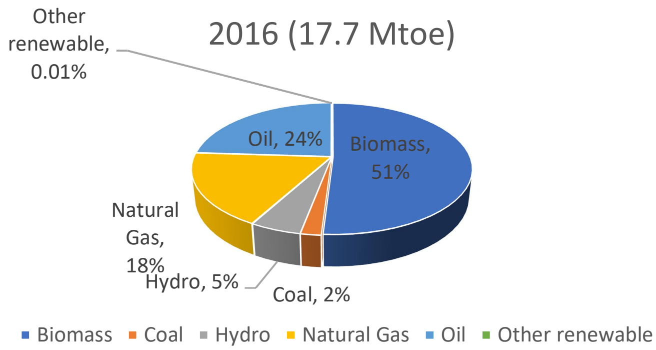
2.1 Development of Electricity in Myanmar

Myanmar is the largest country which is situated in Southeast Asia, between India and China, and also a developing country. Myanmar has abundant natural resources and available current energy resources for energy are natural gas, crude oil, hydropower, coal and biomass, the solar, wind, and geothermal as potential energy resources for the future that, if completely established, would be satisfactory to meet the nation's energy needs. Generally aimed, the energy policy of Myanmar, ensure energy independence by growing national production of available primary energy resources over-development actions and intensive exploration. Consequently, Myanmar also recognizes that electricity is the main power source driving economic development and reports the need to make and deal out more power in terms of greater volume, density, and reliability (Geometry and Analysis, n.d.).

Even though, Myanmar has significant energy resources such as natural gas as well as hydropower, 80% of the country's natural gas from existing four offshore projects (Yadana Project, Yetagun Project, Shwe Project, and Zawtika Project) are respectively exported to Thailand and China and rest portion of natural gas is utilized for local necessary during 2012-2014 financial year, especially in a gas-fired power plant (Madden 2017). Recently, less than 40% of the population of Myanmar has electrification access. According to the Ministry of Electricity and Energy (MOEE), power consumption in Myanmar is growing annually from 15% to 17%. The government plans to implement for distributing electricity sufficiently, involving hydropower, natural gas, coal, and renewable energy as an energy mix. As said by the Myanmar Energy Master Plan (MEMP) (ADB, IES, and MMiC 2015), and the Myanmar National Electrification Project (NEP) have implemented standards to provide 47% sustainable power in 2020, 76% in 2025, and 100% by 2030. In order to achieve this target, off-grid program and a grid electrification rollout will be established under the National Electrification Project (NEP).

Energy demand is strongly interrelated with GDP historically and globally. Total Primary Energy Supply (TPES-2016), biofuel and waste as traditional energy was 51% of total primary energy supply and individually followed by 5% of hydropower, 24 % of crude oil and petroleum products, 18% of natural gas and 2 % of coal. For Total Final Energy Consumption (TFEC-2016), 61% of biofuel and waste (biomass) was a major portion of total energy consumption and individually followed by 25% of petroleum products, 8% of electricity, 4% of natural gas, and 2% of coal. Myanmar heavily relies on 71% of hydropower for electricity generation (Review, n.d.) as in the current status of electricity supply in 2017-2018.

Energy Mix of total primary energy supply in Myanmar had the highest share of Total Primary Energy Supply (TPES 2000-2016) by biomass energy (Electricity, n.d.). However, it will gradually phase out from 51% of total energy in 2016 to 24% in 2040, and the use of conventional energy such as oil and electricity increase. The natural gas share, 18% in 2016 and will be increased to 30% by 2040 (Electricity, n.d.).



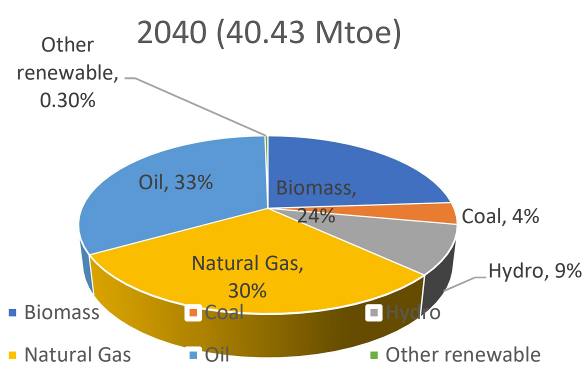
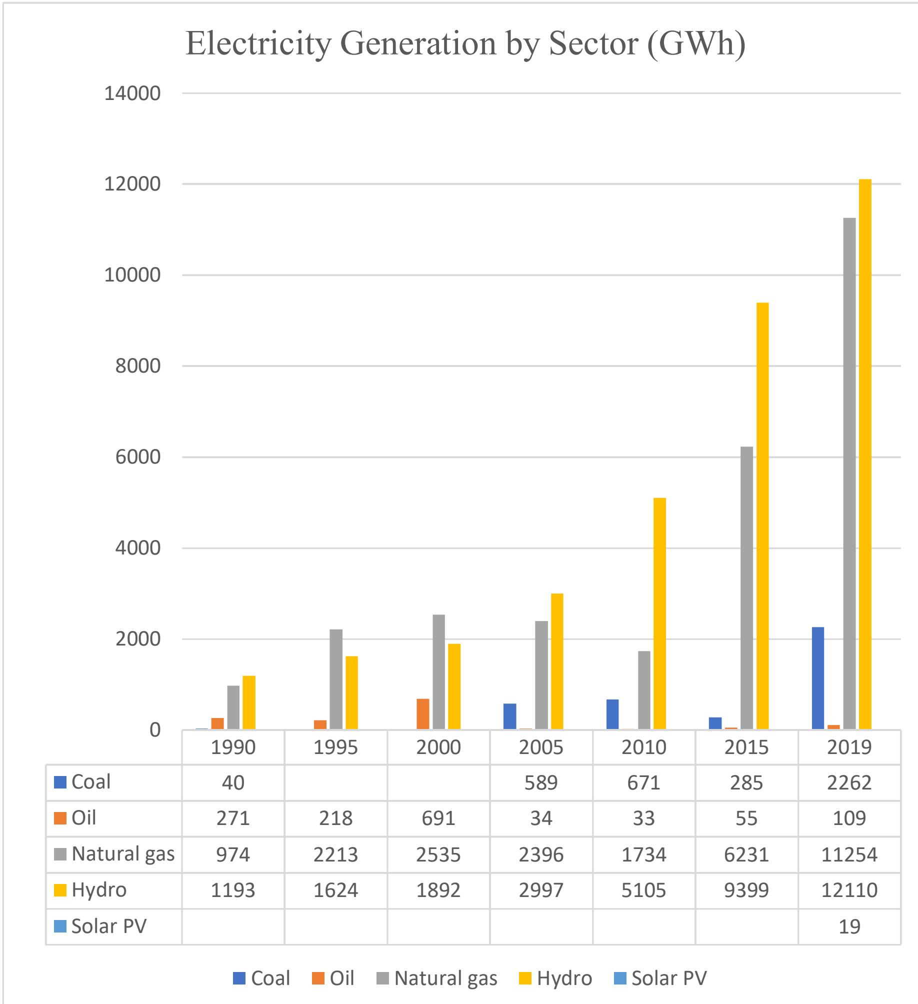


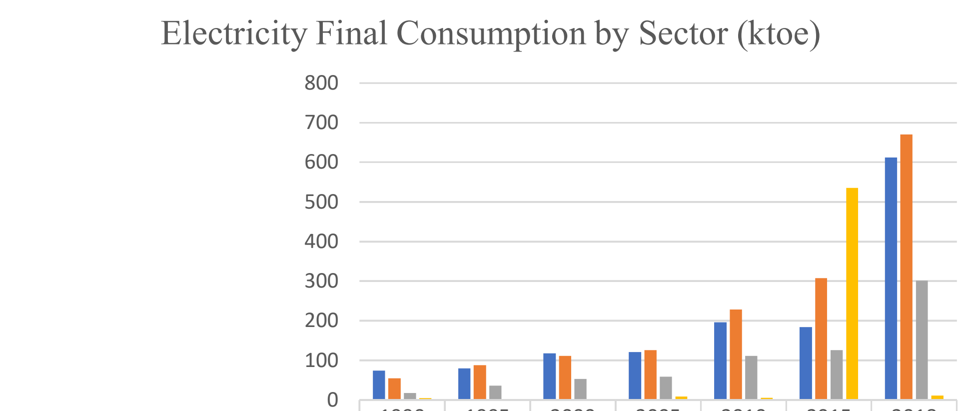
Figure 1. Energy Mix of Total Primary Energy Supply in 2016 and target in 2040



	1990	1995	2000	2005	2010	2015	2019
Coal	40			589	671	285	2262
Oil	271	218	691	34	33	55	109
Natural gas	974	2213	2535	2396	1734	6231	11254
Hydro	1193	1624	1892	2997	5105	9399	12110
Solar PV							19

Figure 2. Electricity Generation by Source[4]

[4] Myanmar - Countries & Regions - IEA



	1990	1995	2000	2005	2010	2015	2018
Industry	74	79	117	121	196	184	612
Residential	54	88	111	126	228	307	670
Commercial and public services	17	36	53	59	111	126	301
Non-specified	4			9	6	535	11

Figure 3. Electricity Final Consumption by Sector (1990-2018)[5]

The electricity development plan in Myanmar is mainly focused on supplying electricity demands, increasing the rate of electrification, and providing electricity access to the country, especially in rural electrification. To increase the rate of electrification and fulfill the electricity demand, the Government of Myanmar has several plans. But Myanmar does not have a complete National Electrification Project (NEP) that set off a systemic approach to energy planning, policy formulation, and sector development (Electricity, n.d.). But the main objective of NEP is to access full electrification in Myanmar. In order to implement short-term and, long-term energy

5 Myanmar - Countries & Regions - IEA

development plans are based on the investigation data on potential energy resources that are possible and can be discovered, considering the minimum impact on the natural and social environments. The national energy policy and sectoral development policies are summarized as electricity development are to increase and expand the national power grid in Myanmar, to utilize power generated from accessible energy sources such as hydro-power, solar, thermal, wind and other alternative sources; to generate and distribute electricity by using advanced technologies, and enhancement the private participation in regional distribution activities: to behave the environmental and social impact assessments for power generation and transmission to minimize these impacts.

By 2030, (National Electrification Project-1 NEP-1) has received a US $ 310 million loans from the World Bank to provide electricity to the whole of Myanmar, with phase projects to supply electricity to 5,080 villages within two miles from the national grid of the first phase and 4,700 villages within two to five miles from the national grid in the second phase. The (National Electrification Project-1 NEP-1) project will be completed in 2021, and when the project is completed, a total of 116,6431 households in 9,780 villages will have access to electricity, according to the Project to be completed in 100 days plan of the new government by Ministry of Electricity and Energy, Electric Power Generation Enterprise (EPGE). By 2021, the gas-fired power plants would be four gas-fired built at a total cost of $5.16 billion in several parts of Myanmar, will increase generation capacity by 3,100 megawatts (MW), and would double the current capacity of around 3,000 MW.

The country energy mix will have about 8,800 MW of power generation in 2020-21, and this is projected to grow to 10,379 MW by 2025-26, and triple to 23,594 MW by 2030, as of the National Electricity Master Plan[6]. The plan showed that the huge introduction of coal is accounting for one-third of total power generation in Myanmar's energy mix by 2030. Nonetheless, Myanmar imported the Liquefied Natural Gas, so that, the National Electrification Project (NEP) Phase 2 would be expanding the LNG terminal facilities to switch more LNG business.

According to the policies from the Ministry of Electricity and energy, hydropower generation is still the main part of the long-term plan for the country's energy needs while gas-turbine power generation is a main to the short-term plan. As shown in Figure 2, coal has a relatively small amount than hydro and natural gas, based on the government plan Figure 1, biomass will have larger sharing. Still, rural area depends on traditional biomass for their needs such as energy, mostly for lighting and cooking. Currently from the hydropower generation, the Government of Myanmar is mainly targeting to be implemented to distribute the electricity to rural areas through the national grid, as explained in the government plan above.

[6] Myanmar developing 4,000 MW of LNG-to-power projects: minister | S&P Global Platts

2.2 Electricity Development Plan

In 2015, the Government of Myanmar formulated the National Electrification Plan (NEP), an ambitious program structured around 5 phases aiming to reach 100% grid electrification by 2030 in the NEP, mini-grids played a limited role as temporary electrification solutions covering 0.7 million people or 2% of the off-grid population.

Access to reliable electricity is a long-standing problem in Myanmar. Out of 10.89 million households, 6.1 million or approximately 56% are not connected to the national electricity grid. Among off-grid households, 4 million have no access to electricity at all and utilize kerosene, oil, and solid fuels as energy sources for lighting, cooking, and other domestic uses. The remaining 2.5 million off-grid households have access to electricity through diesel generators, solar home systems, or other on-site power generation devices[7], however, supply from these off-grid solutions is often unreliable and expensive.

Providing reliable electricity at affordable tariffs to off-grid households and businesses is critical for Myanmar's socio-economic development. In other developing countries, electrification of off-grid areas greatly benefited rural areas. Rural electrification can be achieved through grid expansion and through off-grid solutions. In line with the first priority of NEP Phase-1, will be completed in 2021.

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[7] Decentralized Energy Market Assessment in Myanmar (May 2019)

2.2.1 **Power Plant Sector**

Seven ministries of Myanmar are responsible for energy matters, with the Ministry of Electricity and Energy as the focal point for overall energy policy and coordination. To increase the energy self-sufficiency of the country, The Government of Myanmar is also implementing the energy strategy, regarding the availability of energy sources with the environmental constraints in the country.

Hydro: Most of Myanmar's electricity is produced by hydroelectricity. The rest is from fossil fuel, with gas as the main fuel followed by coal and oil. In 2017, Myanmar had an installed electricity generation capacity of about 5 gigawatts (GW). The country plans to achieve 100% electrification by 2030. The country is targeting 12% of all electricity to be generated from renewable sources by 2025. Currently, Myanmar has a total installed capacity of approximately 3,300 Megawatts by renewable energy sources. As Myanmar has an abundance of renewable energy resources with 50 percent of land covered by forest and four major rivers flowing across the country, there is potential that, if renewable energy sources were managed efficiently, it could meet its future energy requirements for sustainable development in the country.

Among renewable energy sources in Myanmar, four main hydropower plants, the Ayeyarwady, Chindwin, Thanlwin, and Sittaung represent an untapped natural energy resource. The Asian Development Bank (ADB) stated that Myanmar has significant hydropower potential, more than 100,000 MW of installed capacity. Myanmar possesses 7.7 percent of the hydropower resources in Asia; hydropower plants generate almost 62 percent of Myanmar's power. The Government of Myanmar has mapped out potential locations for 41 new power projects which will be under construction during FY 2016-17 to FY 2030-31.[8]

The new power plants are being constructed to grow electricity generation capacity to 29,000 MW by 2031. New projects have to also take into consideration that during the dry season highly dependence on hydropower could lead to shortages in the power supply.

According to the policies set by the Ministry of Electricity and Energy, electricity generation from hydropower is still a key part of the long-term plan for the country's energy needs while gas turbine power generation is a key to the short-term plan. According to the government's 2030 plan, it will reduce the reliance on hydropower to 57 percent, on coal to 30 percent (as the national energy mix), and on non-hydro renewables to 8 percent (with solar power 5 percent).

[8] Burma - Energy | International Trade Administration| Burma-Country Commercial Guide

Liquified Natural Gas: In October 2019, a joint venture between Hong Kong-listed VPower Group and China National Technical Import and Export Corp and the Ministry of Electricity and Energy of Myanmar signed a power purchase agreement for three LNG-to-power projects in Myanmar, 400 MW in Thaketa, 350 MW in Thanlyin and 150 MW in Kyauk Phyu. In 2020 June, the Thaketa plant in Yangon, with an installed capacity of 477.1 MW started generating electricity for the first time LNG was used for power generation in Myanmar and the Thanlyin and Kyauk Phyu plants, CNTIC VPower signed for 60 months. The two plants have an installed capacity of 582.4 MW and have begun operation in phases from June 2020. The plants were built on a fast-track basis to provide critical power supply for summer 2020, and completed in around 9 months, making it the fastest LNG-to-Power project of its kind. But COVID-19 had affected on demand and supply of oil and gas, which in turn threatened the LNG supply chains.[9]

Solar: Myanmar has tremendous solar resources potential, especially in the middle of the country and extensive dry zones. Mini-grids and solar energy home systems are renewable energy solutions that could solve power shortage problems in rural communities because they are not directly connected to the electric power grid. As a result, the government is committing huge resources for off-grid renewables. The overall potential for solar power is approximately 51,973 terawatt-hours per

[9] Myanmar developing 4,000 MW of LNG-to-power projects: minister | S&P Global Platts

year. According to the Ministry of Electricity and Energy, the country plans to build two more solar power plants in Mandalay Division, each to have a generation capacity of 150 MW. Energy subsidies for electricity and lacking tax policy, lack of qualified workforce, and limited public administration capacity are viewed to be among the main obstacles complicating the development of solar energy in Myanmar.

Coal-fired: Tigyit power plant has an installed capacity of 120MW is using lignite coal as a fuel. Because of the poor quality of lignite in comparison to the specified quality, the power plant produces only 20% of the total capacity (Energy and Committee 2014). All contracts for coal-fired power plants signed by the former government with international, however, and regional companies have suspended due to public disagreement and concerns about pollution and other environmental impacts. Although Myanmar has estimated domestic coal resources of 540 million tons, coal extraction has remained slow due to low investment and the remoteness of the country's identified coal sites which is located in the Shan State Highland in the east of Myanmar, very far from the nearest coastal town.[10] As well, The Government of Myanmar participates in Myanmar's Intended Nationally Determined Contribution- INDC), is trying to include greenhouses gas goals in its INDC.

[10] Burma - Energy | International Trade Administration| Burma-Country Commercial Guide

Biomass: Biomass, an important source of energy supply in Myanmar, accounts for about 75% of the total primary energy supply. In 2008, forest wood accounted for 62% of all primary energy consumption, which was more than three times the crude oil and petroleum products. The dependence on biomass is mainly because approximately 70% of the population lives in rural areas. Of the total biomass-sourced energy, over 90% is fuelwood, most of which is harvested from natural forests. Such a high usage of forest wood is a major threat to Myanmar's overall environmental situation. The scale of dependence on biomass is therefore not only an energy supply issue but also raises concerns about degrading the environment(Energy and Committee 2014). The projected power generation from biomass could increase from approximately 13 MW in 2015 to 58 MW in 2025. In Myanmar, the share of renewable energy to the total installed capacity is planning to reach 15–20% for the electricity sector by 2030, regardless of hydropower. Meanwhile, the contribution of biomass in Myanmar is projected to around 50% of the total energy supply.

2.2.2 **Myanmar's Intended Nationally Determined Contribution**

According to the "Myanmar's Intended Nationally Determined Contribution-INDC (2015) (Ministry of Environmental Conservation and Forestry 2015)", is built upon policies under development. Myanmar plans to develop sector-specific policies that will be used to measure GHG emission projections. The INDC focuses on Forestry and Energy sectors. Myanmar states that given the deadline and available data, it did not include a GHG goal in its INDC and will include it in future adjustments. The Government of Myanmar has developed implementation plants to support its mitigation efforts in the 30-year National Forestry Master Plan (2001-2030), Draft Long Term Energy Master Plan which forecasts that by 2030 hydropower capacity could reach roughly 9.4 GWe, Draft National Electrification Master Plan which is being established together with the Energy Master Plan. The Electrification Master Plan estimates, 38% of the primary electricity generation will be hydropower in 2030. Rural Electrification increasing with a goal of 30% renewable generation. Realizing a 20% savings in electric consumption with mainly focusing on energy efficiency in industry and as part of the Ministry of Environmental Conservation and Forestry, the Comprehensive Plan for Dry Zone Greening (2001-2031), distributed 260,000 cook-stoves between 2016-2031. This project under the National Forestry Master Plan and National Energy Policy, in order to lessen the utilizing of wood for cooking by 2030.

Chapter 3. Literature Review

This chapter provides a multi-criteria decision analysis (MCDA), AHP, and relevant previous literature.

3.1 Multi-Criteria Decision Analysis (MCDA)

There are many previous research papers have developed for the multi-criteria decision analysis on the different issues in the different countries. There have many different MCDA studies, that is, some unreliable conditions needed to reflect by making a decision(s) to get well a decision(s) for decision-makers.

The multi-criteria decision analysis has basically four steps of problem evaluation in the process of decision (Roy and Vincke 1981). First, find the problem construction for choosing the best option. Second, sort the problem construction for sorting the actions based on the irregular value. Third, sorting the problem construction with the purpose to support the actions and fourth is to define the action and its consequences in an efficient method.

Table 2. Type of MCDA method (Marttunen, Lienert, and Belton 2017)

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

		pairwise comparisons of the alternatives.
TOPSIS	The Technique for Order Preference by Similarity to Ideal Solution	Ranks alternatives using the geometric distance from the positive and negative ideal solution.

3.2 Analytical Hierarchy Process

In many previous types of research on the decision analysis process, many of the researches use the Analytical Hierarchy Process (AHP). It has developed and most useful and reliable method to unravel the problems of decision making. By making the AHP hierarchy structure is the important thing because of the tendency of the major criteria and sub-criteria (Franek and Kresta 2014). The AHP includes data of the respondent's preference and or quantitative data which is using the RNA (rank number alternative) and interprets into a matrix (Al Garni et al. 2016). The AHP has comprised of three stages which are the first level defined to find modeling of the problem, the second level definite the criteria, and the third level built the sub-criteria relation with each criterion.

"Multi-Criteria Analysis on Renewable and Non-Renewable Technologies for Electricity Generation in Myanmar" (Khin Maung Zaw, 2019) studied the suitable electricity generation technology in Myanmar using the analytic hierarchy process with consideration of four main criteria: Technical, Economic, Environmental and socio-political criteria, and also measured 15 sub-criteria. The four electricity generation technologies that were compared are Natural Gas, Hydro-power, Coal, Wind, and Solar. The paper found that Natural Gas is the most suitable electricity generation technology for Myanmar and economic criteria are the first rankings and socio-political criteria are second with slight differences. The respondents were the expert from the five different backgrounds as Ministry of Natural Resources and Environmental Conservation, Ministry of Electricity and Energy, Non-Governmental Organizations, Private Company, and Academic Institutions. There are different persuasions after knowing the limitations of this previous literature based on the sub-criteria. This previous research has not applied to these following factors for power generating in Myanmar by using AHP; the ability of the system to function according to design conditions and to support failures which are meant technology reliability, foreign investment entry to the country with the expansion of energy industry and job-creation. To make more further study this previous research, I will consider those above factors for generating electricity.

"A study on the Decision-Making Process of the Myanmar Government for National Oil and Gas Development Plan" (Zune, 2020) surveyed This study which significant factors are most important for developing for the oil and gas sector in Myanmar by using AHP method with consideration on four main criteria: Economic, Social, Technology and Environmental and 12 sub-criteria. This study mentioned that among the four main criteria economic criteria (such as income tax, royalty, cost recovery) are graded as the first important issues in the existing oil and gas policy.

"Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP" (Heo, Kim, and Boo 2010) analyzed that 4 main conclusions: 1) importance of economic feasibility, 2) the advancement of the target technology in the global market, 3) the disagreement between the policymaker and the specialist group, and 4) the application of the results. This paper was conducted two different groups; for the first group – Ministry of Knowledge Economy, government-funded organizations (Korea Energy Management Corporation, Korea Energy Economics Institute, and Korea Institute of Energy Research, and Korea Institute of Energy Technology Evaluation and Planning), and Seoul National University, for the second group, was the energy experts - Yonsei University, Inha University, etc., The paper discussed that economic criteria were the first rank and the second rank was the market in policymakers, but in energy experts group technological criteria was the first rank and market was the second rank.

"An Analytic Hierarchy Process Based Approach for Evaluating Renewable Energy Sources" (Robles and Ospino 2017) analyzed that Decision-making in energy planning can be approached as a problem of multicriteria decision analysis in which different types of factors are involved. This task must take into account several aspects due to the increasing complexity of social, technological, and economic factors. In this context, this paper uses the analytic hierarchy process (AHP) to prioritize a set of criteria, sub-criteria, and alternatives as a support for decision-making in the process of energy planning with renewable energies for rural areas in the Caribbean region of Colombia. Based on the participation of experts, 5 criteria, 20 sub-criteria, and 4 alternatives were defined. Using the AHP, the same group of experts was consulted to prioritize all aspects. As a result of this paper showed that the technical and environmental criteria were the most applicable for multicriteria decision-making. In the case of sub-criteria, global priority was the highest for the environmental for land use and water resources. Wind, small hydropower plant, solar PV, and biomass were defined as a renewable resource. For all the estimated alternatives, solar energy was the highest suitability, and wind power was second.

"Studies on Energy Planning and Natural Gas Policy of the Republic of the Union of Myanmar" (Hpyo 2019) studied that and findings Previous research used Analytic Hierarchy Process (AHP) to assess the critical criteria and factor on Myanmar's energy planning among the renewable energy, nuclear energy, and natural gas energy. This study mentioned that the first ranking was economic criteria and the second was technological criteria with minor differences in Natural Gas Energy and socio-political and environmental criteria were low ranking. The first ranking for expansion of electricity supply and improvement of technology and the natural gas energy was the second-ranking in the global priority. This study surveyed two different organizations like the Ministry of Electricity and Energy and the Ministry of Natural Resources and

Environmental Conservation.

"Analysis of Renewable Energy Sources and Technologies for Rural Electrification in Indonesia using AHP" (Alfina, 2019) examined analyzing the renewable energy source and technology for rural electrification in Indonesia, by finding the most important criteria and sub-criteria and also selecting the most suitable renewable energy source for rural electrification. This study discussed the electricity development plan in Indonesia, especially in the rural electrification development plan and also renewable energy potential in Indonesia. Among the five renewable energy alternatives (geothermal energy, solar energy, wind energy, micro-hydro, and bioenergy) recommended by the Indonesia government plans, results of the survey proposed that micro-hydro is the most appropriate renewable energy source and technology for rural electrification in Indonesia, afterward biomass, solar, geothermal and wind energy.

Chapter 4. Methodology

This chapter will discuss that the methodological framework, the AHP hierarchy structure, selecting the criteria, process of survey, a survey on the AHP pairwise comparison, survey design, survey technique, description of the respondent's responses.

4.1 Methodological Framework

The objective of this study is to make decision-making on optimal power plant development in Myanmar by using the analytical hierarchy process (AHP) method. First, this research applies the AHP method for finding the significant factors in selecting optimal power plant development. Second, this research conducts the ranking of power plant alternatives. As described in Figure 2, this survey conducted many steps to attain the results and conclusion. Preliminary with literature review, selected the criteria and sub-criteria, conducted a survey, collected the results, and analyzed.

In line with the AHP method, before starting with the survey, firstly built a hierarchy structure. This study of AHP comprises three stages, the first stage starts with the goal of this research, the second stage is defining the criteria, and the third stage defining the alternatives. Figure 3, described in three stages of this research hierarchy structure.

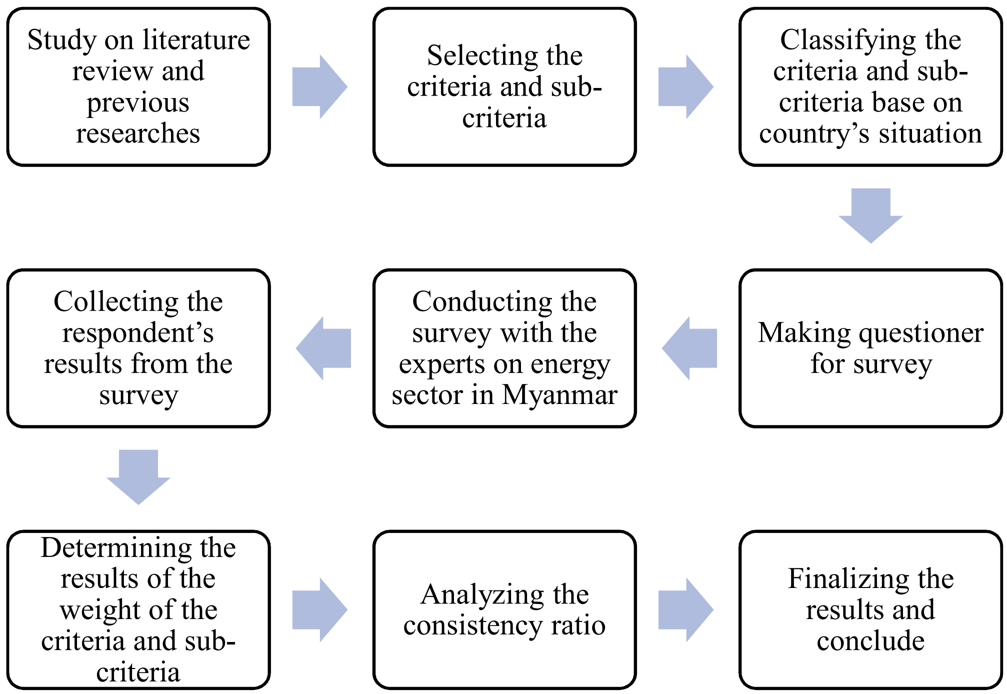

Figure 4. Methodological Framework of this research

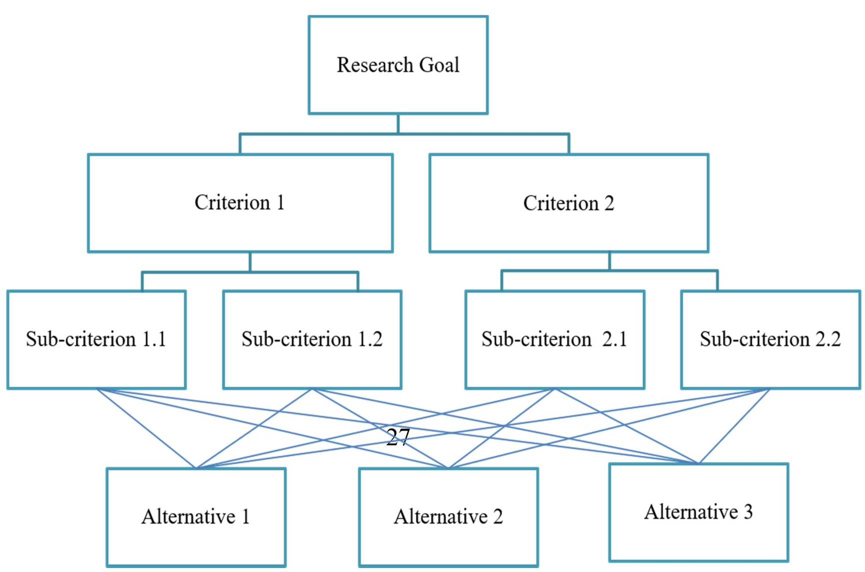

Figure 5. Example of Hierarchy Structure

4.2 Criteria Descriptions

The Analytic Hierarchy Process (AHP) is used by many researchers to unravel the problem in the decision-making process. According to the (Saaty 1987) paper, the AHP comprises three stages, firstly starts with a goal, the middle stage or second includes criteria and sub-criteria and the lowest stage consists of the alternatives as described in Figure 4. This study applies a four-level stage of hierarchy structure. The research goal of this study, the first stage, is to find the optimal power plant development. The second stage comprises four main criteria which are technology, economic, socio-political, and environmental criteria. There are three alternatives to the last stage. For the sub-criteria, in the third stage, there are eleven sub-criteria. Main criteria and sub-criteria are as described below:

4.2.1 Description of Main Criteria

A. Technology Criteria

This criterion is defining the technical relevance of the optimal power plant to be implemented, according to the scope established in the sub-criteria.

B. Economic Criteria

This criterion is used as a measurement of cost and benefit that can be affected on investment for power plant development and allow for incorporation of the benefits and costs incurred in implementing the project.

C. Socio-political Criteria

This criterion is taking account of the benefits and problems in the socio-political. For example, after the implementation of the project, it can be affected by creating job opportunities for local people and local companies and human resource development.

D. Environmental Criteria

This criterion is to incorporate the impact of the implementation of the project in the environment.

4.2.2 Description of Sub-Criteria

a. Reliability

This factor is used to measure the ability of the system to function according to design conditions and to support failures.

b. Technology Expansion

This factor is used to indicate the expansion of technological development for developing the power sector.

c. Technology Transfer

This factor is used to measure the transfer of technology from foreign joint ventures that are based on the potential impact on the development of the power sector.

d. Investment Costs

This factor is used to measure the total costs of equipment and materials.

e. Foreign Investment Entry

This factor is used to indicate foreign investment entry to the country with the expansion of the energy industry.

f. Operation and Maintenance Costs

This factor is used to measure the costs of preventive and corrective maintenance for the implementation of the power sector.

g. Acceptability of residents

This factor is measuring the willingness of the community to accept the implementation of the project in their localities.

h. Policy, Law, and Regulation

This factor is measuring to enact in terms of government policies, laws, and regulations.

i. Job Creation

This factor is measuring the number of local jobs creating for installation, maintenance and repair, and local company participation.

j. Gas Emissions

This factor is used to measure Emissions of greenhouse gases produced by the project to be implemented.

k. Hazardous Materials

This factor is used to measure the generation of waste that impacts the environment and community, for example, storage, transfer, and accidental release from tanks, pipes, and in transport vessels and vehicles.

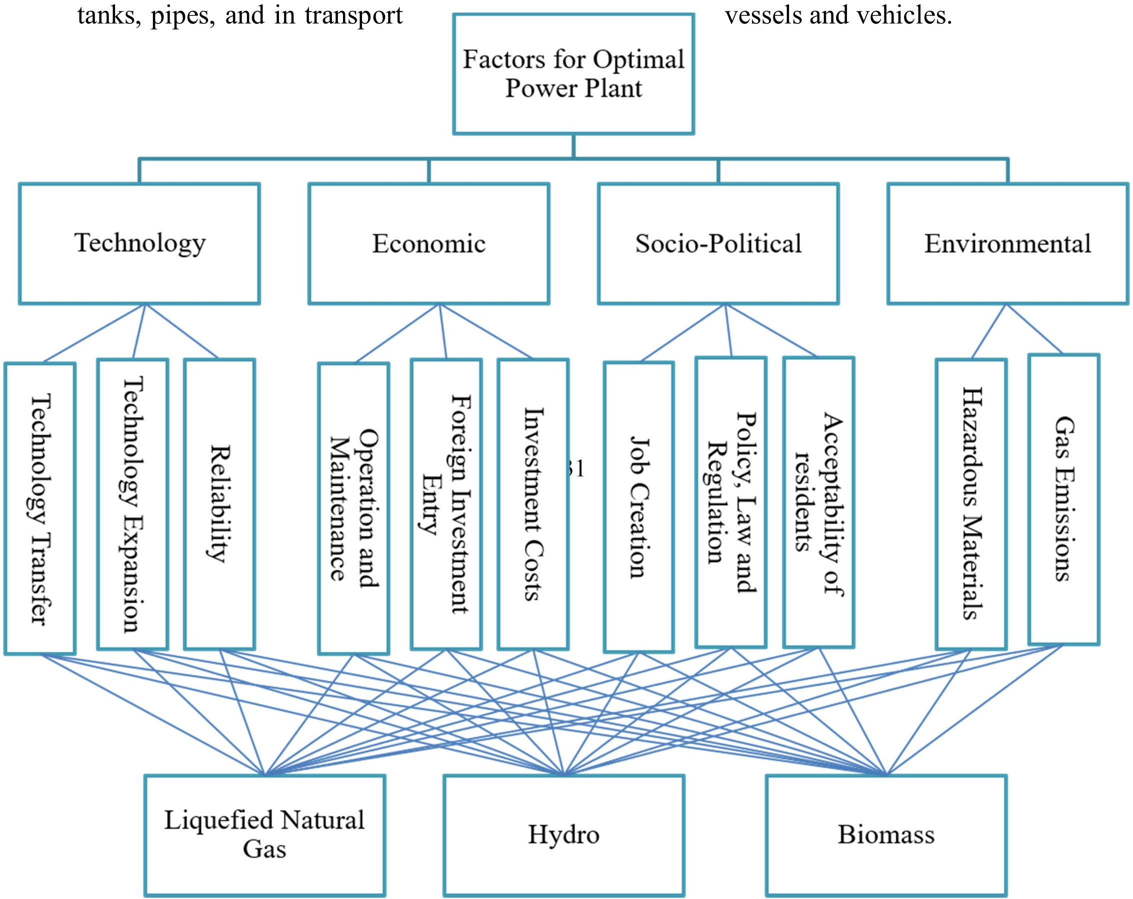

Figure 6. Analytic Hierarchy Structure of this research

For the next step after organizing the hierarchy structure, construct the pairwise comparison in each level. According to the expert's or respondent's preference, the pairwise comparison will be evaluated. Afterward, the number of pairwise comparisons is attained based on the total criteria n, following this formula (Saaty 1987):

$$\binom{n}{2} = \frac{n!}{2!(n-2)!} = \frac{n(n-2)}{2} = \frac{n^{2-n}}{2} \quad (1)$$

To assess the pairwise comparison, experts or respondents need to judge the rank of one item in the pairwise, it needs to make available numerical judgment scale (Saaty 1987). There are nine scales point to simplify the respondent's evaluations, as shown in Table 3. For using the AHP scale to make a comparison, using the odd numbers and for the even numbers are using if there is a better way to show them other than by using the even numbers. Criteria I and criteria j will be compared (Aij), where i.j=1,2…,n.

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

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

Table 3. Analytic Hierarchy Process (AHP) fundamental scales (Saaty 1987)

Scale	Definition	Explanation
1	If criteria i and j have **equal** importance	Two activities contribute equally to the objective
3	If criteria i is **moderately** more important than criteria j	Experience and judgment slightly favor one activity over another
5	If criteria i is **strongly** more important than criteria j	Experience and judgment strongly favor one activity over another
7	If criteria i is **very strongly** more important than criteria j	Activity is strongly favored and its dominance demonstrated in practice
9	If criteria i is **extremely** more important than criteria j	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	For intermediate evaluations	When compromise is needed

According to the (Triantaphyllou 2000),(Saaty 1987) papers,

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{12} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \qquad (2)$$

$$\left({W_i}/{W_j} \right) n \times n = A \qquad (3)$$

$$A = \begin{bmatrix} w1/w1 & w1/w2 & \cdots & w1/wn \\ w2/w1 & w2/w2 & \cdots & w2/wn \\ \vdots & \vdots & \ddots & \vdots \\ wn/w1 & wn/w2 & \cdots & wn/wn \end{bmatrix} \quad (4)$$

$$AW = \begin{bmatrix} w1/w1 & w1/w2 & \cdots & w1/wn \\ w2/w1 & w2/w2 & \cdots & w2/wn \\ \vdots & \vdots & \ddots & \vdots \\ wn/w1 & wn/w2 & \cdots & wn/wn \end{bmatrix} \begin{bmatrix} 1 \\ \vdots \\ n \end{bmatrix} = \begin{bmatrix} \lambda_{max} w1 \\ \vdots \\ \lambda_{max} wn \end{bmatrix} = \lambda_{max} W \quad (5)$$

where n represents a number of matrix row, then the Consistency Index (CI) value can be calculated as below:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (6)$$

According to (Franek and Kresta 2014), consistency index value is zero when the matrix is consistence. λ_{max} point to the weight and the number per line (Lestari, Setyohadi, and Suyoto 2018).

(Saaty 1987) recommended to evaluate the consistency ratio (CR) can be calculated by the following formula. The consistency ratio (CR) should be lower than 0.1 (10%) for consistency value. Random Index (RI) value will be different based on the number of criteria.

$$CR = \frac{CI}{RI} < 0.1 \quad (7)$$

Table 4. Random Consistency Index (Wind and 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

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

For ranking the alternatives, there is one function in the AHP method. Firstly, to make the pairwise comparisons of alternatives for each sub-criterion and/or main criterion. To find an alternative, for example, based on the weight of sub-criteria, the alternative varies in each sub-criterion. At that time, find the weight based on the pairwise comparison results. Afterward, the alternative weight in each sub-criterion is developed with the result of the weight of the sub-criterion into the relevant criterion. Afterward, the weight of the final alternative can be evaluated as the best alternative.

4.3 Progression of the Survey

For developing the electricity and energy sector in Myanmar, the data were required of qualitative and quantitative analysis of the Analytic Hierarchy Process (AHP). This survey was conducted online from October 7th to 27th, 2020.

This research of the survey questionnaire was considered for two parts; the explanation of the questionnaire on how to answer, and the questionnaire and recommendation of respondents. All the results were collected by email.

4.4 Survey on the Analytic Hierarchy Process Pairwise Comparison

In this research, the Analytic Hierarchy Process (AHP) is selected to compare the liking of energy experts about the criteria and sub-criteria in the decision-making of factors for optimal power plant development and its alternative. Before conducting the criteria and sub-criteria for the survey, this research was determined by reviewing the previous works of literature with four main criteria which are technology, economic, socio-political, and environmental and eleven sub-criteria are divided into four different criteria, there are three sub-criteria in technology, economic, socio-political and two sub-criteria in environmental, as described in Table 5.

This survey was conducted on 30 energy experts who are from the government official from the Ministry of Electricity and Energy. However, this survey acknowledged the response of 21 respondents. After analyzing the consistency ratio of the results with the AHP method by using expert choice software, a total of 21 respondents out of 30 respondents were passed the level of consistency ratio and 9 respondents were rejected that the consistency ratio is higher than 0.1 or 10% for this study. The detailed evaluation result is described in the next chapter.

Table 5. Criteria and sub-criteria for the survey

Criteria	Sub-criteria	References
Technology	Reliability	(Robles and Ospino 2017), (Hpyo 2019)
	Technology Expansion	(Aras, Erdoğmuş, and Koç 2004), (Hpyo 2019)
	Technology Transfer	(Madden 2017), (Program 2020), (Tun 2018)
Economic	Investment Costs	(Heo, Kim, and Boo 2010),
	Foreign Investment Entry	Opportunities book from MOEE, PSC Contracts, (Hpyo 2019), (Robles and Ospino 2017)
	Operation and Maintenance	Opportunities book from MOEE, PSC Contracts, (Robles and Ospino 2017)
Socio-political	Acceptability of residents	(Code, n.d.), (Robles and Ospino 2017)
	Policy, Law, and Regulation	(Robles and Ospino 2017), Opportunities book from MOEE, PSC Contracts
	Job Creation	(Robles and Ospino 2017), Opportunities book

		from MOEE, PSC Contracts
Environmental	Gas Emissions	(Code, n.d.), (Robles and Ospino 2017)
	Hazardous Materials	(Robles and Ospino 2017)

4.5 Survey for Selecting of the Alternatives for Optimal Power Plant Development in Myanmar

In this section for the selecting of the alternatives for optimal power plant development in Myanmar, the method is also using the Analytic Hierarchy Process (AHP) to have the judgment of energy experts in Myanmar. All the respondents were having knowledge skills and experience in the electricity and energy sector in Myanmar. The questionnaire is finding the appropriate power plant development in future Myanmar for power generation. This alternative selecting questionnaire used the same sub-criteria. In this survey, all the sub-criteria were considered about the three optimal power plants: Liquefied Natural Gas (LNG), Hydro Power Plant, Biomass Power Plant. In this survey is considered the whole country energy sources. Detailed information about energy sources as described in the previous chapter. All the respondent's results were evaluated and are described in the next chapter.

Chapter 5. Research Results

This chapter presents the analysis of research results such as consistency ratio, the weight of each criterion and sub-criteria, alternatives for optimal power plant development, local priorities, and global priorities and concluding which factors are the most significant in this research through the analytic hierarchy process (AHP).

Based on the (Wind and Saaty 1980) paper, the AHP method, this research offered a hierarchy using research goal, main criteria, sub-criteria, and alternatives. The main criteria and sub-criteria were changed into pairwise comparisons and done the alternatives and spread to respondents as a questionnaire. The results were evaluated in the matrix form were used to estimate weights and ranks of each criterion and sub-criterion. If the consistency ratio (CR) is 0, the results of the pairwise comparison will be fully consistent (Wang, Chakraborty, and Ouyang 2011), and the results of the pairwise comparison will not be consistent when the consistency ratio (CR) is higher 0.1 or 10%.

Moreover, to analyze the optimal power plant development, this research uses the ranking of optimal power plant alternatives. In the questionnaire, all the sub-criteria were on condition that the information of each alternative. The final scores concluded the most appropriate power plant development for electricity generation and achieving plans in future Myanmar. Details of the results are presenting follows.

5.1 Consistency Ratio of Main Criteria

The AHP method does allow the respondents to evaluate options according to their personal inclination and opinion. So that the AHP method, the accurate consistency of the results are not easy to obtain. In (Saaty 1987) his research, he explained that there are limitations to the inconsistency of evaluation that can still be stand if the consistency ratio (CR) is less than 0.1 or 10%. The 21 respondents out of 30 respondents from the Ministry of Electricity and Energy have answered in line with the consistency ratio of less than or equal to 0.1. The other 9 respondents' results were higher than 0.1. So, these 9 respondents will not be considered in this research.

5.2 Estimated Weight of Main Criteria

In this section will be discussed the evaluation result of the pairwise comparison of the main criteria. The four main criteria were technology, economic, socio-political, and environmental. As the result from expert respondents, economic criteria is the first priority and followed by technology criteria as shown in Figure 7.

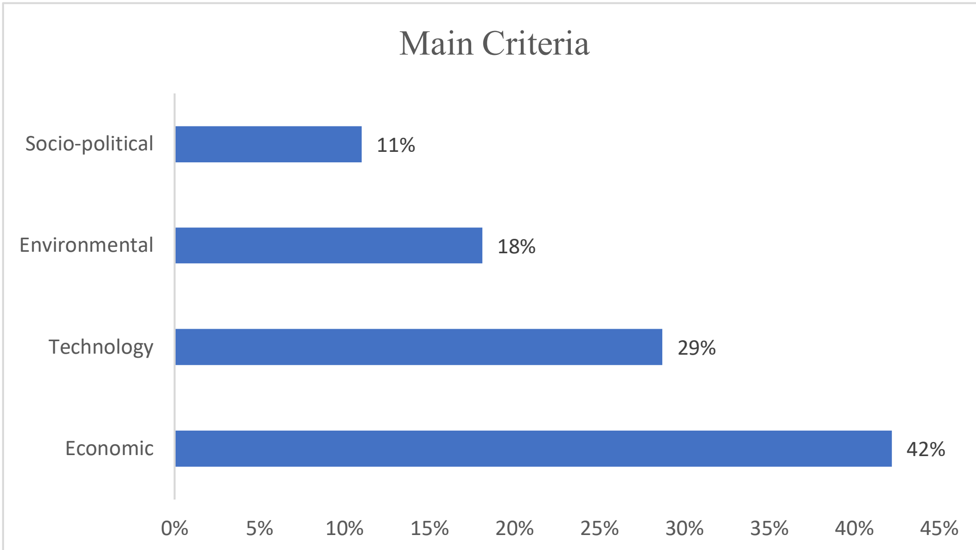

Figure 7. The result of weighting and ranking for the main criteria

5.3 Estimated Weight of Sub-Criteria

In this section will be presented the evaluation of the pairwise comparisons to 11 sub-criteria. The 11 sub-criteria; reliability, technology expansion, technology transfer sub-criteria are spread from technology criteria, investment costs, foreign investment entry, and operation, and maintenance sub-criteria come from economic criteria, acceptability of residents, policy, law and regulation, and job creation sub-criteria are derived from socio-political criteria, and gas emission and hazardous materials sub-criteria come from environmental criteria.

As the result from energy experts, foreign investment entry, and investment costs sub-criteria are under the economic criteria is the highest priority and followed by the technology transfer sub-criteria from technology criteria as shown in Table 6.

Table 6. The result of the weighting and ranking for sub-criteria

Sub-criteria	**Priority Weight**	**Priority Weight (%)**	**Rank**
Foreign Investment Entry	0.203	20.3%	1
Investment Costs	0.166	16.6%	2
Technology Transfer	0.128	12.8%	3
Hazardous Materials	0.099	9.9%	4
Gas Emission	0.082	8.2%	5
Reliability	0.081	8.1%	6
Technology Expansion	0.078	7.8%	7
Policy, Law, and Regulation	0.06	6%	8
Operation and Maintenance	0.053	5.3%	9
Acceptability of residents	0.029	2.9%	10
Job Creation	0.021	2.1%	11

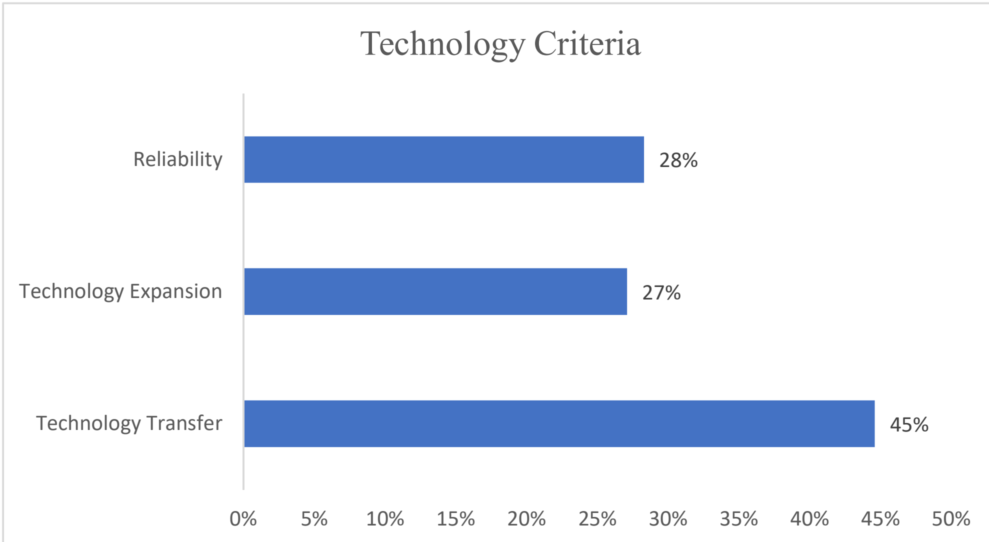

Figure 8. Local priorities in technology criteria

According to the experts' results, the technology transfer sub-criteria is the highest rank in technology criteria as shown in Figure 8.

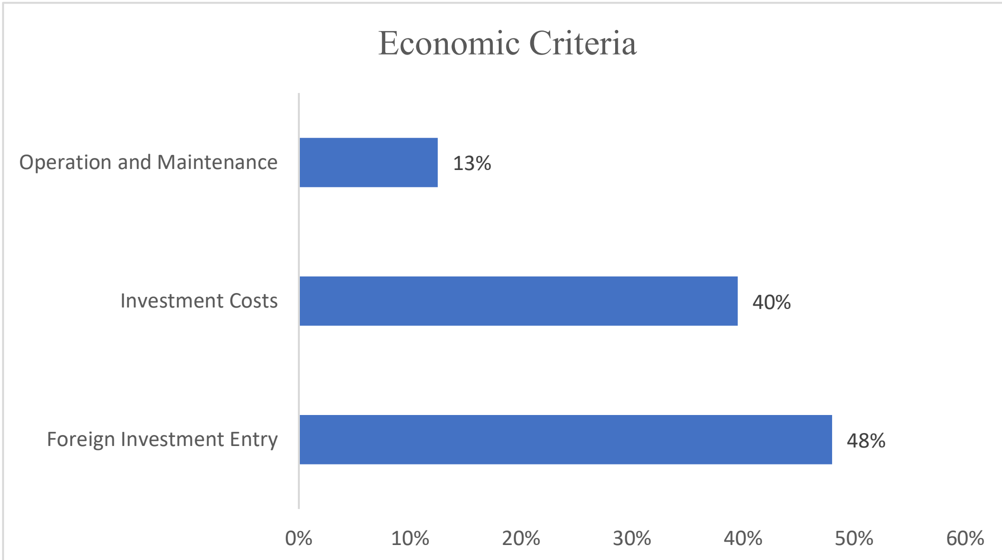

Figure 9. Local priorities in economic criteria

According to the experts' result, foreign investment entry sub-criteria is the highest rank and followed by the investment costs in economic criteria as shown in Figure 9.

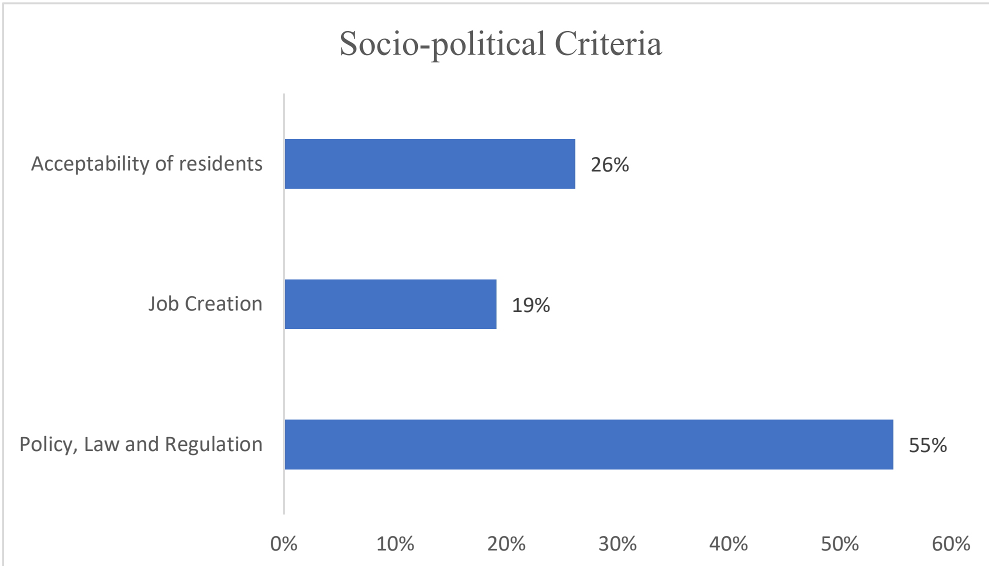

Figure 10. Local priorities in socio-political criteria

According to the experts' result, policy, law, and regulation sub-criteria is the highest rank in socio-political criteria as shown in Figure 10.

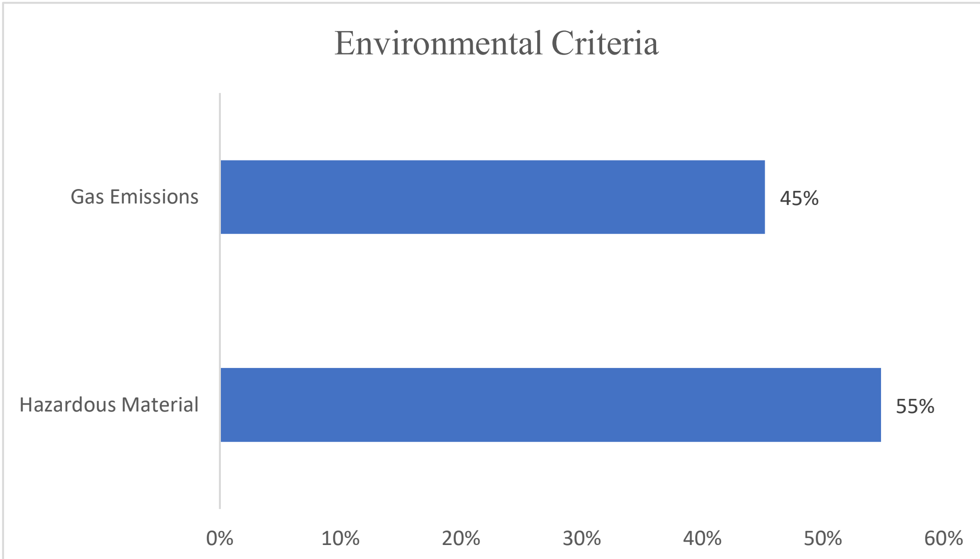

Figure 11. Local priorities in Environmental criteria

According to the experts' results, hazardous material sub-criteria is the highest rank in environmental criteria as shown in Figure 11.

5.4 Estimated Alternative for Optimal Power Plant Development

This research aims to identify the most appropriate power plant in future Myanmar. In this part, three alternatives power plants were asked to rank based on eleven different sub-criteria information, and their personal experiences in the relevant projects. All the responses were relatively collected on each sub-criterion as shown in Table 7 and Figure 10.

Table 7. The results of the ranking of the optimal power plant

Alternatives	**Priority Weight**	**Priority Weight (%)**	**Rank**
Liquefied Natural Gas	0.504	50.4%	1
Hydropower Plant	0.378	37.8%	2
Biomass	0.117	11.7%	3

According to the experts' results of the ranking of the optimal power plant, Liquified Natural Gas (LNG) is the highest rank and is followed by the hydropower plant and biomass.

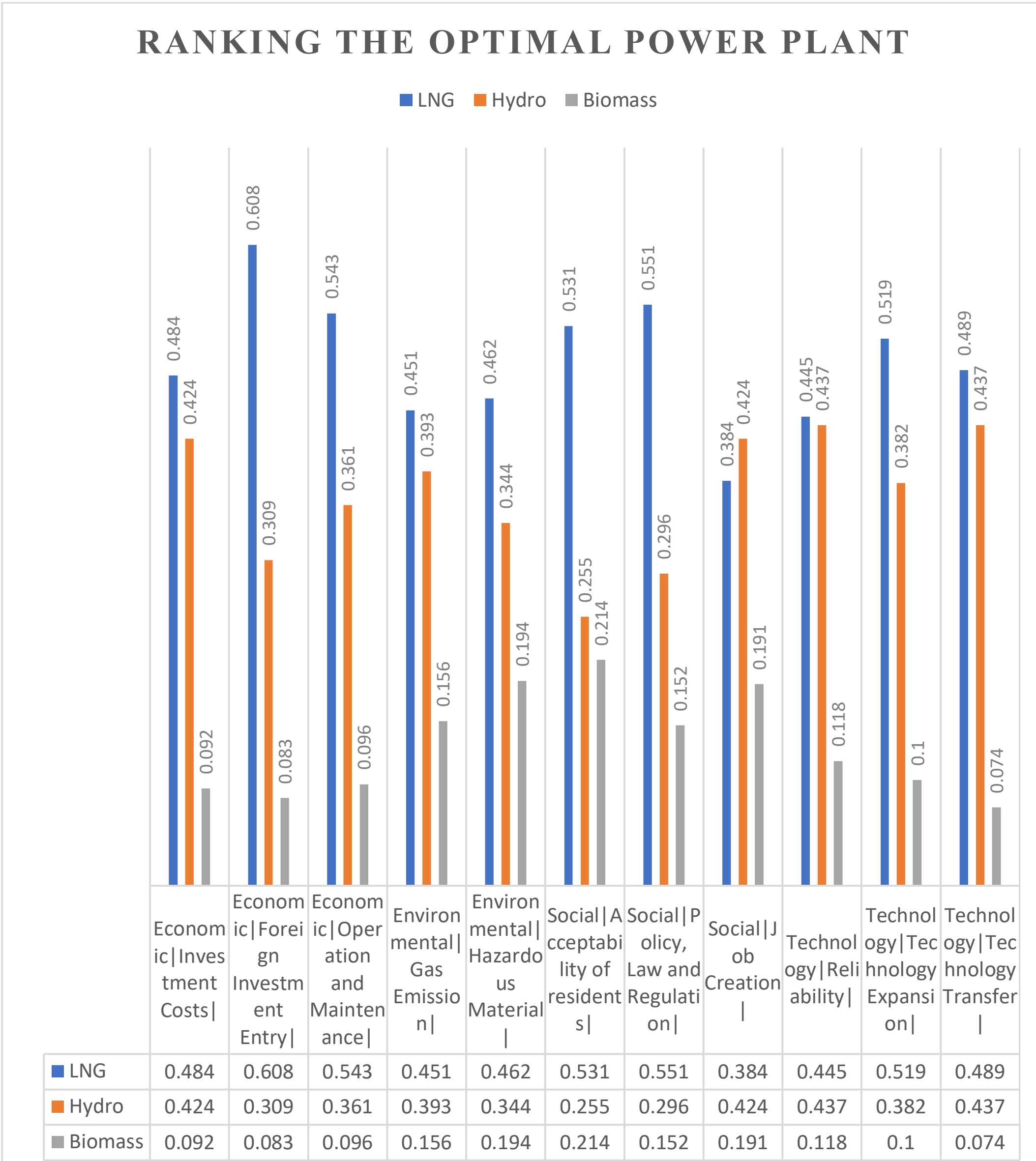

Figure 12. The result of the ranking of alternatives criteria

Chapter 6. Conclusion

6.1 Conclusion and Implementation

This study discussed the decision-making of factors for optimal power plant development in Myanmar, specifically on electricity generating. By the end of 2019, Myanmar achieved the electrification ratio is 50% which is higher than the expectation targeted by the government of 47% in 2020 but there are still many regional areas that do not access fully electrification, such as rural areas, remote areas and far from the national grid and also in some urban areas have power outages. To tackle that problem, the government of Myanmar focused on accessing full electrification in 2030. Other than that, Myanmar has determined a target, by 2040, to achieve 30% of natural gas in the total energy mix by replacing the renewable sources (Electricity, n.d.). The abundant oil and gas potential in Myanmar is one of the reasons to focus on increasing natural gas in the energy mix. In this situation, the government has plans for making available full electricity in Myanmar by using natural gas power plant. Succeeding the government plan, this research purposes to analyze the decision-making of factors for optimal plant development to achieve full electrification in Myanmar.

This research applied the Analytic Hierarchy Process (AHP) methodology in finding the most important criteria and sub-criteria in the decision making of factors for optimal power plant development in Myanmar. There are four main criteria used in this research: technology, economic, socio-political, and environmental, and eleven sub-criteria are divided from that main criteria. In technology, criteria are the reliability, technology expansion, and technology transfer sub-criteria. Investment costs, foreign investment costs, and operation and maintenance costs are the sub-criteria from economic criteria. The acceptability of residents, policy, law and regulation, and job creation sub-criteria are fragmented from socio-political criteria. In environmental criteria, gas emissions and hazardous materials are sub-criteria. For ranking the appropriate power plant for electricity generating in Myanmar, the survey used to give scoring on three alternatives which are a liquified natural gas power plant, hydropower plant, and biomass power plant.

After collecting the responses and calculating the results, the AHP method showed that the most important factor for decision-making for the optimal power plant is economic criteria, followed by technology but among of all main criteria, environmental and socio-political criterion are scored in the lowest with 42%, 29%,18%, and 11%, separately.

Weighting and ranking results on sub-criteria, foreign investment entry, investment costs (local), and technology transfer are the priorities in decision-making for optimal power plant development, according to the energy experts from the official government.

The reason is that the economic factor has the highest attention in building a large-scale LNG power plant such as a storage unit, generator, etc. By certifying the availability of foreign investment, it can be sure the technology will be developed by following economic development.

To provision that the utilization of a local natural gas could be one of the ways out. In June 2020, the Myanmar government started first importing liquified natural gas from Malaysian energy giant Petronas, which has a total LNG volume of 190,000 cubic meters. LNG imported at Yangon will supply integrated LNG-to-power projects located near the regasification facilities: Thaketa (400-megawatt (MW) capacity), Thanlyin (350 MW capacity), and Thilawa (1,250 MW capacity).[11]

Likewise, the technology criteria are important because the Myanmar government has not developed research and development centers for the energy sector, the reason is that also fast-track to develop the research and development centers. To solve the problem is that needed to corporate at the international level and needed to invite foreign investments.

This research purposed to analyze the decision-making of factors for optimal power plant development in Myanmar through ranking the criteria and sub-criteria in

[11] https://www.offshore-energy.biz/eia-myanmar-joins-lng-importers-circle/#:~:text=In%20June%202020%2C%20Myanmar%20became,liquefied%20natural%20gas%20(LNG).&text=LNG%20import%20facility%20includes%20a,gas%2Dfired%20electric%20power%20plants.

selecting the alternatives. The empirical analysis makes known that the important criteria and sub-criteria and appropriate alternative power plants can be routine for policy decision-makers in Myanmar. It can also benefit electricity industries and/developers by selecting the liquified natural gas power plant for not only providing the electricity but also improving the country's economy.

This research contributes gives as one of the academic researches by using Analytic Hierarchy Process (AHP) and weighting and ranking to find out the vital factors in deciding on the appropriate power plant development for electrification and country's economic development in Myanmar.

6.2 Study Limitations and Future Work

This study was considered by analyzing the decision-making of factors for optimal power plant development in Myanmar by finding the most important factors and selecting the most appropriate for electrification. To improve this research for the future, other organizations, and a variety of local companies should be considered so that the results can be more applicable valid in this field.

This research was conducted with only one official government. For future work, this research can be developed by selecting other specific electrification in Myanmar and also can be applied by inquiring the energy experts from many areas of Myanmar.

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Appendix

Questionnaires on the "Decision Making on Power Plant Development in Myanmar using AHP"

This survey is used as one of the methodologies for my research titled Decision Making on Power Plant Development in Myanmar using AHP. This survey question was made under the supervision of Associate Professor Yoonmo Koo, Graduate School of Engineering Practice, Department of Technology, Management, Economics and Policy (TEMEP), College of Engineering, Seoul National University (SNU).

This survey will be conducted on the expert and government officer from the electricity and energy fields. All of the respondent's information and the answer will be remaining as confidential and only use for my academic research. All the respondent's answers will be analyzed to find the ranking of criteria and sub-criteria on choosing which factors are important in power generation in Myanmar.

In this survey, five main criteria and 11 sub-criteria have identified and 11 alternatives questions relevant to each sub-criterion which is means there are two survey methods in this survey, the respondent needs to choose which criteria are the more important option in between two sub-factors based on your own experiences and knowledge.

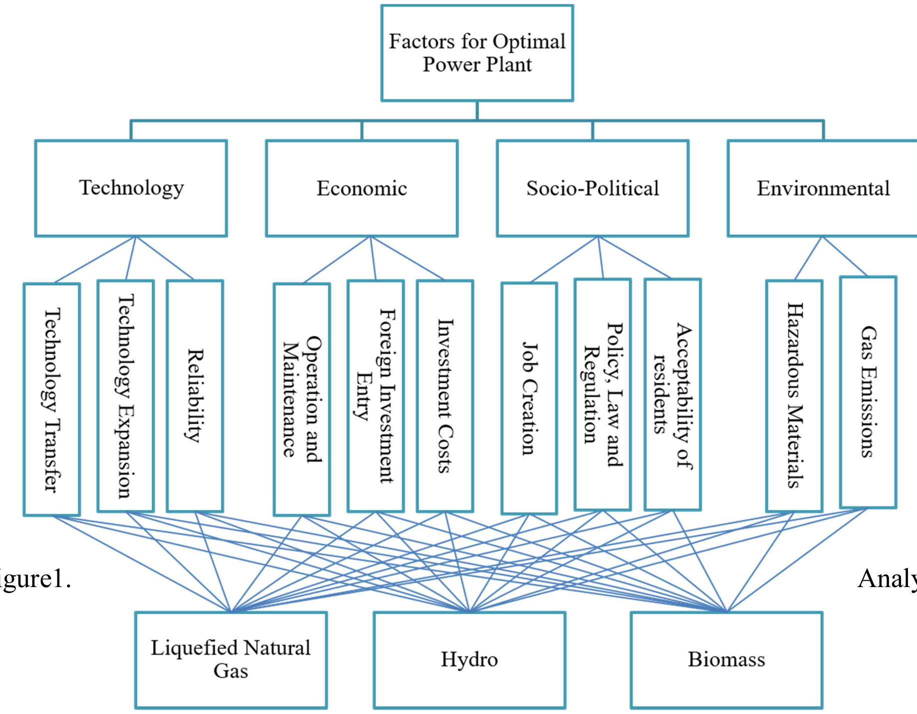

Figure1. Analytic Hierarchy Structure of this research

1. Guideline to answer the questionnaire

Selecting numerical scales for pair-wise comparisons were presented in Table 1.

Table 1. Selecting numerical scales for pair-wise comparisons

Explanation	**Numeric scale**
If option A and B have equal importance	1
If option A is **moderately** more important than option B	3
If option A is **strongly** more important than option B	5
If option A is **very strongly** more important than option B	7
If option A is **extremely** more important than the option	9
You can choose an even number for intermediate evaluation	2, 4, 6, 8

Table 2. Example to do pair-wise comparisons

Option A	**Extremely**		**Very Strongly**		**Strongly**		**Moderately**		**Equally**		**Moderately**		**Strongly**		**Very Strongly**		**Extremely**	**Option B**
Technology	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Economic**

Option A (Technology) is very strongly important to the development of optimal power plant compared to **Option B** (Economic)

Option A (Technology) and **option B** (Economic) are equally important to the development of

Option B (Economic) is very strongly important to the development of optimal power plant

2. Main Criteria of Decision Making of Factors for Optimal Power Plant Development

Please provide your judgment in comparing two relatives important of two factors in the main criteria.

2.1 Description of the main criteria

A. **Technology Criteria (T)**

This criterion is defining the technical relevance of the optimal power plant to be implemented, according to the scope established in the sub-criteria.

B. **Economic Criteria (E)**

This criterion is used as a measurement of cost and benefit that can be affected on investment for power plant development and allow for incorporation of the benefits and costs incurred in implementing the project.

C. **Socio-political Criteria (SP)**

This criterion is taking account of the benefits and problems in society. For example, after the implementation of the project, it can be affected by creating job opportunities for local people and local companies and human resource development.

D. **Environmental Criteria (En)**

This criterion is to incorporate the impact of the implementation of the project in the environment.

(To avoid printing the questionnaire you can highlight the answer in blue directly in this

Word document)

In this decision making of optimal power plant development, which criteria are that you consider more important? (Table 3)

Table 3. The rank main criteria on Decision Making of Factors for Optimal Powerplant Development

Option A	**Extremely**		**Very Strongly**		**Strongly**		**Moderately**		**Equally**		**Moderately**		**Strongly**		**Very Strongly**		**Extremely**	**Option B**
T	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**E**
T	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**SP**
T	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**En**
E	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**SP**
E	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**En**
SP	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**En**

2.2 Description of sub-criteria for Technology Criterion

In this section, you have to make available your personal decision in comparing two relatives important of two factors in technology criterion, by the following questions:

A. Reliability

This factor is used to measure the ability of the system to function according to design conditions and to support failures.

B. Technology Expansion

This factor is used to indicate the expansion of technological development for developing the power sector.

C. Technology Transfer

This factor is used to measure the transfer of technology from foreign joint ventures that are based on the potential impact on the development of the power sector.

Please rank the sub-criteria of the Technology Criterion in order of importance (Table4).

In this decision making of optimal power plant development, which sub-criteria do you consider more important? (Table4)

Table 4. The rank of technology sub-criteria on Decision Making of Factors for Optimal Power Plant Development

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
Reliability (Ability of the system to function according to design conditions and to support failures)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Technology Expansion** (Expansion of technological development)
Reliability (Ability of the system to function according to design conditions and to support failures)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Technology Transfer** (the transfer of technology from foreign joint ventures that is based on the potential impact on the development of the LNG sector)
Technology Expansion (Expansion of	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Technology Transfer** (the transfer of technology from

technological development)																		foreign joint ventures that is based on the potential impact on the development of the LNG sector)

2.3 Description of sub-criteria for Technology Criterion

In this section, you have to make available your personal decision in comparing two relatives important of two factors in economic criterion, by the following questions:

A. **Investment Costs**

This factor is used to measure the total costs of equipment and materials.

B. **Foreign Investment Entry**

This factor is used to indicate foreign investment entry to the country with the expansion of the energy industry.

C. **Operation and Maintenance Costs**

This factor is used to measure the costs of preventive and corrective maintenance for the implementation of the power sector.

Please rank the sub-criteria of the Economic Criterion in order of importance (Table 5).

In this decision making of optimal power plant development, which sub-criteria do you consider more important? (Table 5)

Table 5. The rank of economic sub-criteria on Decision Making of Factors for Optimal Power Plant Development

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
Investment Costs (Total costs of equipment and materials)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Foreign investment entry** (Foreign investment entry to the country with the expansion of energy industry)
Investment Costs (Total costs of equipment and materials)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Operation and maintenance** (Costs of preventive and corrective maintenance)
Foreign investment entry (Foreign investment entry to the country with the expansion of energy industry)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Operation and maintenance** (Costs of preventive and corrective maintenance)

Description of sub-criteria for Socio-political Criterion

In this section, you have to make available your personal decision in comparing two relatives important of two factors in Socio-political criterion, by the following questions:

A. **Acceptability of residents**

This factor is measuring the willingness of the community to accept the implementation of the project in their localities.

B. **Policy, Law, and Regulation**

This factor is measuring to enact in terms of government policies, laws, and regulations.

C. **Job Creation**

This factor is measuring the number of local jobs creating for installation, maintenance and repair, and local company participation.

Please rank the sub-criteria of the Socio-political Criterion in order of importance (Table 6).

In this decision making of optimal power plant development, which sub-criteria do you consider more important? (Table 6)

Table 6. The rank of Socio-political sub-criteria on Decision Making of Factors for Optimal Power Plant Development

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
Acceptability of residents (Willingness of the community to accept the implementation of the LNG project in their localities)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Policy, Law, and Regulation** (Government, to enact in terms of policies, laws, and regulations)
Acceptability of residents (Willingness of the community to accept the implementation of the	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Job Creation** (Number of local jobs created for the installation, maintenance and

LNG project in their localities)																		repair, and local company participation)
Policy, Law, and Regulation (Government, to enact in terms of policies, laws, and regulations)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Job Creation** (Number of local jobs created for the installation, maintenance and repair, and local company participation)

2.3 Description of sub-criteria for Environmental Criterion

In this section, you have to make available your personal decision in comparing two relatives important of two factors in Environmental criterion, by the following questions:

A. **Gas Emissions**

This factor is used to measure Emissions of greenhouse gases produced by the project to be implemented.

B. **Hazardous Materials**

This factor is used to measure the generation of waste that impacts the environment and community, for example, storage, transfer, and accidental release from tanks, pipes, and in transport vessels and vehicles.

Please rank the sub-criteria of the Environmental Criterion in order of importance (Table 7).

In this decision making of optimal power plant development, which sub-criteria do you consider more important? (Table 7)

Table 7. The rank of Environmental sub-criteria on Decision Making of Factors for Optimal Power Plant Development

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
Gas Emissions (Emissions of greenhouse gases produced by the project to be implemented)	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	**Hazardous Material** (generation of waste that impacts the environment and community)

In this part, please the respondents need to answer the following alternative questions to develop the country's power generation. *(To avoid printing the questionnaire you can highlight the answer in blue directly in this Word document)*

1. In terms of technological reliability, which option do you think is more advantageous?

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

2. **In terms of technology expansion, which option do you think is more attractive to local and foreign?**

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

3. In terms of technology transfer, which option do you think is more attractive?

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

4. In terms of economic investment, which option do you think is more advantageous for investment?

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

5. In terms of foreign investment entry, which option do you think is making more attractive or advantageous?

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

6. **In terms of operation and maintenance costs, which option do you think should be more developed?**

Option A	**Extremely**		**Very Strongly**		**Strongly**		**Moderately**		**Equally**		**Moderately**		**Strongly**		**Very Strongly**		**Extremely**	**Option B**
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

7. In terms of the acceptability of residents, which option do you think is more attractive?

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

8. In terms of the policy, law, and regulation, which option do you think is more advantageous?

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

9. **In terms of job creation opportunity, which option do you think is more advantageous?**

Option A	**Extremely**		**Very Strongly**		**Strongly**		**Moderately**		**Equally**		**Moderately**		**Strongly**		**Very Strongly**		**Extremely**	**Option B**
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

10. To contribute to greenhouse gas reduction and climate change, which option do you think is more appropriate?

Option A	Extremely		Very Strongly		Strongly		Moderately		Equally		Moderately		Strongly		Very Strongly		Extremely	Option B
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

11. In order to prevent the generation of waste that impacts the environment and the community, which option do you think is more advantageous?

Option A	**Extremely**		**Very Strongly**		**Strongly**		**Moderately**		**Equally**		**Moderately**		**Strongly**		**Very Strongly**		**Extremely**	**Option B**
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Hydro
LNG	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass
Hydro	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Biomass

Demographic and general information of the respondent

Name ……………………………………….

Email ……………………………………….

Organization ……………………………………….

Job Position ………………………………………

Job Experience (in years) ……………………………………….

Information provided by respondents is confidential and will not be disclosed. The answers provided will only be used for academic purposes.

To improve the quality of this survey, please share your comments, recommendations, and questions at the following email address: myothantoo1993@gmail.com

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International Energy Policy Program

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Abstract (Korean)

미얀마는 전력의 발전과 공급에 어려움을 겪고 있는 국가이다. 특히 마을, 농촌 지역과 같은 국가 그리드 지역에서 멀리 떨어진 곳은 전력의 접근성이 매우 낮다. 미얀마는 다른 개발도상국에 비해 원유와 천연 가스 및 기타 에너지 자원이 풍부함에도, 이러한 에너지 자원을 국내 전력 수요를 충족시키기 위해 합리적인 비용으로 사용하지 못하고 있다. 최근까지도 기술력의 부족과, 국내외 투자가 적기 때문에 이 문제를 해결하지 못하고 있다.

이 연구는 계층적 분석방법(AHP, Analytic Hierarchy Process)과 다른 천연 가스 생산국들의 경제적 영향, 생산 및 국내 이용률을 참조하여 미얀마의 실정에 맞는 최적의 발전소 개발계획을 도출하는 것을 목표로 한다. 본 연구에서는 계층적 분석방법 적용을 위해 기술, 경제, 사회 및 정치, 그리고 환경이라는 4 가지 기준을 수립하여 이 중 어느 요인이 최적의 발전소 개발계획에 유의미한 영향을 미치는지를 분석하였다. 또한, 본 연구에서는 설문조사를 통해 미얀마의 정부에서 제시한 발전소 개발계획에 대한 순위를 분석하였다. 본 연구의 결과는 미얀마 정부의 전기화를 위한 의사결정의 기초 연구로써 사용될 수 있다.

주요어 : 전기화, 계층적 분석방법, 다기준 의사결정방법론, 미얀마, 미얀마 전력에너지부
학 번 : (2019-27826)

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Thank you

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