DEPLOYMENT OF
MARINE CURRENT ENERGY
IN INDONESIA

A Thesis

by

ROHIT RAMACHANDRAN 47-136841

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Advisor: Professor Ken Takagi

Co-Advisor: Project Associate Professor Hirotaka Matsuda

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ABSTRACT

Marine Current Energy Generation (MCEG) is a new technology that harnesses the velocity of sea currents to produce emission-free electricity. This technology has the potential to greatly contribute toward climate change mitigation. While MCEG is a clean and renewable energy technology, in order to be sustainable, it must also be economically affordable and socially acceptable. While much attention is paid to the technical, economic, and environmental aspects of this technology, an assessment that collectively analyzes the interactions between these three aspects is necessary. Moreover, current studies focus on developed countries like the United Kingdom, the United States, and Canada. However, developing countries, such as Indonesia and Brazil, also have high potential for adapting MCEG to meet increasing energy demands.

Bearing this in mind, this research aims to collectively analyze the environmental, economic and social impacts of MCEG in the context of a developing country. By placing a high degree of importance on stakeholder input, this research explores the acceptability and sustainability of MCEG technology compared to the current methods of electricity generation. Findings from this research are used to offer the most appropriate course of actions for introducing MCEG in a developing country.

For this research a field site has to be selected that is part of a developing country that has an increasing need for additional electricity, and, most importantly, that has favorable conditions for MCEG installation. Indonesia, although home to one of the fastest growing

economies in the world, has a great need for additional electricity generation capacity, with close to 50 million people still with no access to electricity. There are many locations within Indonesia where sea current flows are concentrated due to constraining topography, such as straits between islands, providing ideal sea conditions for MCEG installation. Considering the large size of the country and the numerous feasible MCEG sites, further narrowing of the research site is necessary. After looking at the marine current velocities, surrounding population and power demands, water depths, strait widths, presence of major shipping lanes, electricity grids, the states of infrastructure, and availability of data, Larantuka strait in Flores Timur Regency is selected as the research area.

For sustainability assessment and decision-making, the framework suggested by Santoyo-Castellazo and Azapagic (2014) is adapted and used for this research. The framework is made up of the following steps:

[1] Selection of environmental, economic and social indicators for measuring sustainability

[2] Selection and specification of technologies to be compared

[3] Development of scenarios based on selected technologies

[4] Environmental, economic and social impact assessment

[5] Integration of sustainability indicators using Multi-Criteria Decision Analysis (MCDA) to determine the most sustainable option for future

Literature survey, field observation, interviews and focus group discussions with various stakeholder groups aided in the identification of the sustainability indicators. The two environmental indicators selected for this research are Carbon Emissions and Disturbance to Biodiversity. Electricity Tariff and Cost of Fuel for Production of electricity are the two economic indicators, and the two social indicators are Public Acceptance and Security and Diversity of Supply. Currently Flores Timur Regency only uses diesel generators for electricity production, so this research compares between MCEG and diesel electricity generation. Based on estimated future energy demands three scenarios are developed that are assessed for their sustainability. In scenario 1, 6 MW of electricity generation capacity comes from diesel generators; in scenario 2, 3 MW capacity comes from diesel generators and 3 MW capacity from MCEG; and in scenario 3, MCEG provides the entire 6 MW capacity. With these scenario options, MCDA is conducted three times using the Analytic Hierarchy Process (AHP).

In MCDA 1 the stakeholders are asked to make pair-wise comparisons between each criteria and sub-criteria based on their experience and judgment. The results identify the most preferred scenario for each group of stakeholders along with the weights each stakeholder group places on each criteria and sub-criteria. But, MCDA 1 is based on personal experience and judgment so lacks scientific data and, thus, can include error in the decision. MCDA 2 is conducted using scientific data and treats all criteria and sub-criteria equally. However, in reality, all the criteria and sub-criteria are not of equal importance to the different stakeholder groups. MCDA 3 takes this into account and is conducted with the weights elicited from MCDA 1, along with the scientific data that contributed to MCDA 2. In this way, the final output of MCDA considers both stakeholder input and scientific basis.

In MCDA 1, all stakeholder groups prefer Scenario 3 the most and scenario 1 the least. MCDA 2 shows similar results as MCDA 1, though with a different degree of preference. However, results vary in the final MCDA 3, in which three out of the five stakeholder groups prefer scenario 3 most while the two other groups most prefer scenario 2. Overall, Disturbance to Bio-Diversity and Public Acceptance are the two most important indicators. The relatively expensive electricity tariff of MCEG is a hindrance to the selection of MCEG overwhelmingly over other scenarios as the most preferred future energy generation choice. Reduced emissions, although an important factor in the promotion of renewables, are considered to be of extremely low importance according to the public. A lack of information regarding the impacts of MCEG on marine biodiversity in tropical waters is another factor contributing to the low preference for MCEG.

Based on the findings, it can be concluded that it is vital to conduct studies on the types of biota in the waters of Larantuka strait and assess the impacts on this ecosystem by monitoring the strait for a long period of time. Efforts should also be made to lower the electricity tariff of MCEG, either by developing the technology further or by availing subsidies as currently enjoyed by diesel. A favorable Feed-in-tariff (FIT), like the FIT for solar PV, can also be helpful for making the electricity from MCEG affordable. Finally, public awareness should be increased to ensure the successful deployment of MCEG. The benefits of fuel-free electricity generation, and the importance of emission-free electricity have to be highlighted to the people. These courses of actions can help lead towards sustainable deployment of MCEG in Indonesia, and the deployment of a renewable energy source to quench the growing need for electricity in developing countries.

ACKNOWLEGEMENTS

I would like to express my sincere gratitude to Professor Takagi for his patience and support during two years of my master's research including the fieldwork and thesis writing is invaluable. His constant guidance helped me broaden my knowledge and deepen my understanding of marine energy and its significance to developing countries. I would also like to thank my co-advisor Project Associate Professor Matsuda for his guidance on vital areas of my research.

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All the calculations for the research were performed using Web-HIPRE software developed by Aalto University, Finland and provided for use, free of cost. This software was vital for arriving at the results and I am grateful for being allowed its use.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
ADCP	Acoustic Doppler Current Profiling
AHP	Analytic Hierarchy Process
ATDP	Argyll Tidal Demonstrator Project
BPS	Department of Statistics of Flores Timur Regency
CM	Consistency Measure
CO_2	Carbon dioxide
DM	Decision Maker
DOE	Department of Energy
EERE	Energy Efficiency and Renewable Energy
EIA	Environmental Impact Assessment
EMEC	European Marine Energy Centre
EMP	Environmental Monitoring Program
ESDM	Ministry of Energy and Mineral Resources of Indonesia
FIT	Feed-in Tariff
GHG	Green House Gas
IEA	International Energy Agency
IPCC	Inter-governmental Panel on Climate Change
LCOE	Levelised Cost of Energy
MCDA	Multi-Criteria Decision Analysis
MCEG	Marine Current Energy Generation

NGO	Non-Governmental Organization
NWCC	National Wind Coordinating Committee
OERA	Offshore Energy Research Association of Nova Scotia
OES	Ocean Energy Systems
OPEC	Organization of Petroleum Exporting Countries
PT PLN	Perusahaan Listrik Negara Electricity Company
PV	Photo-voltaic
RITE	Roosevelt Island Tidal Energy
UK	United Kingdom
US	United States

LIST OF UNITS OF MEASUREMENT

%	Percentage
C_p	Power co-efficient
$GtCO_2$	Giga tons of CO_2
$GtCO_2eq$	Giga tons of CO_2 equivalent
GW	Gigawatt
kg	Kilogram
km	Kilometer
KW	Kilowatt
kWh	Kilowatt-hour
ltr	Liter
m	Meter
m/s	Meter per second
MW	Megawatt
mWh	Megawatt-hour
P	Power in watts
Rp	Indonesian Rupiah
tWh	Terawatt-hour
V	Velocity
yr	Year
ρ	Density

1. Introduction

1.1 Renewable Energy and Sustainability

With the growing awareness of the global links between increasing environmental problems, socio-economic issues dealing with poverty and inequality and concerns about a healthy future for humanity, sustainable development is an urgent need. Sustainable development recognizes that past growth models have failed and have also damaged the environment upon which we depend. Past growth models have been coupled with a downward spiral of increasing poverty and environmental degradation (Hopwood et al, 2005). Sustainable development aims to create a future where social progress and environmental protection are considered as important as economic growth. Though increasingly more researchers and policymakers worldwide are striving to work towards a sustainable future, there still remain many hurdles, with climate change being a major threat.

A major factor in achieving sustainable development is securing sustainable sources of energy. The reliance of the society on energy can be traced back to historical times. This reliance became increasing evident during the industrial revolution, when economics came to be the dominating issue of human relations with economic growth, defined by increasing production, as the main priority (Douthwaite, 1992). This led to an improvement in the standard of living and a more convenient and comfortable life in many countries. This growth was largely driven by our ability to exploit fossil sources of energy like coal and oil. In the transition from human and horse power to horsepower, the carbon emissions that result from producing an amount of energy equivalent to over a billion horses working continuously have created significant climate change risks (Chu and Majumdar, 2012).

According to the IPCC Fifth assessment report titled Climate Change 2014, the anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Between 1750 and 2011, cumulative anthropogenic CO_2 emissions to the atmosphere were 2040 ± 310 $GtCO_2$. The total anthropogenic Green House Gas (GHG) emissions for the year 2010 themselves were 49 (±4.5) $GtCO_2eq$. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century.

One of the key sources of these emissions is the energy supply sector. GHGs emitted by burning of fossil fuels for production of electricity is hence one of the major causes of climate change. Figure 1.1.1 shows the allocation of global greenhouse gas emissions by economic sectors in 2010.

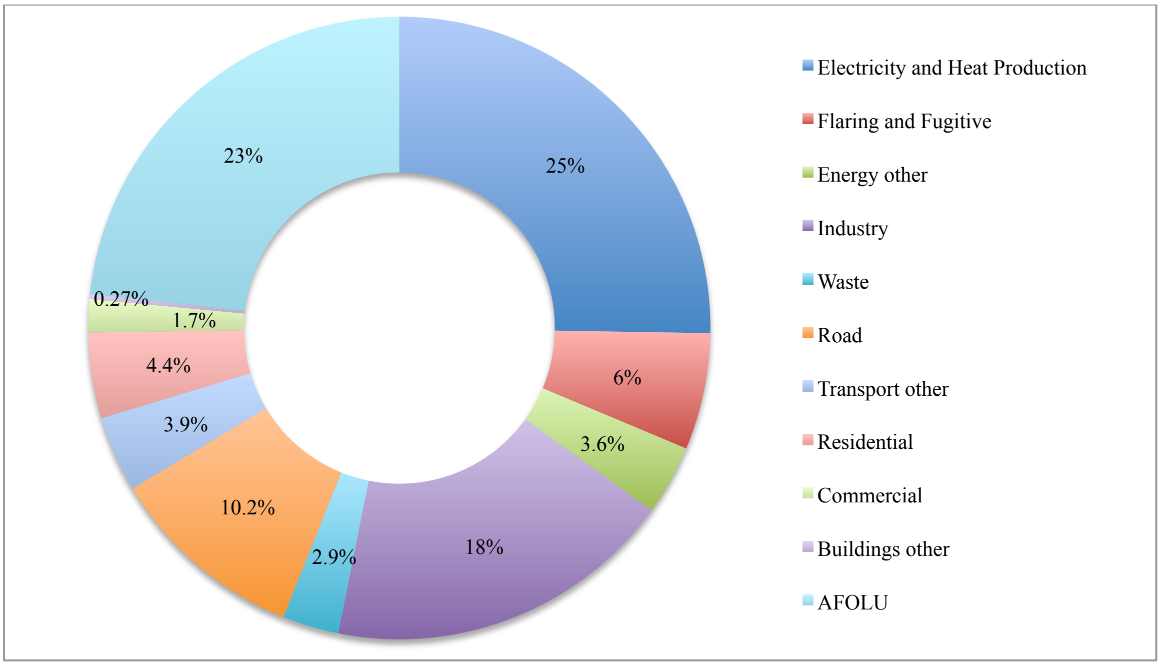


Figure 1.1.1 Global GHG emissions by economic sectors

Source: Mitigation of Climate Change: Climate Change 2014 by Intergovernmental Panel on Climate Change (IPCC) Technical Summary, pp.14
Note: Totals in graphs do not add up due to rounding.

Out of the 49 $GtCO_2eq$ emissions in 2010, 35% (17 $GtCO_2eq$) of GHG emissions were released in the energy supply sector. . Electricity and heat production (including indirect emissions) is responsible for 25% (12.25 $GtCO_2eq$) of the global GHG emissions. Though heat production is included in this figure, the production of electricity was the major contributor towards GHG emissions. The high amount of GHG emission from electricity production can be attributed largely to the types of fuels used. Figure 1.1.2 shows the share of fuels for generation of electricity in 2012.

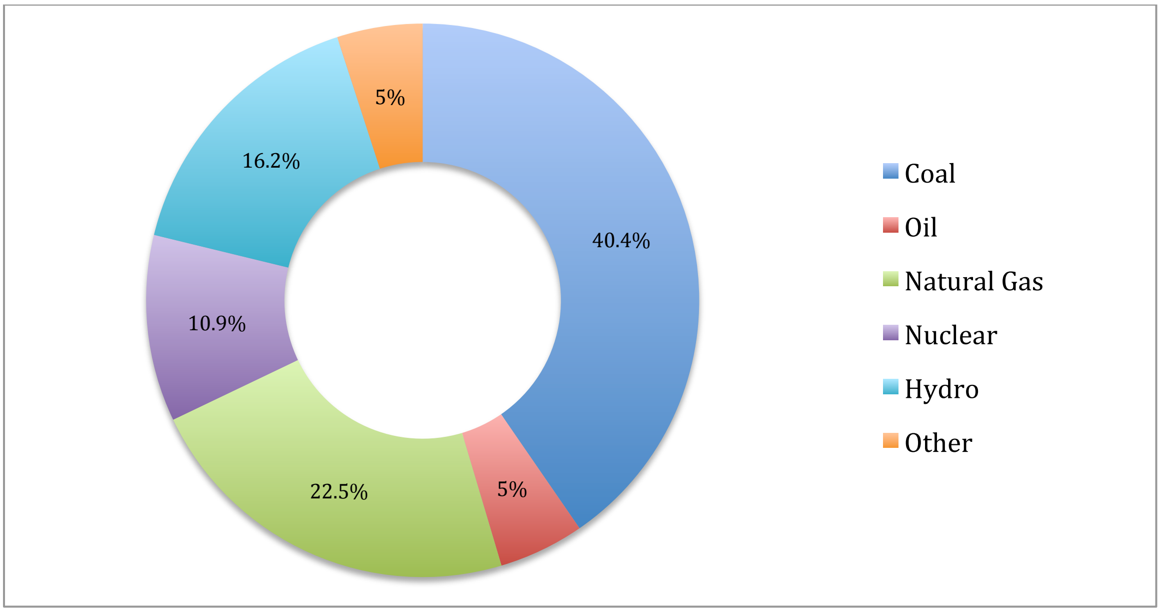


Figure 1.1.2 Fuel shares in world electricity production in 2012

Source: IEA Key World Energy Statistics 2014 by International Energy Agency (IEA), pp.24.

In 2012, fossil fuels dominated the electricity production methods with a share of 67.9% (coal, oil and natural gas). While hydropower accounted for 16.2% of electricity, the share of other renewable sources like wind, solar, geothermal, biofuels, and waste accounted for only 5% of the electricity produced globally. Although nuclear energy has the potential to produce clean energy, it also carries with it security and social acceptability issues.

According to Dincer (1999, pp.171) "sustainable development demands a sustainable supply of energy resources that, in the long term, is readily and sustainably available at reasonable cost and can be utilized for all required tasks without causing negative societal impacts. Supplies of such energy resources as fossil fuels (coal, oil, and natural gas) and uranium are generally acknowledged to be finite; other energy sources such as sunlight, wind and falling water are generally considered renewable and therefore sustainable over the relatively long term". Sustainable development of energy systems is becoming increasingly important for decision and policy makers worldwide (Santoyo-Castelazo et al., 2014). Decision and policy makers have progressively recognized the necessity of considering and integrating all three of the energy system sustainability aspects: environmental, economic and social aspects (Ness et al., 2007). A number of studies reflect on the integration of these three sustainability aspects in energy systems, and sustainable energy is beginning to be seen as the engine for sustainable development (Tester et al, 2005).

1.2 Marine Current Energy

Oceans represent a renewable energy resource that can easily satisfy the demands of the whole planet, although much technological innovation is still needed before this full potential can be realized. Marine Current Energy Generation (MCEG) is a particularly attractive source of renewable energy that is reaching its practical maturity. Operating similarly to wind turbines, underwater marine current turbines convert the kinetic energy of marine currents into electrical energy that can be used in homes and businesses, similar to the operation of a wind turbine. Though the velocities of typical marine currents are a fraction of the typical wind cutout speeds, they are steadier and more accurately predictable. The power produced by an ocean current of 2 knots is equal to the power produced by a wind flow of 9m/s, making the total power production potential of marine currents enormous (Erwandi et al., 2011). The gross kinetic energy of marine currents at 2-4 m/s is extremely large, as the density of water is 800 times heavier than that of air, and the power of the flow is proportional to the cube of the velocity of the fluid. It can be said that marine current turbines are superior to wave power or wind power generators because it is harder to be affected by severe weather such as typhoons or storms (Takagi, 2011). Moreover, currents appear regularly and predictably in perfect tune with the motion of the Earth, Moon and Sun. Therefore the power from marine current is a renewable resource that is relatively potent, yet can deliver power predictable to a timetable (Fraenkel, 2002).

1.2.1 Operation of MCEG Turbine

The operation of MCEG is explained using the following figure 1.2.1.1

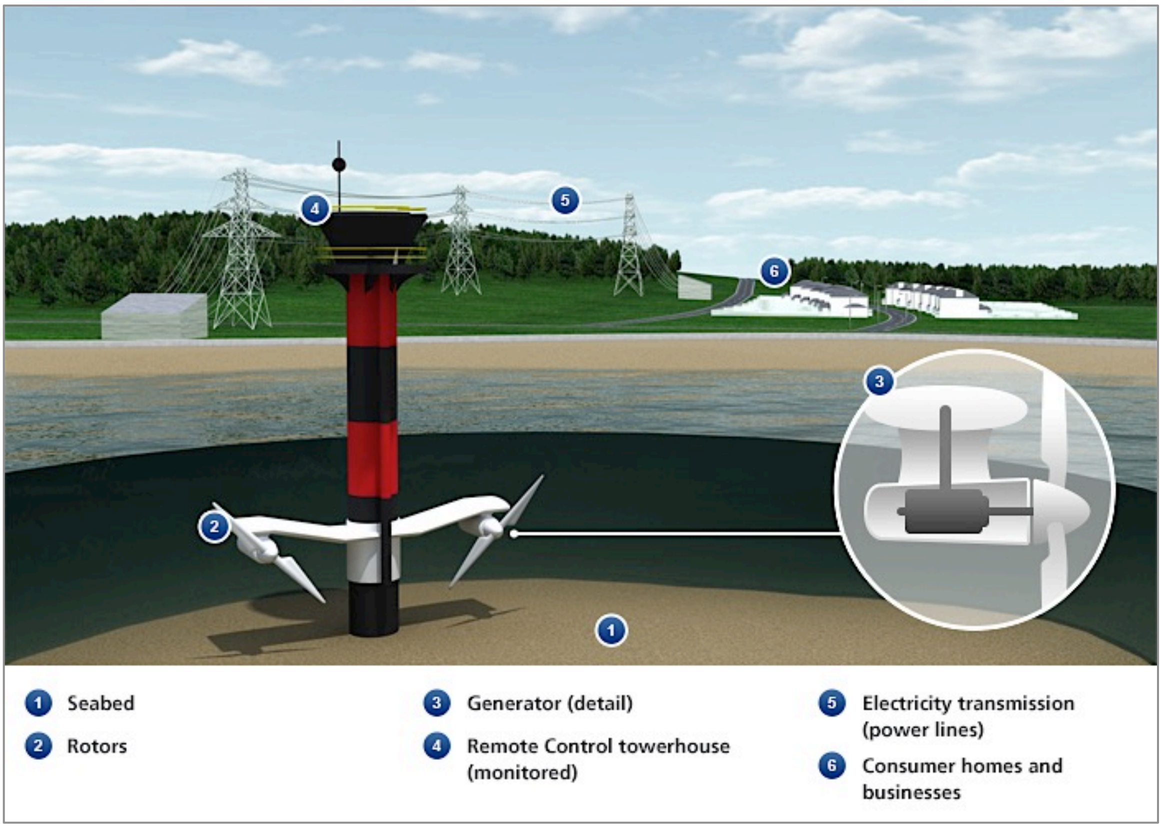


Figure 1.2.1.1 Operation of MCEG

Image source: EDF Energy (http://www.edfenergy.com/energyfuture/generation-marine)

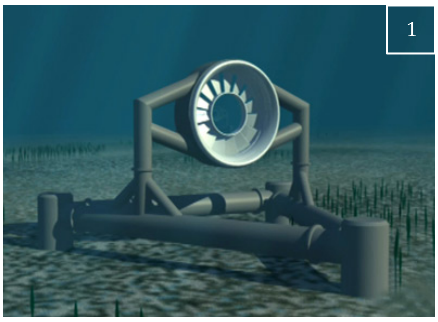
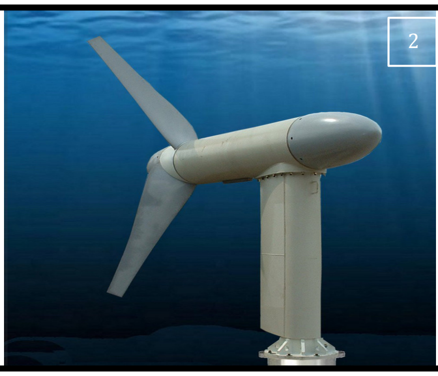
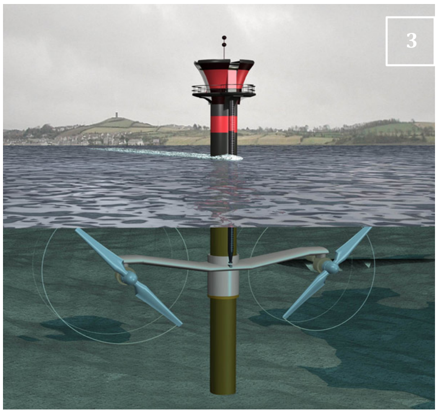
Marine turbines are installed on the seabed (1) in places where the marine currents have high velocities. When the fast moving marine currents flow over the turbine rotor blades (2) the rotor blades turn at a steady pace. The blades are attached to a generator (3) that uses an electromagnetic field to convert rotational mechanical energy into electrical current. The electricity thus produced provides a steady supply that can be monitored remotely (4). Electricity is delivered to the shore via an undersea cable and is converted to the correct voltage via a transformer (5) to be transmitted to houses and businesses (6) in need of electricity. At this point other transformers change the voltage back to usable levels. In this manner electricity is produced in a clean way, without emissions of any GHG during the entire operation.

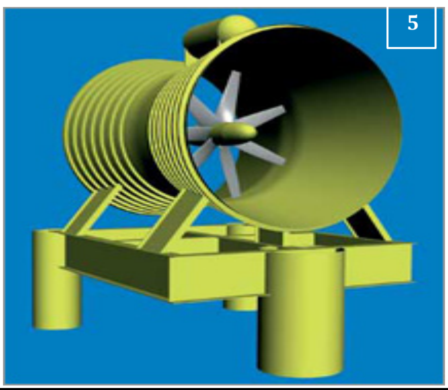
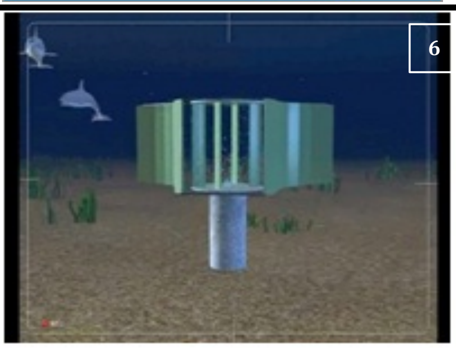
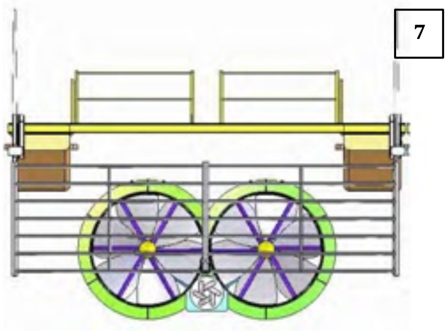
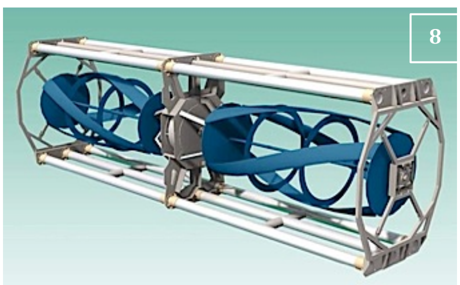
1.2.2 MCEG Devices

As of May 2015, there are nearly 60 distinct marine current technologies included in DOE's Energy Efficiency and Renewable Energy (EERE) hydrokinetics database. However, only a handful of these have been deployed at sea for extended durations. There are many types of devices that have been developed for marine current electricity generation. In addition to the conventional turbine designs, i.e. the ones with either a vertical axis or a horizontal axis, there are also other types of devices such as Archimedes screw shaped turbines, oscillating hydrofoils, enclosed tip Venturi turbines and tidal kites. Out of all the current technologies, the horizontal axis turbines seem to be the most widely preferred. Some of the marine current energy generation technologies that are currently being tested or deployed are summarized in table 1.2.2.1.

Table 1.2.2.1 MCEG technologies and their locations

Source: Made by author

Device	Details
	**Name** Open Centre Turbine **Company** Open Hydro Tidal Technology **Location** Orkney, Scotland, UK Bay of Fundy, Canada Alderney, Channel Islands, UK Paimpol-Brehart, Brittany, France
	**Name** Roosevelt Island Tidal Energy (RITE) **Company** Verdant Power **Location** New York City, East River, USA
	**Name** SeaGen **Company** Marine Current Turbines Ltd **Location** Lynmouth, Devon, UK Strangford Narrows, Northern Ireland Anglesey, North Wales, UK Bay of Fundy, Canada
	**Name** Blue Concept **Company** Hammerfest Strom AS **Location** Kvalsundet, south of Hammerfest, Norway

Device	Details
	Name Venturi Company Lunar Energy Location European Marine Energy Centre (EMEC), Scotland, UK
	Name DHV Turbine Company Tidal Energy Pty Ltd Location Gold Coast, Queensland, Australia
	Name Underwater Electric Kite Company Underwater Electric Kite Corporation Location Yukon River, Alaska, US Atchafalaya River, Louisiana, US Maine, US
	Name Gorlov Helical Rotor Company GCK Technology Location Uldol-muk strait, South Korea

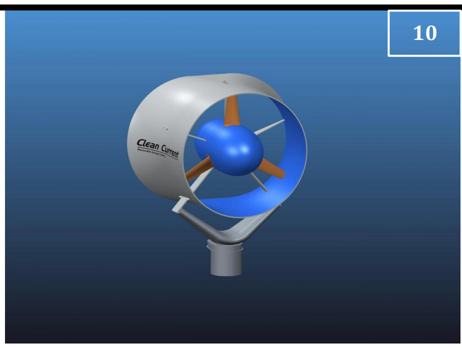
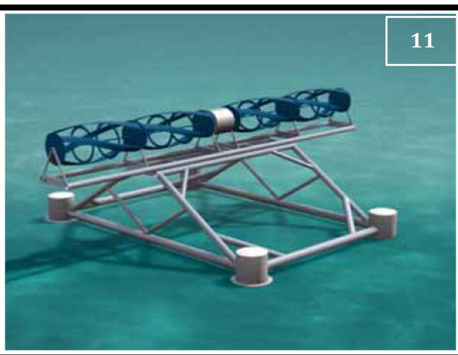
Device	Details
	**Name** Nereus/Solon **Company** Atlantis Resources Corporation **Location** Tow Tested
	**Name** Clean Current **Company** Clean Current **Location** Race Rocks, Vancouver Island, Canada
	**Name** TidGen **Company** Ocean Renewable Power Company **Location** Alaska, US Maine, US

Image Source:
1. Open Hydro Tidal Technology (www.openhydro.com)
2. Verdant Power (www.verdantpower.com)
3. Marine Current Turbines Ltd (www.marineturbines.com)
4. Hammerfest Strom AS (www.hammerfeststrom.com)
5. Lunar Energy (www.lunarenergy.co.uk)
6. Tidal Energy Pty Ltd http://www.tidalenergy.com.au)
7. Marine and Hydrokinetic Technology Database (http://en.openei.org)
8. GCK Technology (www.gcktechnology.com/GCK/pg2.html)
9. Atlantis Resources Corporation (www.atlantisresourcesltd.com)
10. Clean Current (www.cleancurrent.com)
11. Ocean Renewable Power Company (www.orpc.co)

1.3 Research Objective

1.3.1 Previous Studies of MCEG

Current research on marine current energy mainly focuses on element technologies, with a myriad of research focusing on technical aspects (Takagi, 2011, 2012; Sakata, 2012; VanZwieten, 2006). Other studies have focused on the economic aspects of this technology. For example, Li et al. (2010) developed a model integrating a marine hydrodynamic model, with high accuracy for predicting energy output, with a comprehensive cost-effective operation and maintenance model for estimating possible energy production costs in order to predict energy costs of tidal current turbine farms. Allan (2010) used publicly available cost data to calculate the private levelised costs for electricity generation in UK, while Denny (2009) researched the break-even capital cost for tidal generation on a real electricity system. Environmental monitoring and impact assessments have also been addressed by the project reports from the testing of devices by ATDP (2013), OERA (2012); MEYGEN (2011) and Marine Current Turbines (2011). In terms of policy, uncertainties in regulating marine current energy have also been explored in the context of the United States and the following factors examined: (1) agency roles and authority, (2) agency interactions, (3) regulatory change, and (4) challenges faced in the regulatory and permitting process (Jansujwicz & Johnson, 2013).

However, there remains a lack of studies that examine the public approval of a marine current energy projects. Moreover, studies that take a holistic approach – essential for sustainability – are also lacking. Collective analysis of the environmental, economic and social aspects needs to be conducted to ascertain the sustainability of MCEG.

1.3.2 Developing Countries and MCEG

In addition to there being a lack of holistic research there is also a misbalance in the distribution of study site locations. All previous studies have been conducted in the context of developed countries such as the UK, US and Canada, and the devices listed earlier in table 1.2.2.1 are being tested or deployed exclusively in developed countries. However developing countries are the countries that need renewable energy technologies now more than the developed countries, since developing countries now account for about 60% of GHG emissions globally as shown in figure 1.3.2.1.

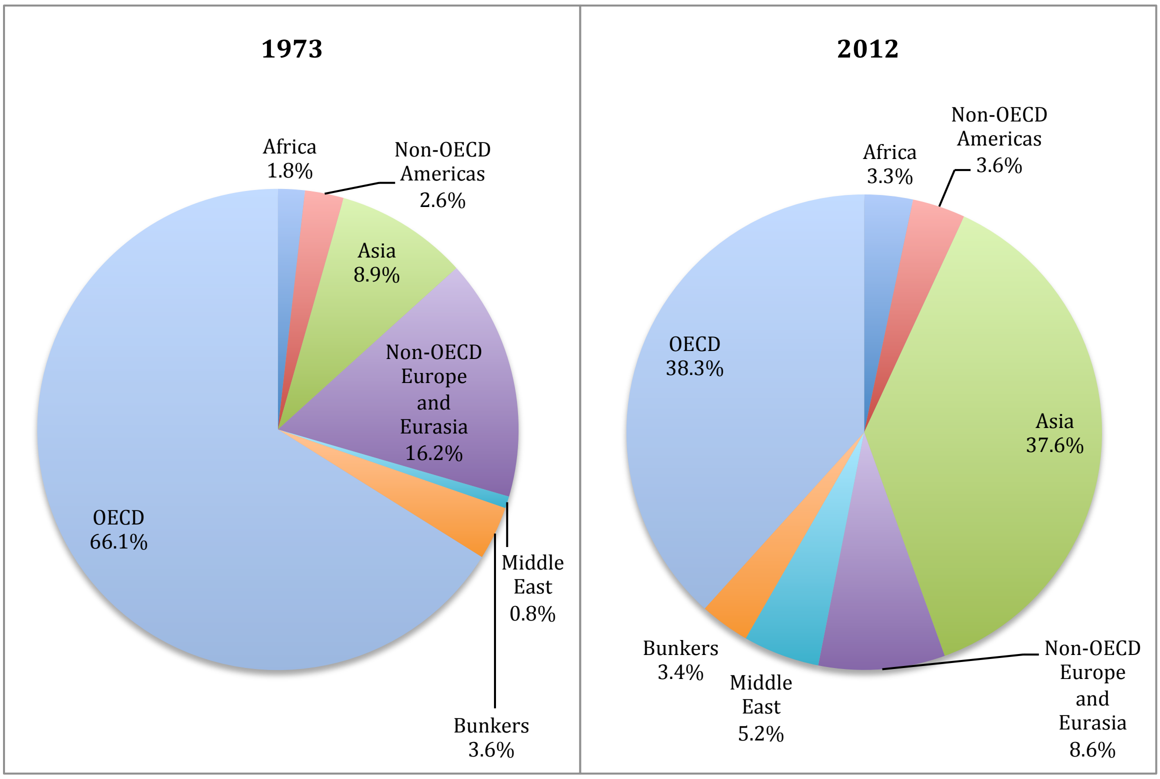


Figure 1.3.2.1 Regional share of emissions in 1973 and 2012

Source: IEA Key World Energy Statistics 2014

The energy use, and thereby the emissions produced by the developing countries are expected to continue to increase while they continue to develop at the current rate. Fueling the development in these countries by renewable energy technologies like MCEG can allow these countries to develop sustainably. Though all the previous researches for MCEG targeted only developed countries, developing countries such as Brazil and Indonesia have high potential for MCEG. Figure 1.3.2.2 shows the tidal current energy potential around the world and the ocean current energy potential can be inferred from figure 1.3.2.3.

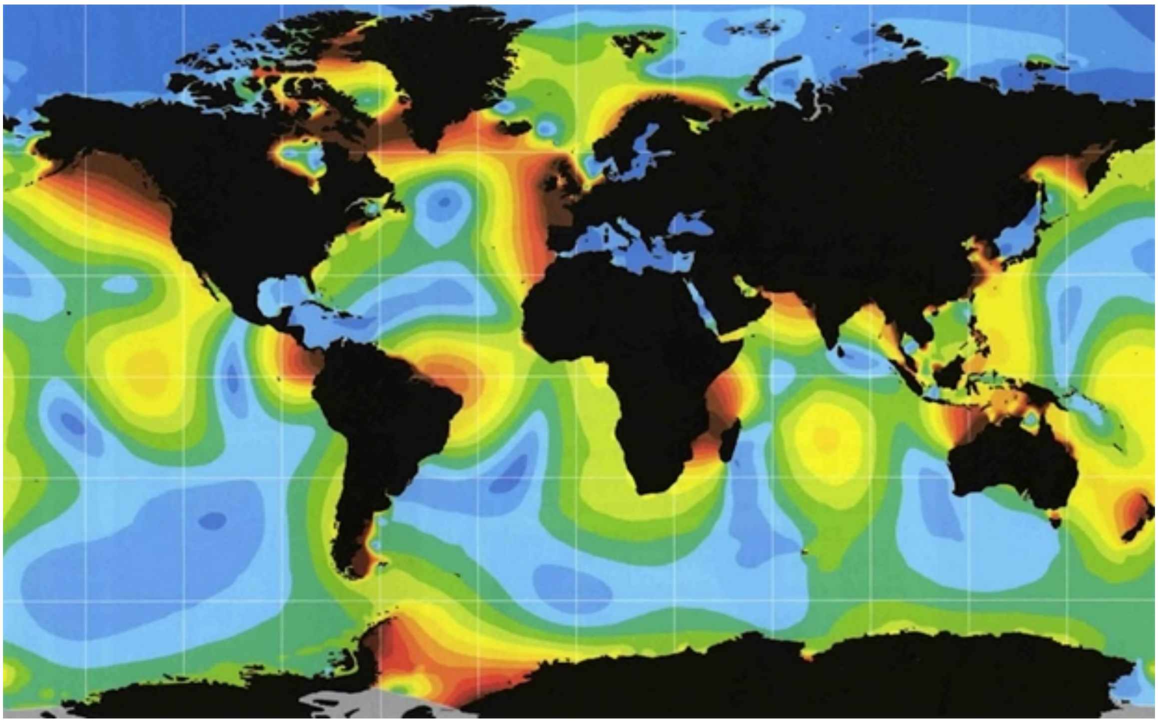


Figure 1.3.2.2 Global tidal current energy potential

Source: Minesto (http://minesto.com/ocean-energy/)

In figure 1.3.2.2 the areas in red show areas with high potential for tidal current energy. Parts of Indonesia, southeast Africa and Latin America, regions comprised of developing countries show great potential for MCEG through tidal currents.

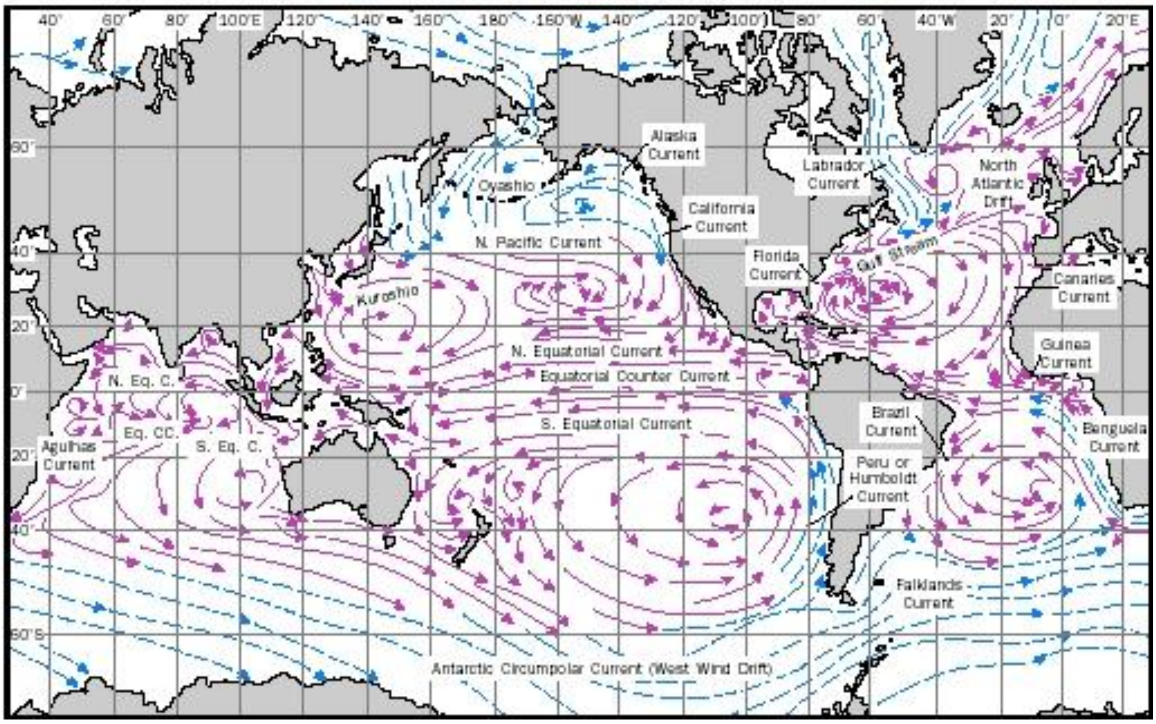


Figure 1.3.2.3 Global ocean currents

Source: Water Encyclopedia (www.waterencyclopedia.com/Mi-Oc/Ocean-Currents.html)

In addition to having great potential for MCEG through tidal currents, some of the developing countries also show great potential for MCEG through ocean currents. The ocean currents shown in figure 1.3.2.3 point towards great potential for MCEG using ocean currents in the developing countries of Southeast Asia and Latin America.

1.3.3 Research Objective

Considering the gap in previous studies about the collective analysis of MCEG projects and the lack of context in developing countries, the objective of this research is to assess the potential social, economic and environmental impacts of generating electricity through marine currents in a developing country.

In developing countries there may be no tradition of consultation and participation in decision-making (Wood, 1995) though stakeholder engagement is of prime importance to sustainability. This research aims to make a comparison between MCEG and the present technology/technologies used for generating electricity in terms of sustainability by paying careful consideration to the opinion of the stakeholders. Electricity that is environmentally friendly, economically affordable and socially acceptable would be considered the most sustainable option. Based on the findings, this research also aims to offer the most appropriate course for actions for introducing MCEG in a developing country. While recommendations of the most appropriate course of actions will be presented, they cannot be considered as the best solution for the energy generation as MCEG is a technology that will be fully functional only in the future.

Moreover, the sustainability of any particular action is impacted by the local factors like education, religion, traditions, and local politics of the people. These dynamics and importance of these factors can change from time to time, and so there cannot be a universal best scenario for finding the solution to the future electricity generation. This research will however consider the current information about the local dynamics and provide recommendations about the most important factors that influence electricity generation, and the factors that can be improved upon, to find the most appropriate outcome for the future electricity generation.

2. Research Area

Considering the objectives mentioned above, certain criteria have to be satisfied for research area selection. Most importantly, the research area should be located in a developing country that experiences strong marine currents and has high potential for MCEG. The research area should be part of a country that is facing increasing demands for electrical power. Also, the research area should in a country that is looking to diversify its energy generation capacity and aims to include more renewable energy sources in its electricity generation mix.

Indonesia is a developing country that meets the above requirements. It is the world's largest archipelago with many locations suitable for MCEG. It has recently stopped being an OPEC member and cannot afford to be highly reliant on fossil fuels any more. The reasons for selection of Indonesia as the country for research have been explained in detail in the following sections.

2.1 Marine Currents in Indonesia

Indonesia is a developing country with a fast growing economy and a large population. In Indonesia, there are many locations where the flows of the sea current flows tend to be concentrated due to constraining topography, such as straits between islands. Such kinds of places exist in the straits of Lesser Sunda Islands (figure 2.1.1) where the speed of the sea currents typically have peak velocities at spring tide in the region of 2-4 m/s or more (Erwandi, 2011).

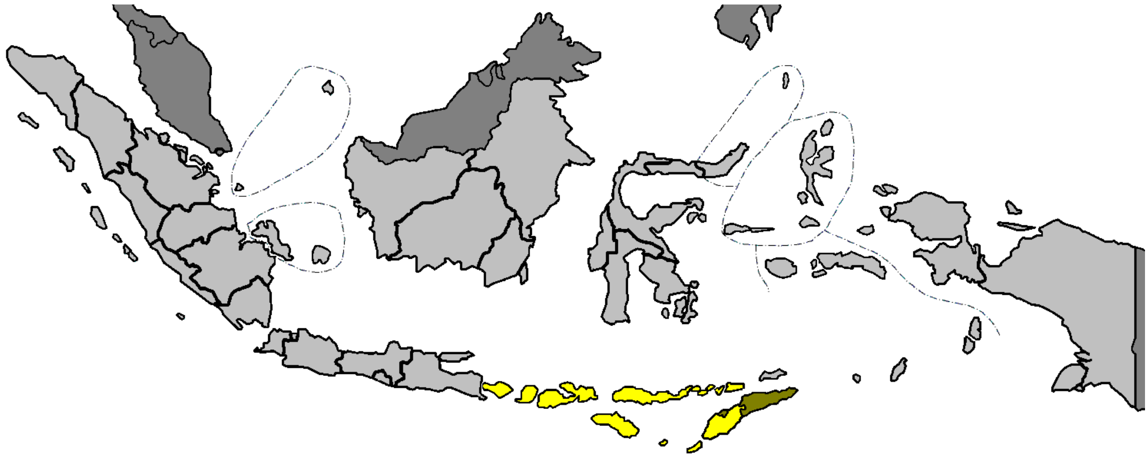


Figure 2.1.1 Map of Indonesia highlighting Lesser Sunda Islands

Image source: Wikimedia
(https://commons.wikimedia.org/wiki/File:Lesser_Sunda_in_Indonesia.png)

The current velocities of 2-4 m/s as found in the Lesser Sunda Islands are similar to the current velocities in the Scottish waters (Couch and Bryden, 2006) where a majority of research and development takes place, and where marine current farms totaling 1,000 MW have been planned (Crown Estate, 2011). Current velocity is a very important factor in the selection of the research area as it contributes greatly towards the power generated. The power produced from a marine current turbine is given by

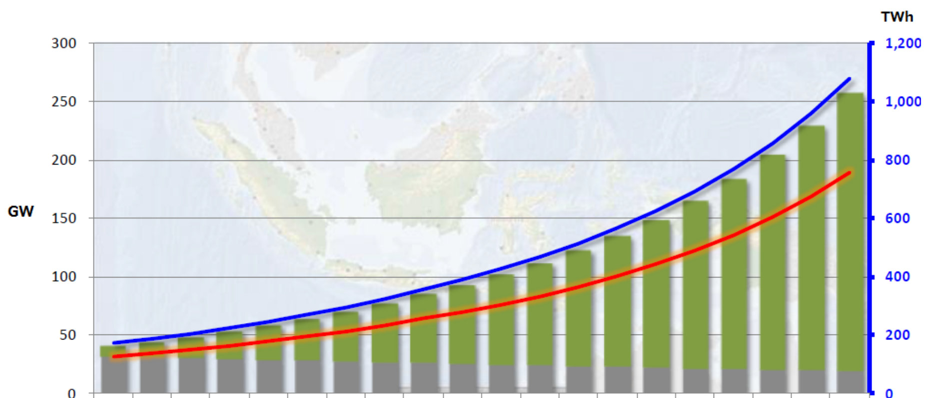
$P = 0.5 \times \rho \times C_p \times A \times V^3$

where
P = Power (watt)
ρ = density of sea water (kg/m^3)
A = Swept area of turbine rotor (m^2)
C_p = Power Co-efficient
V = Velocity

As the power generated is directly proportional to the cube of the velocity, even small changes in the velocity can create large variations in amount of power produced. The greater the velocity, the more power can be extracted from the marine current turbine, which, in turn, decreases the price of the generated electricity. Currents with velocities nearing 4 m/s provide extremely favorable conditions for generation of electricity.

2.2 Electricity Demand and Infrastructure of Indonesia

As Indonesia annually experiences economic growth exceeding 5% (ADB, 2015), its energy demand is also growing steadily. Figure 2.2.1 shows Indonesia's increasing energy demand as forecasted by the government in the draft general plan of electricity in 2013. In 2012, the electrical power demand was 171 TWh, but is expected to increase to 1,075 TWh in the following two decades. While the electricity generation capacity was 32 GW in 2012, the capacity would have to be increased to 254 GW by 2031 to satisfy this growing demand. If no additional capacity is added, the existing aging capacities will decline and the gap between the supply and demand will potentially stand at a staggering 237 GW.



	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
Need for additional power (GW)	9	13	18	23	29	36	43	50	59	67	77	87	99	112	126	143	162	183	208	237
Existing capacity (GW)	32	32	31	30	29	28	28	27	26	26	25	24	24	23	23	22	22	21	20	20
Capacity of current year (planned)(GW)	41	45	49	53	58	64	70	77	85	92	101	110	121	133	147	163	181	202	226	254
Peak load (GW)	31	34	37	40	44	48	53	58	64	69	76	83	91	100	110	122	135	150	168	189
Electrical Power Demand (TWh)	171	186	203	223	244	268	294	324	356	389	425	466	512	564	623	690	767	855	957	1,075

Figure 2.2.1 Electricity demand forecast for Indonesia

Source: Draft General Plan of Electricity (RUKN) 2012 – 2031 (ESDM, 2013)

Indonesia is facing both a great demand and need for increasing its electricity generation capacity. Figure 2.2.2 shows the electrification rate in Indonesia.

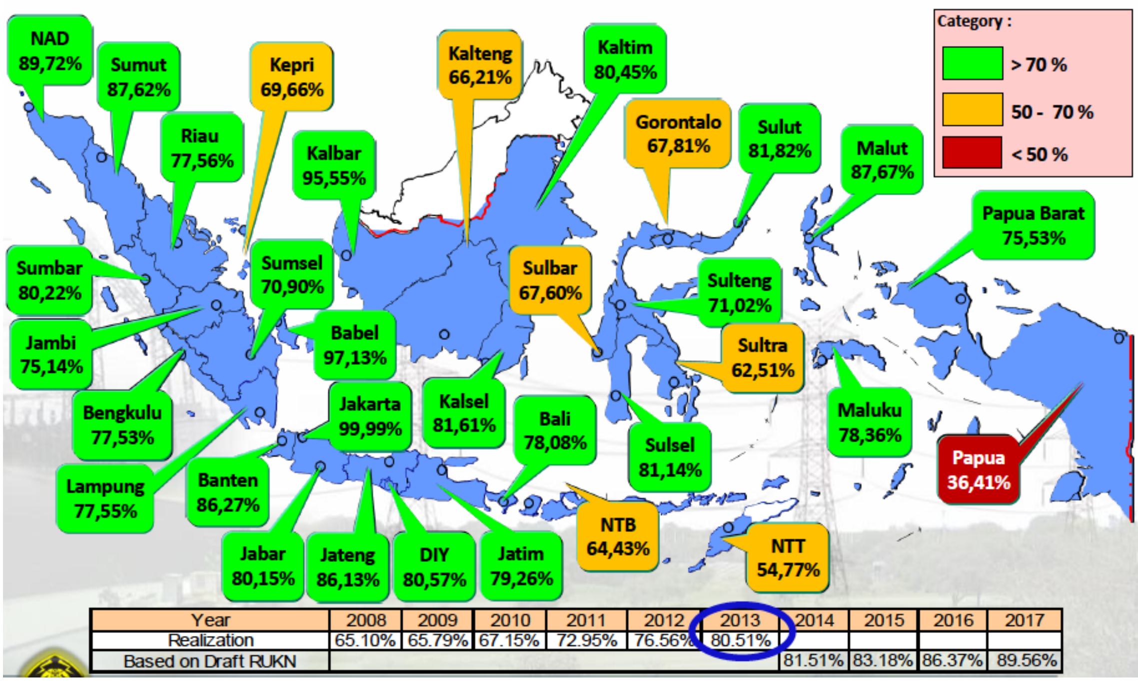


Figure 2.2.2 Electrification rate of Indonesia

Source: Draft General Plan of Electricity (RUKN) 2012 – 2031 (ESDM, 2013)

Not only is there a shortage in electricity generation capacity, there are also issues of accessibility to electricity. Around 20% of Indonesia's population, about 50 million people, still have no access to electricity. Moreover the electricity distribution is concentrated in the Java-Bali area with only Jakarta enjoying full 100% access to electricity. The situation is very grave, however, in the remote islands. Only 36% of the population has access in case of Papua, and only 55% of the people have access Nusa Tenggara Timur province of the Lesser Sunda Islands.

Moreover, almost 95% of the electricity generated throughout Indonesia comes from fossil fuels. Figure 2.2.3 shows the electricity mix of Indonesia in 2012 and the expected electricity mix envisioned by the government in years 2025, 2030 and 2050.

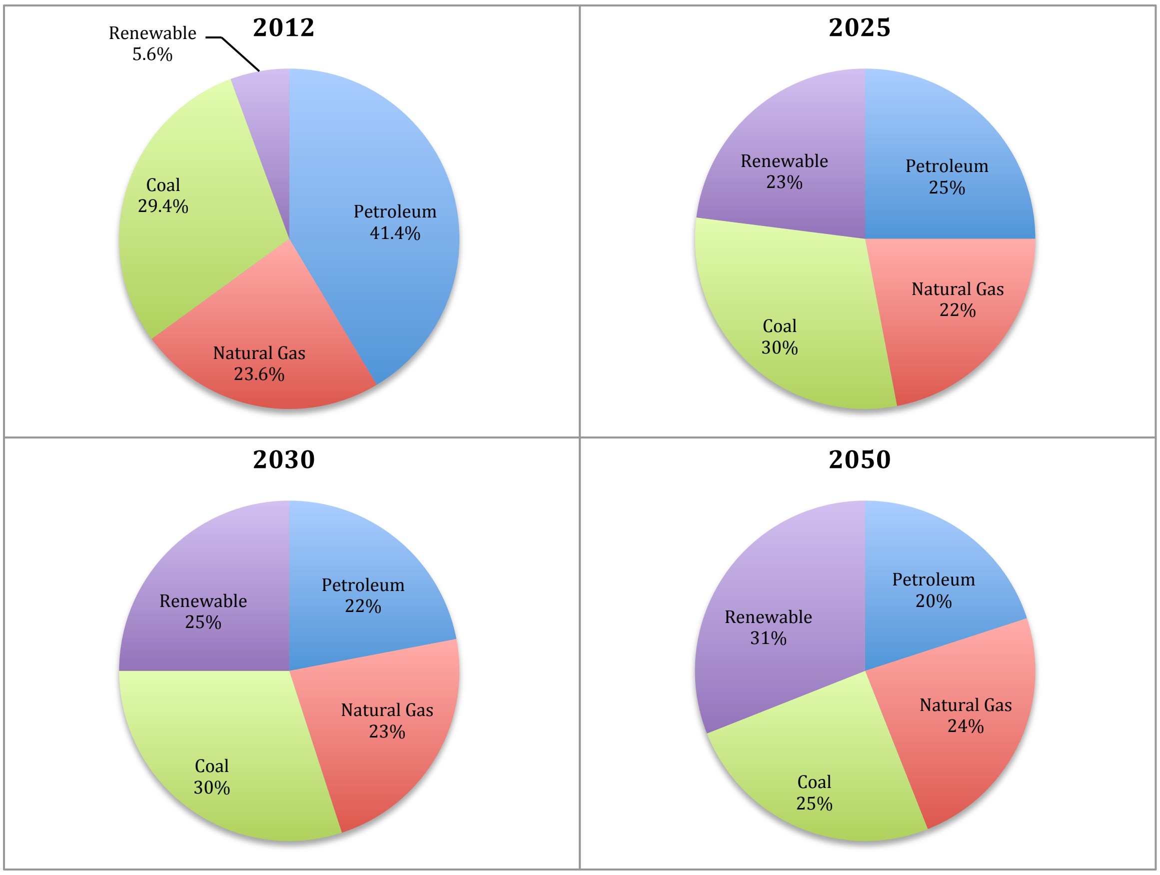


Figure 2.2.3 Indonesia's electricity mix in 2012 and expected electricity mix in future

Source: Tumiran, New Paradigm of National Energy Policy Towards Energy Security and Independence, March 2014

The government acknowledges that the current scenario is not sustainable and aims to increase the share of its electricity produced by from renewable sources to 25% by 2030. This translates into the generation capacity of 56.5 GW of renewable energy out of the total capacity of 226 GW by the year 2030 as planned by the government.

Considering all of the above this, Indonesia serves as an appropriate research area.

2.3 Research Area in Indonesia

Indonesia consists of more than 17,500 islands and close to 54,720 km of coastline. In terms of combined land and sea area, Indonesia is the seventh largest country in the world, making further narrowing of the research site necessary. As already mentioned current velocity is one of the most important factors for MCEG and Lesser Sunda Islands have many areas with high velocity currents. The straits in Lesser Sunda Islands, located in the southeast part of Indonesia are shown in figure 2.3.1

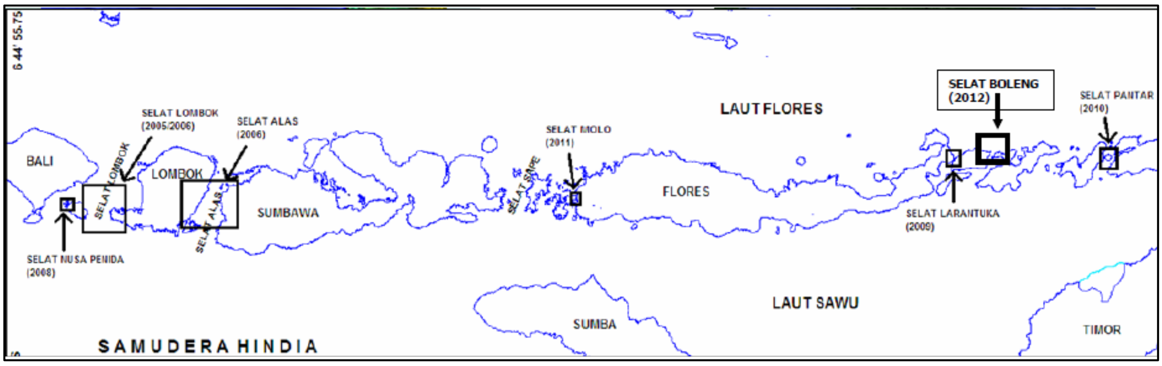


Figure 2.3.1 Map of Lesser Sunda Islands

Source: Marine Geological Institute, Indonesia

A total of nine straits in Lesser Sunda Islands were considered for the selection as the research area. The ranges of current velocities in the straits of Lesser Sunda Islands are shown in the table 2.3.1. Larantuka strait has the highest velocity range out of the nine straits considered, while Lombok strait has the lowest. The populations of the islands surrounding the strait were also considered. A population that is neither so large that the demand can't be satisfied by MCEG nor so small that the demand is negligible is deemed ideal. Table 2.3.2 shows the population data of the islands surrounding the straits under consideration. The total consumption and demand are calculated using the average annual per capita electricity consumption figure for Indonesia of 680 kWh (ESDM, 2012).

Table 2.3.1 Current velocity range of straits in the Lesser Sunda Islands

Source: PT PLN Electric Power Research and Development Centre

No	Strait	Location	Velocity Range (m/s)
1	Lombok strait	Between Bali and Lombok Island	0.2 – 2.3
2	Alas strait	Between Lombok and Sumbawa Island	0.2 – 2.4
3	Sape strait	Between Sumbawa and Komodo Island	0.2 – 3.2
4	Linta strait	Between Komodo and Rinja Island	0.2 – 3.2
5	Larantuka strait	Between Flores and Adonara Island	0.3 – 3.8
6	Boleng strait	Between Adonara and Lembata Island	0.3 – 3.6
7	Lamakera strait	Between Solor and Lembata Island	0.3 – 3.2
8	Alor strait	Between Lembata and Pantar Island	0.3 – 3.2
9	Pantar strait	Between Pantar and Alor Island	0.3 – 3.2

Table 2.3.2 Population and area of islands surrounding the straits in Lesser Sunda Islands along with their estimated energy consumption and demand

Source: Wikipedia; Flores Timur in Figures, 2012; ESDM 2012

No	Strait	Location	Population	Area (km^2)	Total Annual Electricity Consumption (MWh)	Estimated Electricity Demand (MW)
1	Lombok strait	Between Bali and Lombok Island	7,386,789	10,294	5,023,016	573
2	Alas strait	Between Lombok and Sumbawa Island	4,496,855	19,638	3,057,861	349
3	Sape strait	Between Sumbawa and Komodo Island	1,332,066	15,514	905,804	103
4	Linta strait	Between Komodo and Rinja Island	3,000	588	2,040	0.2
5	Larantuka strait	Between Flores and Adonara Island	232,605	1,813	157,972	18
6	Boleng strait	Between Adonara and Lembata Island	222,152	1,723	151,063	17
7	Lamakera strait	Between Solor and Lembata Island	144,679	1,448	98,381	11
8	Alor strait	Between Lembata and Pantar Island	157,534	1,954	107,123	12
9	Pantar strait	Between Pantar and Alor Island	185,155	3,528	125,905	14

In addition to the current velocities, surrounding population, and power demand, other factors such as water depth, strait width, presence of major shipping lanes, electricity grid, the state of infrastructure, and availability of data play an important role for the development of MCEG projects. Table 2.3.3 summarizes which of these factors each of the nine straits under consideration satisfy.

Table 2.3.3 Factors considered for selection of research area in Indonesia

Source: Made by author

Straits	Current Velocity	Water Depth	Strait Width	No major shipping lanes	Electricity Grid	Availabili ty of Data	Present Infrastruct ure
Lombok strait	✓				✓	✓	✓
Alas strait	✓				✓	✓	✓
Sape strait	✓		✓	✓			
Linta strait	✓		✓	✓			
Larantuka strait	✓	✓	✓	✓	✓	✓	✓
Boleng strait	✓	✓	✓	✓			
Lamakera strait	✓	✓	✓	✓			
Alor strait	✓	✓	✓	✓			
Pantar strait	✓	✓	✓	✓			

After taking into consideration the above factors Larantuka strait was selected as the research site. Figure 2.3.2 shows the aerial view of Larantuka strait from south direction looking towards the north.

Figure 2.3.2 Larantuka strait

Image source: Google Maps

Larantuka strait lies in the Flores Timur Regency and lays between the regency capital city Larantuka and the island of Adonara. Larantuka strait is about 10 km long in the north-south direction. The strait is 650 – 750 m wide at it northern edge, 1.25 – 1.3 km wide in the middle and 2.4 – 2.5 km wide at the southern tip.

The bathymetry of Larantuka strait, along with the power potential of the tidal currents in the strait is shown in figure 2.3.3.

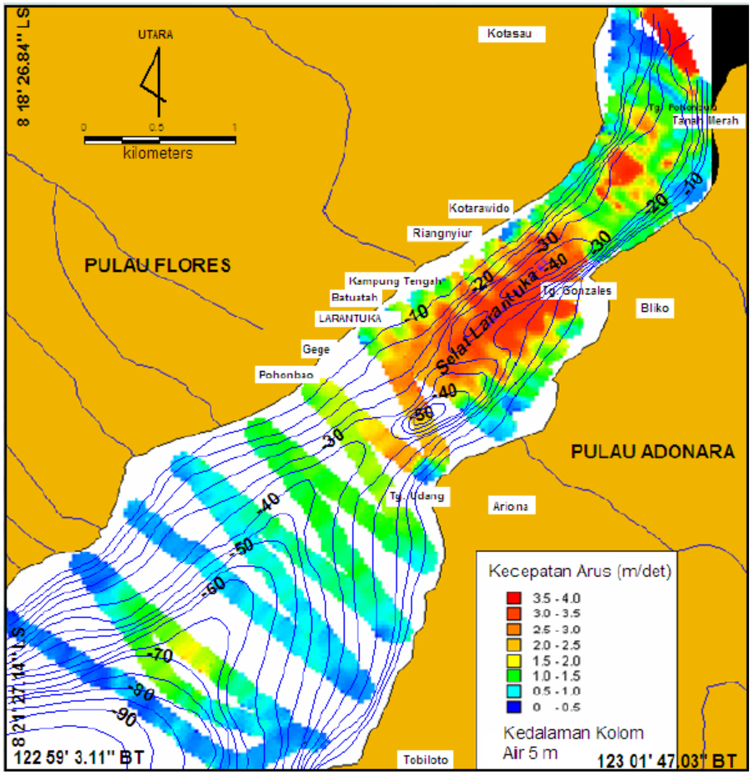


Figure 2.3.3 Bathymetry and tidal current energy potential of Larantuka strait

Figure 2.3.3 Bathymetry and tidal current energy potential of Larantuka strait
Source: Susilohadi, Mapping of Ocean Energy in Indonesia, Marine Geological Institute

Although the depth of the strait exceeds 90 m at the southern tip, Larantuka strait is quite shallow towards the center (30-40 m) where the strongest currents are found. Larantuka strait is away from major shipping routes and fishing areas. The city of Larantuka has good infrastructure and will be connected to the national grid by 2018 (PT PLN, 2014). There have been some studies conducted in Larantuka strait by Indonesian (Erwandi, 2011; Masduki, 2011) and German researchers and some data is currently available related to the bathymetry, measured velocity and direction of the currents as well as the potential energy that can be extracted practically. While Larantuka strait is the location where the MCEG turbine devices may be installed, the environmental, economic, and social impacts will be assessed for the whole of Flores Timur Regency with a population of 232,605. The map of Flores Timur Regency is shown in figure 2.3.4.

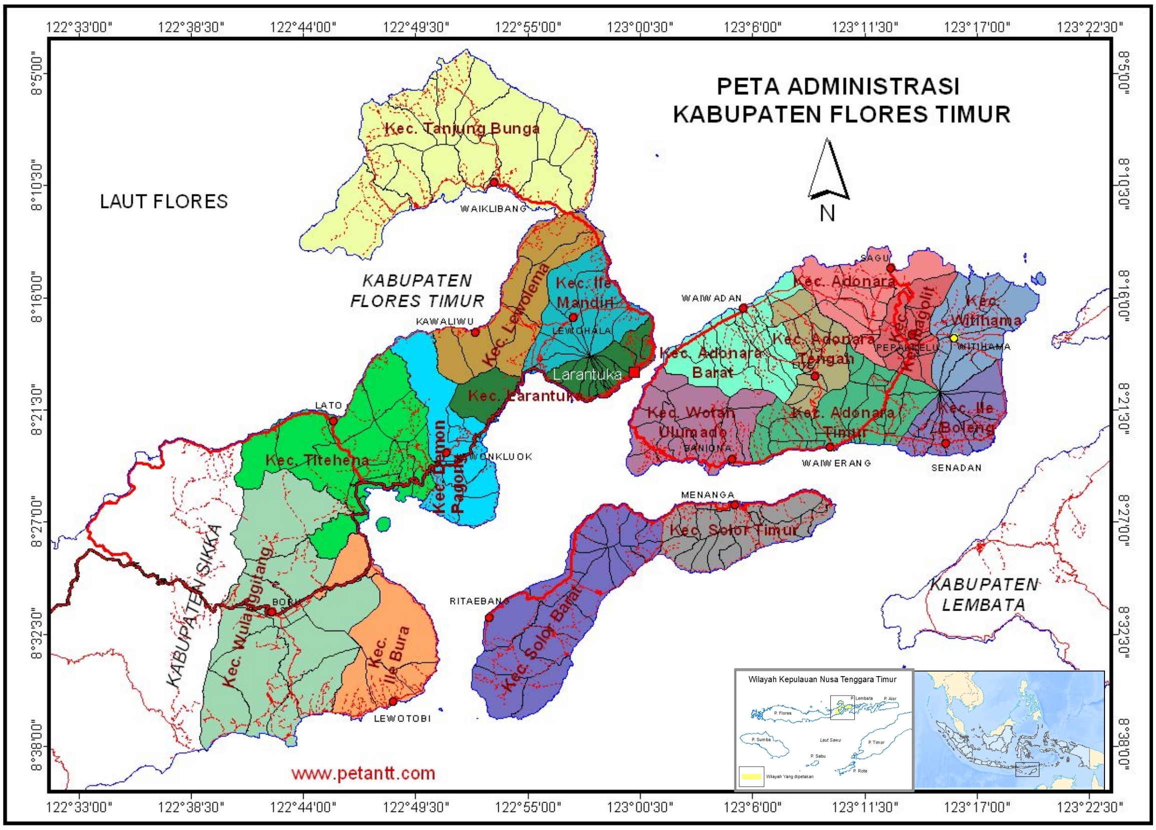


Figure 2.3.4 Map of Flores Timur Regency

Source: Flores Timur in Figures 2012, BPS Statistics of Flores Timur Regency

3. Methods and Methodology

The framework suggested by Santoyo-Castellazo and Azapagic (2014) has been adapted and used for this research. Figure 3.1 shows the adapted framework.

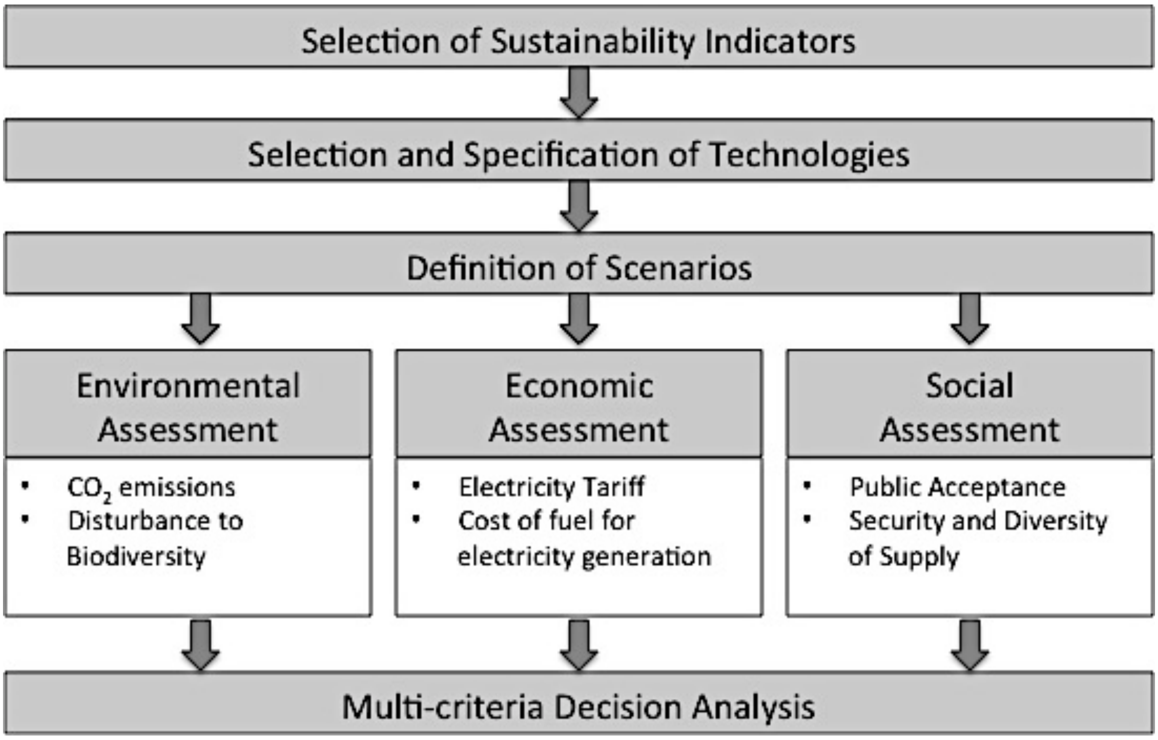


Figure 3.1 Framework for sustainability assessment and selection of the most preferable scenario

Source: Created by author by adapting framework suggested by Santoyo-Castellazo and Azapagic (2014).

The framework involves the following steps:

[1] Selection of environmental, economic and social indicators for measuring sustainability

[2] Selection and specification of technologies to be compared

[3] Development of scenarios based on the technologies selected

[4] Environmental, economic and social impact assessment

[5] Integration of sustainability indicators using Multi-Criteria Decision Analysis (MCDA) to determine the most sustainable option for future

For the selection of the indicators and the understanding of the potential impacts, interviews or focus group discussions were conducted with the following groups of stakeholders presented in table 3.1.

Table 3.1 List of stakeholders interviewed

Source: Made by author based on interviews

Stakeholder Group	Date of Interview
Government	
Managing Director of Indonesian Hydrodynamic Laboratory of BPPT	6th October 2014
Head of Regional Development Planning of Flores Timur Regency	8th October 2014
Head of Resources and Energy Division of Flores Timur Regency	8th October 2014
Head of Development Tourist Destination Division of Flores Timur Regency	9th October 2014
Head of Environmental Office of Flores Timur Regency	9th October 2014
Head of Aquaculture division of Flores Timur Regency	10th October 2014
Head of Non-formal Education Division of Flores Timur Regency	10th October 2014
Manager, PT PLN Electricity Company, Flores Timur Regency	10th October 2014
Local Academia (University of Nusa Cendana, Kupang)	
Faculty of Marine Sciences and Fisheries	18th March 2015
Faculty of Economics and Business	19th March 2015
Faculty of Science and Engineering	19th March 2015
Faculty of Social and Political Science	20th March 2015
Local NGOs	
Reef Check (n=1)	21st March 2015
The Nature Conservancy (n=2)	21st March 2015
Local Population	
Fishermen groups (4 groups)	11th October 2014, 24th March 2015
Farming groups (3 groups)	12th October 2014, 25th March 2015
Ferry Operators (1 group)	9th October 2014
Fishing Company owner	12th October 2014
Small Business owners (n=6)	12th October 2014, 26th March 2015

The detailed discussion of each of the steps involved in the framework is presented in the following sections.

3.1 Sustainability Indicators

Past researches on sustainability of energy systems have considered as few as three indicators (Heinrich et al., 2007) to as many as 75 indicators (Roth et al., 2009). In this research, six indicators – two for environmental, social, and economic impacts each – are used. Previous researches on sustainability of energy systems have played an important role in the selection. Interviews with local stakeholders, including the local government officials and the local community members, have also influenced the selection of each of the indicators.

3.1.1 Environmental Indicators

The two environmental indicators selected for this research are (1) Carbon Emissions and (2) Disturbance to Biodiversity. As mentioned in the introduction earlier, carbon emissions, to due use of fossil fuels are the major causes of climate change. Carbon emissions from energy production can hence be an effective gauge to assess the sustainability of energy systems from the environmental point of view. Secondary data from previous research conducted by other academics will be used to assess the carbon emission as an indicator of environmental sustainability.

While renewable energy technologies may not have high GHG emissions they can have negative environmental impacts by proving to be a hindrance to the local biodiversity.

The impact of wind turbines on wildlife, most notably on birds and bats, has been widely document and studied (NWCC, 2010). Geothermal energy technologies have hydrogen sulfide emissions that have a distinctive ‘rotten-egg’ smell that can be a cause of disturbance to the nearby animals and birds alike (Kagel, 2007). Similarly, marine current energy technologies can possibly cause disturbance to the surrounding marine life. Hence it is important to consider the disturbance to biodiversity as an indicator of environmental sustainability. Disturbance to biodiversity will be estimated based on observation of the research area and other studies related to the topic.

3.1.2 Economic Indicators

For developing countries like Indonesia, economic aspects are perhaps the most important ones. The economic indicators for sustainability in this research are (1) Electricity Tariff and (2) Cost of Fuel for Production of electricity. These two were identified as the most important factors through interviews with the local stakeholders. Since Flores Timur Regency is located in a remote southeast part of the country, away from the population centers of Java and Bali, most goods and amenities are relatively expensive in the regency. The residents of Flores Timur Regency already pay higher electricity tariff than the residents of Jakarta. Hence electricity tariffs are an important indicator for economical sustainability as far as energy issues are concerned. This research will be using data collected from primary and secondary sources for the assessment of electricity tariff as an economic indicator for sustainability.

Because of the location of the regency and the lack of fuel resources, all the fuel used in Flores Timur Regency must be imported from other areas of the country, causing the more expensive fuel prices. Moreover with global oil price fluctuations, the costs of fuels have been constantly changing, making the fuel costs another important metric for assessing sustainability. Secondary data sources will be used for the assessment of the cost of fuel for economic assessment of sustainability.

3.1.3 Social Indicators

(1) Public Acceptance and (2) Security and Diversity of Supply are the two social indicators considered in this research. Public perception and acceptability is of foremost importance for the deployment of any energy technology, be it conventional technologies using fossil fuels, renewable energy technologies or even nuclear power technologies (Gallego-Carrera and Mack, 2010; Onat and Bayar, 2010). For example, with regards to wind energy, the main public acceptance issues are land acquisition, visual intrusion and noise (Evans, et al., 2009). Public concerns about large hydropower plants include land transformation and population relocation (Lokey, 2009). Public perception of nuclear power plants are shaped by the concerns related to health and safety issues, nuclear accidents, and radioactive waste disposal (Jazayeri et al., 2008). Interviews with local stakeholders revealed how certain energy projects could not be successfully implemented due to a lack of public acceptance and engagement. Public Acceptance hence is the most important criteria for assessment of social sustainability. To assess the public acceptance Analytic Hierarchy Process (AHP) will be used. Explanation about AHP will be presented later in the section titled Multi-criteria Decision Analysis (MCDA).

Depletion of fossil fuel reserves and large fluctuations in the fossil fuel prices can make a huge impact on the security and diversity of energy supplies. According to IEA (2008) it is vital to establish a diversified energy sector based on low-carbon technologies in order to secure the energy supply for the future. Secondary data and field observations will be used for the assessment of the indicator of security and diversity of supply.

3.2 Selection and Specification of Technologies

After the selection of indicators has been accomplished, the proposed framework asks for selection of the technologies to be assessed as the next important step. Presently, all the electricity produced in East Timur Regency comes from diesel generators.

Figure 3.2.1 shows some of the diesel powered electricity generators currently used at the diesel power plant at Waibalun in Larantuka operated by PT PLN, the national electricity company.

Figure 3.2.1 Diesel electricity generators at Waibalun power plant in Larantuka

Source: Taken by author in October 2014

These diesel generators – some owned by the company and others rented – have a total installed capacity exceeding 5 MW. However only around 3 MW of the capacity is used at all times as is practically possible. In addition to these generators that are used to feed electricity to the local grid, there are also some small off-grid diesel generator used by farmers for agricultural operations like pumping water.

As there is a tremendous potential for MCEG in Larantuka strait, this research proposes to compare electricity production using diesel generators and MCEG based on the indicators mentioned earlier.

3.3 Development of Scenarios

In order to compare the different technologies mentioned about, a few scenarios are developed, as proposed by the framework. The scenarios developed are based on the size and type of technology. It is essential to estimate the future demand of electricity to develop the scenarios. Indonesia's annual per capita electricity consumption is 680 kWh (ESDM, 2012) but the annual per capita electricity consumption of Flores Timur Regency is less than one fifth of the national average and stands at 123 kWh (BPS, 2012). While this value seems surprisingly low compared to the already low national average, compared to the energy consumption in the rest of the world, the people of Flores Timur Regency lead a low energy lifestyle. A majority of the people in Flores Timur Regency lead a simple agrarian life, depending on fishing or agricultural activities, with minimal use of electricity. Through observations and interviews with local people it was estimated that an average household in Flores Timur Regency presently requires electricity for only two light bulbs and a television. Figure 3.3.1 shows some typical houses in Flores Timur Regency.

Figure 3.3.1 (1) and (2) Houses in Larantuka. (3) and (4) houses in Adonara island
Source: Taken by author in October 2014

However even to sustain the present simple lifestyle, the annual per capita consumption of 123 kWh is not enough. There are constant blackouts and they face a huge shortage of electricity as some villages do not have access to any electricity. For every person to sustain this present simple life-style they need an estimated 150 kWh annually. Moreover, the local stakeholders, including the local government and the population at large indicated a preference for an improved lifestyle with a higher standard of living. After taking into consideration the need for economic development, a future per capita annual electricity consumption of 250 kWh was assumed to be sufficient to satisfy the needs of the people. The current usable capacity of 3 MW is not enough to satisfy this assumed future demand. For regency with a population of 232,605 people, with each person consuming 250 kWh of electricity annually (58,151,250 kWh in total), an estimated 6 MW capacity is needed, corresponding to the need for an additional 3 MW of electricity generation capacity. The Managing Director of Indonesian Hydrodynamic Laboratory (IHL) of the Agency for the Assessment and Application of Technology (BPPT), a non-departmental government agency under the coordination of the Ministry of Research and Technology of Indonesia, also indicated the need for an additional 3 MW capacity for Flores Timur Regency.

Considering the need for a 6 MW electricity generation capacity in Flores Timur Regency in the future, the following three scenarios were established:

- Scenario (1) The present diesel electricity generation capacity of 3 MW is maintained and an additional 3 MW of diesel electricity generators are added in future.
- Scenario (2) The present diesel electricity generation capacity of 3 MW is maintained and an additional capacity of 3 MW from MCEG is added.
- Scenario (3) All of the present diesel generators are removed and the entire 6 MW of electricity generation capacity comes from MCEG

3.4 Sustainability Assessment

These three scenarios, differing based on the capacity and type of electricity generating technology used, will be assessed using the environmental, economic, and social indicators for sustainability, and the best scenario for future electricity generation for Flores Timur Regency will be identified. In total there are six indicators and each of these indicators will be assessed in each scenario. As local insight into the impacts is necessary and valuable, the potential environmental, social, and economic impacts of each scenario will be considered based on interactions with local stakeholders including the local academics, NGOs, the local government and the local population. Secondary data based on previous research and relevant statistics will also be used for the assessment. To help evaluate the results and identify the most sustainable scenario for future electricity generation, the outputs of the assessment will be fed into multi-criteria decision analysis.

3.5 Multi-criteria Decision Analysis (MCDA)

Multi-criteria Decision Analysis (MCDA) incorporates several predetermined criteria in a decision making process. A criterion, similar to an indicator, can be defined as a standard by which a particular outcome can be adjudged to be more desirable than another one. In MCDA a Decision Maker (DM) uses several criteria to assess the appropriateness of different decision alternatives, which include outcomes or potential courses of action.

MCDA can be used in any real life scenario where a large number of criteria have to be considered. It has been used to solve issues relating to business, manufacturing, medicine, and public policy amongst other cases. Selection of a potential source of energy can be complex and involve a consideration of wide range of criteria, making MCDA an appropriate tool for analysis.

In this research a specific MCDA procedure called value tree analysis is used whereby the decision-making problem is defined as a hierarchical weighting problem. Weighting is the process of assigning weights to the indicators in order to reflect their significance or adequacy. Weights usually have an important impact on the resulting ranking especially whenever higher weight is assigned to indicators on which outputs excel or fail. Moreover, it should be considered that weights are essentially value judgments and have the property to make explicit the objectives underlying the construction of a decision. Commonly used methods for weighting include equal weighing, weighting based on statistical models, and weighting based on public/expert opinion.

In value tree analysis, the objectives are structured hierarchically and then weighted by their importance to the DM. The total value of the alternatives is then calculated from the weights. MCDA typically involves three steps:

[1] Problem Structuring

[2] Preference Elicitation

[3] Recommendation of Decision

These steps are explained in the following sections.

3.5.1 Problem Structuring

The main process involved in problem structuring, the first step in MCDA process, is the construction of a hierarchical model in the form of a value tree that includes all the criteria, sub-criteria and alternatives in the form of a value tree. Ideally, all the relevant objectives are covered in the hierarchy and the selected indicators completely define the degree to which the overall objective is achieved.

The value tree used in this research is shown in figure 3.5.1.

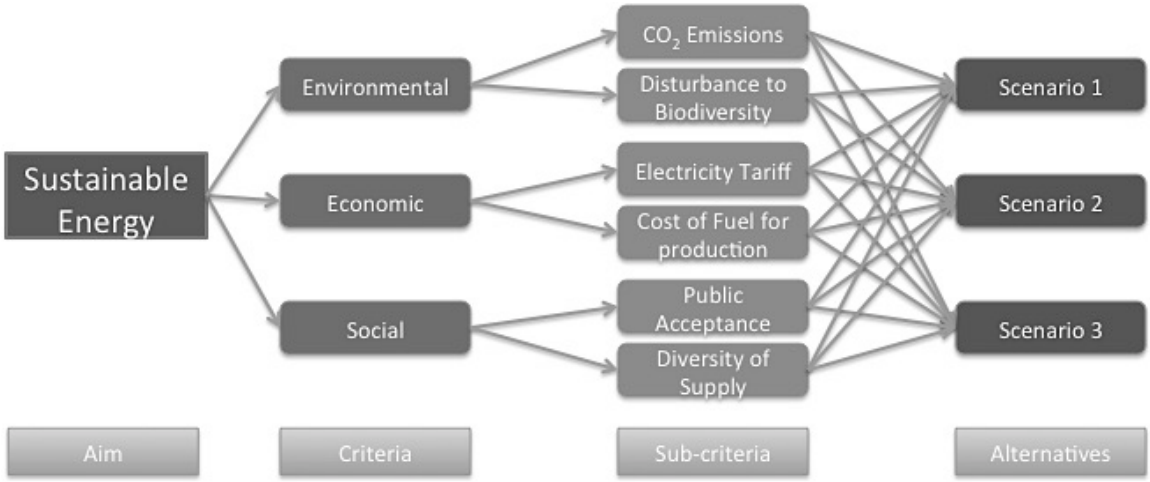


Figure 3.5.1.1 Value tree for selection of future sustainable energy generation scenario

Source: Made by author

This research takes a top-down approach, as it begins with the identification of the fundamental aim, which is then divided into criteria and sub-criteria. In this value tree the three criteria are environmental, economic and social. The indicators for each of the criteria as mentioned earlier – Carbon Emissions, Disturbance to Biodiversity, Electricity Tariff, Cost of Fuel for Electricity Generation, Public Acceptance and Security and Diversity of Supply – compose the six sub-criteria. The three scenarios defined earlier. i.e. electricity from diesel generators, electricity from a combination of diesel generators and MCEG, and electricity only from MCEG are the three alternatives.

3.5.2 Preference Elicitation

For sustainable energy decision-making, AHP has been found to be the most comprehensive method for MCDA (Wang et al., 2009) due to its ability to effectively combine objective and subjective questions in the decision making process. In this research AHP is used for preference elicitation. AHP is ideal in capturing the voices of the local stakeholders, as it uniquely combines data, experience, insight, and intuition in a logical way. According to Saaty, AHP overcomes many of the problems associated with weighting of the variables by deriving ratio scales through pairwise relative comparisons. Pairwise comparisons are a better way to solicit information and weights because humans are much more capable of making relative judgments than absolute judgments. The mathematical soundness of AHP provides a result, with a high degree of confidence, that a criterion with 30% importance is twice as important as a criterion with 15% importance. Another advantage of AHP is that its structured approach allows different individuals and institutions to equally participate in a quantitative and non-biased process, rather than in a subjective and value-laden process.

AHP uses pairwise comparisons in comparing the decision criteria and alternatives to elicit weights and scores, respectively (Saaty, 1980). Thus, for example, in assessing decision criteria weights, the decision-maker is asked a series of questions, each of which tries to find how important one particular criterion is relative to another in the context of that particular decision problem. The same process is repeated for the comparison of alternatives, whereby the score is calculated for each alternative by evaluating their performance on each criterion (Azapagic, 2005). A9-point ratio (rather than interval) scale is used for all judgments. To ease the assignment of weights, verbal statements associated with each pairwise comparison ratio are used. The AHP comparison scale along with the accompanying verbal statement is presented in table 3.5.1.1.

Table 3.5.2.1 AHP pairwise comparison scale

Source: Made by author based on (Saaty, 1990)

Verbal Statement	Scale
Equally important	1
Slightly more important	3
Strongly more important	5
Very strongly more important	7
Extremely more important	9
Intermediate values between two adjacent scale values	2,4,6,8

The most effective way to concentrate judgment is to take a pair of elements and compare them on a single property without concern for other properties or other elements. This is why paired comparisons in combination with the hierarchical structure are so useful in deriving measurement.

This process to elicit weights and arrive at a result using the matrices is illustrated now using an exemplar AHP conducted by one group of stakeholders involved – the academics from Nusa Cendana University. The value tree shown in figure 3.5.1.1 is used to make the hierarchy. The academics are asked to make pairwise comparisons between the various criteria based on a scale of 1-9 outlined in table 3.5.2.1. The results of the paired comparisons are presented in a comparison matrix. The output of the matrices provide priority vector, which are the weights for the elements in discussion. Consistency Measure (CM) is used to check the consistency of the comparisons. A consistency measure of 0.2 is deemed to be acceptably consistent. The matrix of pairwise comparisons of the criteria given by the academics is shown in table 3.5.2.2.

Table 3.5.2.2 Pairwise comparison matrix for sustainable energy criteria

Source: Made by author

Criteria	Environmental	Economic	Social	Weighting
Environmental	1.0	1.6	0.71	0.339
Economic	0.63	1.0	0.63	0.237
Social	1.4	1.6	1.0	0.424

CM = 0.080

The stakeholder group now makes pairwise comparisons between the sub-criteria. Because of six sub-criteria, there are three 2 x 2 matrices obtained. These matrices provide the priority vector for each sub-criterion. The pairwise comparison matrices for the sub-criteria are shown in table 3.5.2.3.

Table 3.5.2.3 Pairwise comparison matrices for sub-criteria

Source Made by author

Environmental (CM: 0.00)			Weighting
Sub-criteria	Carbon Emissions	Disturbance to Bio-Diversity	
Carbon Emissions	1.0	0.18	0.154
Disturbance to Bio-Diversity	5.5	1.0	0.846
Economic (CM: 0.00)			Weighting
Sub-criteria	Electricity Tariff	Cost of Fuel for Production	
Electricity Tariff	1.0	0.3	0.233
Cost of Fuel for Production	3.3	1.0	0.767
Social (CM: 0.00)			Weighting
Sub-criteria	Public Acceptance	Security and Diversity of Supply	
Public Acceptance	1.0	2.0	0.667
Security and Diversity of Supply	0.5	1.0	0.333

The next step involves pairwise comparison of the three scenarios – scenario 1, scenario

2, and scenario 3 – with respect to how much better one scenario is than the other scenario in satisfying each sub-criterion. This leads to formation of six 3 x 3 matrices of judgments, since there are six sub-criteria, and three scenarios to be pairwise compared against each other. These matrices provide the local priority vectors for each of the scenarios. In this case the priority vectors provide the weighting of the preferences for the scenarios. Table 3.5.2.4 shows the comparison matrices and the derived local priorities for each of the scenarios.

Table 3.5.2.4 Comparison matrices and local priorities for the most preferred scenario

Source: Made by author

Carbon Emissions (CM = 0.145)				Preference Weighting	Cost of Fuel For Production (CM = 0.29)				Preference Weighting
Scenario	1	2	3		Scenario	1	2	3	
1	1.0	0.13	0.16	0.066	1	1.0	0.14	0.14	0.056
2	7.6	1.0	0.48	0.368	2	7.1	1.0	0.14	0.204
3	6.3	2.1	1.0	0.566	3	6.9	7.0	1.0	0.740
Disturbance to Bio-Diversity (CM = 0.177)				Preference Weighting	Public Acceptance (CM = 0.063)				Preference Weighting
Scenario	1	2	3		Scenario	1	2	3	
1	1.0	0.16	0.14	0.065	1	1.0	0.19	0.18	0.084
2	6.4	1.0	0.29	0.282	2	5.3	1.0	0.67	0.394
3	6.9	3.4	1.0	0.654	3	5.5	1.5	1.0	0.522
Electricity Tariff (CM= 0.22)				Preference Weighting	Security and Diversity of Supply (CM = 0.332)				Preference Weighting
Scenario	1	2	3		Scenario	1	2	3	
1	1.0	0.53	0.4	0.169	1	1.0	0.13	0.18	0.063
2	1.9	1.0	0.26	0.224	2	7.5	1.0	0.16	0.228
3	2.5	3.9	1.0	0.607	3	5.5	6.4	1.0	0.709

The final step involves establishing the composite or global priorities. The local priorities are laid out with respect to each sub-criterion in a matrix and each column of vectors is multiplied by the corresponding sub-criterion and each row is added across. This results in the derivation of the desired global priority vectors, or the weighting of the scenario preferences. The matrices and the final global vectors signifying the weights of the scenario preferences are presented in table 3.5.2.5.

Table 3.5.2.5 Local and global priorities for the most preferred scenario

Source: Made by author

	Carbon Emissions	Disturbance to Bio-Diversity	Electricity Tariff	Cost of Fuel for Production	Public Acceptance	Security and Diversity of Supply	Scenario Preference Weighting
Local Priority	0.154	0.846	0.233	0.767	0.667	0.333	
Scenario 1	0.066	0.065	0.169	0.056	0.084	0.063	0.074
Scenario 2	0.368	0.282	0.224	0.204	0.394	0.228	0.293
Scenario 3	0.566	0.654	0.607	0.740	0.522	0.709	0.633

Scenario 3 is nine times are preferred as scenario 1 and more than twice as preferred as scenario 2. In this manner the scenario with the largest priority vector can be selected, with mathematical certainty, as the most preferred scenario.

In the derivation of the local priorities it is observed that the CM exceeds 0.2 in three of the six matrices, which can introduce error in the final results. In order to overcome this error, this research conducts MCDA three times. This method of eliminating error is explained in the later sections.

3.5.3 MCDA Application in This Research

In order to obtain the final results, MCDA will be used three times in this research. In the first MCDA (MCDA 1) different groups of local stakeholders are asked to be decision makers. They are asked to undergo the AHP process as detailed in the previous section, using their experiences and judgments, and in this way, their preferred scenario will be identified. The stakeholders involved in MCDA 1 will be local academics, local NGOs, the government electricity company PT PLN, the local government and the local population. The main purpose of MCDA 1 is to elicit weights for each criteria and sub-criteria according to each group of stakeholders, which will be used for further analysis in the final MCDA (MCDA 3).

While the MCDA 1 uses the experience and judgment of the stakeholders it may lack scientific analysis using the latest available data. To include more objective analysis, in the second MCDA (MCDA 2) the author will act as the decision maker and equal weighting will be given to each criterion and sub-criterion. In MCDA 2 equal weighting is used since there is a lack of sufficient knowledge of causal relationships. Also, MCDA 2 is treated as independent from MCDA 1, and so there is a lack of consensus on alternative solutions, making the use of equal weighting appropriate. The impact of equal weighting on the indicator also depends on whether equal weights are applied to single indicators or to criteria (which may group different number of indicators). To overcome these obstacles, equal weights are applied to each criterion and sub-criterion.

Primary and secondary data, obtained from literature survey and interviews with stakeholders, is used to analyze each sub-criterion for its contribution to each alternative. The identification of the preferred scenario, according to the local stakeholders, accomplished in MCDA 1 will provide the numerical value to the Public Approval sub-criterion. This process is shown in figure 3.5.3.1.

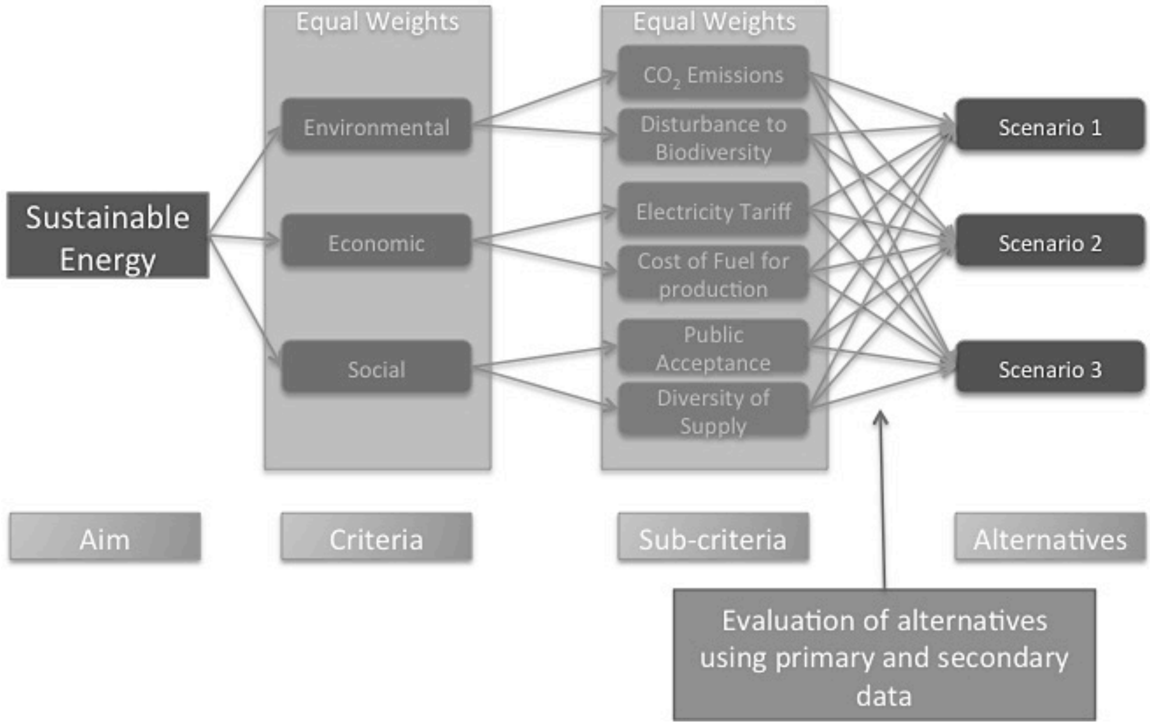


Figure 3.5.3.1 MCDA 1 conducted by author as decision maker using equal weights for each level of criteria and sub-criteria

Image source: Made by author

While the MCDA 1 may lack scientific data, MCDA 2 lacks stakeholder input and judgment. To overcome the shortcomings of both the previous MCDAs the final MCDA 3 is conducted where the weights elicited in the MCDA 1, according to the preference of the local stakeholders, will be directly attributed to the criteria and sub-criteria in place of pairwise comparisons. Using AHP, these weights are used in conjunction with the analysis conducted using scientific data by the author in MCDA 2 earlier to provide the final results. This process is illustrated in figure 3.5.3.2

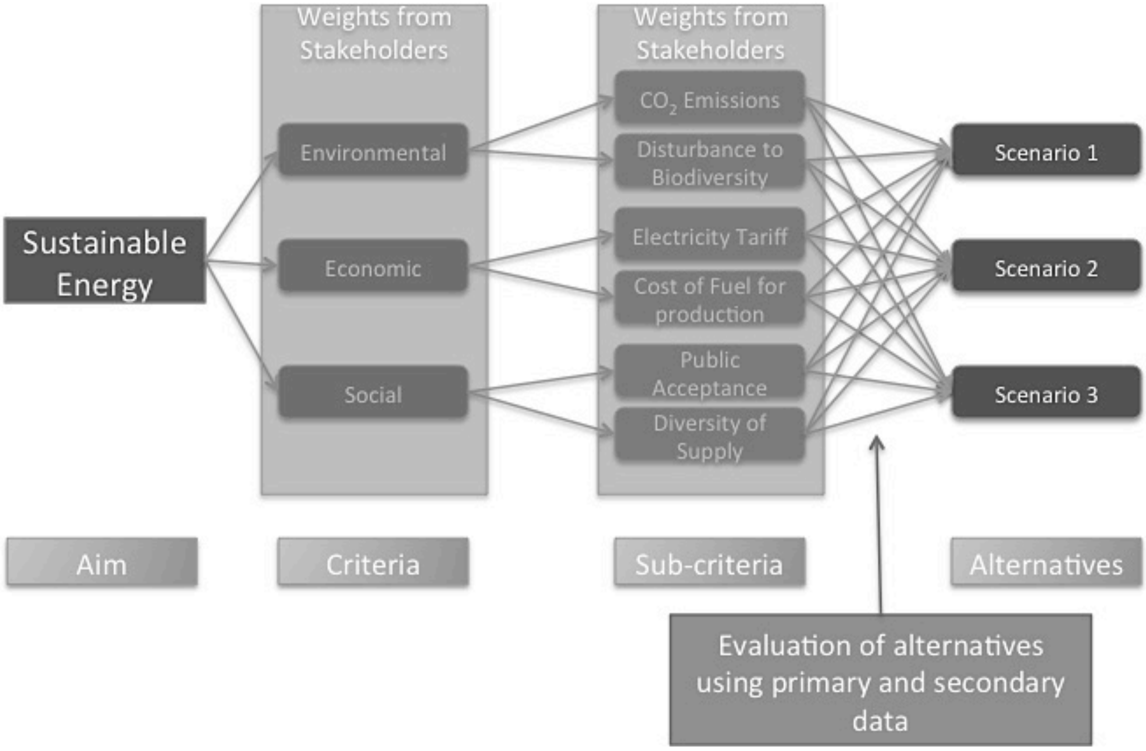


Figure 3.5.3.2 MCDA 3 conducted by author as decision maker using weights elicited from stakeholders in MCDA 1 for each level of criteria and sub-criteria

Image source: Made by author

In this manner three MCDA methods will be used to combine relevant sources of data along with stakeholder insight after assessing the potential environmental, economic and social impacts of each scenario to arrive at the most appropriate alternative for the future sustainable energy source. The three MCDAs will give point out the importance of stakeholder input or scientific analysis. Comparisons between the results of all the three MCDAs will also show the most important criteria and sub-criteria and how they affect the final results.

3.5.4 Expected Results From Analysis Using Scientific Data

Scientific data obtained from literature survey, interviews, or MCDA 1 will be used to assess each indicator. The following sections will look at the data used by each indicator and the expected results based on the three scenarios.

3.5.4.1 CO_2 Emissions

Flores Timur Regency used 560,112 ltr of diesel in September 2014 to feed its generators, according to data provided by the government electricity company PT PLN. This adds up an average annual consumption of 6,721,344 ltr of diesel to generate electricity in Flores Timur Regency. For feeding its 6 MW future demand, as per scenario 1, it will need 13,442,688 ltr of diesel. Diesel generators typically produce 3.15 kgCO_2/ltr of fuel used (Dufo-Lopez et al., 2011). So if the entire 6 MW capacity in future comprises of only diesel generators, the emissions will total an estimated 42,244,467 kgCO_2. MCEG, meanwhile, produces no emission in its entire operation. There may be some emissions during its manufacturing and maintenance processes, but these are negligible compared to the emissions from diesel power plants. Scenario 2, where the capacity is shared between diesel generators and MCEG, will produce an estimated 21,172,234 kg of CO_2 emissions. Scenario 3 with entire power coming from MCEG will produce no emissions during its operation. Hence as far as CO_2 Emissions are concerned scenario 3 is highly favorable to scenario 1, with scenario 2 in between.

3.5.4.2 Disturbance to Bio-Diversity

Discounting the effects of emissions, which were covered above, the effect of the different energy scenarios on the surrounding bio-diversity in case of Flores Timur Regency is not potentially widespread. The diesel power plants in Flores Timur Regency are not situated in places that are high in biodiversity. Observation of a typical power plant was conducted in October 2014 to identify the potential effects of the power plant on the local surroundings. The bio-diversity in the areas around the power plant is representative of the regency. While expanding the power plant to accommodate the extra capacity mentioned in scenario 1 may create some disturbances, it may not have extreme impacts. Scenario 3 proposes the addition of four to six turbines in Larantuka strait. As discussed earlier MCEG has not been found to have negative effects on the surrounding bio-diversity based on the cases of the UK, the US and Canada. However the conditions in Indonesia are completely different these experiences, making the potential impact less certain. Moreover the testing was conducted using only one device, so the effect of four to six devices, rather than a single device, could be different. So one cannot say that scenario 3 is favorable to scenario 1, in regard to environmental effects in the case of Flores Timur Regency, as there is no scientific data to prove that currently. Environmental monitoring of the area has to be conducted before ascertaining it as a better option. Scenario 2 could be a favorable option, as no expansion of diesel power plant is necessary while the number of turbines will be limited to two or three. However this situation will also have to be ascertained by monitoring the waters of Larantuka strait. Because of these reasons, none of the scenarios can be decisively deemed as overwhelmingly favorable.

3.5.4.3 Electricity Tariff

According to the information provided by PT PLN officials, the people of Larantuka pay an electricity tariff of 938.48 Rupiah/kWh or about 7 US cent/kWh. This is more than three times as favorable to the around 23 US cent electricity tariff for MCEG as estimated by the IEA for MCEG. Hence scenario 1 is three times more favorable than scenario 3 in terms of tariffs. Scenario 2, where the tariff would be around 15 US cent, based on the mean of the tariffs for both the technologies, may be more favorable compared to scenario 3. Though the tariff for MCEG could be subsidized or reduced in the future to the level of the tariff from diesel generators, no consideration is given to this possible occurrence, as at present there is no certainty in the possibility. Similarly, the subsidies to diesel energy could be cut and diesel energy may become more expensive in future. However, the situation as it stands currently is used in this research while avoiding future tariff scenarios. Hence scenario 1 is the most preferred scenario, with scenario 2 following it, while scenario 3 is three times less preferred to scenario 1.

3.5.4.4 Cost of Fuel for Production

In 2014, the cost of diesel fuel in Indonesia was 0.62 USD (World Bank, 2015). Considering that an estimated 13,442,688 liters of fuel is required annually to feed the 6MW diesel generators, it could cost 8,334,467 USD just to procure the necessary fuel for scenario 1, making scenario 1 an expensive option. In scenario 2, 6,721,344 liters of fuel will be used leading to a cost of 4,167,233 USD. Scenario 3 will use tidal currents, requiring no money to be spent on fuels. Hence scenario 3 is the extremely favorable option compared to the others, especially scenario 1, when considering the cost of fuel for production.

3.5.4.5 Public Acceptance

In MCDA 1 conducted earlier using stakeholders experience and judgment, it was clearly visible that the stakeholders not only accepted MCEG but also preferred it to the present method of generating electricity. The mean of MCDA 1 results from all the stakeholder groups will be used here to calculate the public acceptance for each of the three scenarios. An example of the type of data to be used is presented in table 3.5.4.5.1.

Table 3.5.4.5.1 Example of MCDA 1 results from all stakeholder groups for preference of the scenarios

Source: Made by author

Scenario	Scenario 1	Scenario 2	Scenario 3
Preference (%)	18.06	36.26	45.68

According to this example, scenario 3 is 2.5 times as preferred to scenario 1 and 1.25 times more preferred to scenario 2. Scenario 2 is twice as preferred as scenario 1. These exemplar results can be taken as an indication of public acceptance for conducting MCDA 3.

3.5.4.6 Security and Diversity of Supply

With the increasing demand for energy and the decrease in the availability of conventional sources of energy, it is essential, for sustainable development, to secure and diversify the energy resources. Oil is a finite quantity and is not a secure solution for energy production in the long term. Global fluctuations in the oil prices can affect the security of the energy supply, making scenario 1 consisting of only diesel generators unfavorable. Scenario 3 is a renewable resource, but leaves no back-up supply of electricity in case of a breakdown. Scenario 2 is ideal for this indicator and better than scenarios 1 and 3 as it is not overly reliant on only one source of energy and can provide electricity resilience in the case of extreme events, such as a global shock in oil prices or complete breakdown of the turbines.

4. Results and Discussion

The results and their related discussions are divided in two parts:

[1] Results from interviews, focus group discussions, and literature survey to identify the potential impacts of MCEG for sustainability assessment

[2] MCDA results, after considering the potential impacts, identifying the most appropriate outcome for future electricity generation in Flores Timur Regency

4.1 Potential Impacts of MCEG

Interviews and group discussions, along with literature survey have been used to investigate the potential impacts of the technologies in discussion here. The impacts of MCEG in Indonesia can only be termed as potential impacts as this technology has not yet been implemented on a commercial scale. In this research, the potential environmental, economic, and social impacts of MCEG are investigated. Potential environmental impacts include the effects on the marine mammals and corals, while possible economic impacts include the changes in the local economy and tourism, and changes in lifestyle and lack of public acceptance are potential social impacts.

4.1.1 Potential Impacts of MCEG Based on Literature Survey of Documents Provided by the Local Government

There are possible environmental impacts of MCEG on seaweed cultivation in Larantuka strait, which could also have an economic impact. The seaweed cultivation area is highlighted in green in map of aquaculture utilization areas shown in appendix 1. The diverse biota found in this area can also be impacted by MCEG. According to this map provided by the government, appendix 2, turtles are found in the Larantuka strait with their nesting sites found along the coastline at both the northern and southern ends. Whales are also found in the strait and dolphins can be seen in the nearby waters. With such biodiversity Flores Timur Regency has proposed a marine conservation area in the regency in future, which would normally make the installation of turbines impossible within this proposed conservation area. However Larantuka strait is excluded from this proposed conservation area, as shown in appendix 3, thereby making Larantuka strait a possible location for MCEG regardless of future conservation developments.

Appendix 4 details the major fishing operation in Flores Timur Regency. While there are no major fishing operations in Larantuka strait, there is traditional artisanal fishing practiced still here. The traditional fishing areas are shown in appendix 5. In addition to artisanal fishing, there are also some destructive fishing methods practiced in Larantuka strait. Explosives and toxic chemicals continue to be used even though these methods are illegal. The areas notorious for the use of destructive fishing methods are shown in appendix 6. Turbine installation in these fishing areas may restrict fishermen access, leading to a negative economic impact. There are also some areas in Larantuka strait that are used for tourism purposes, especially for diving, and turbine installation at these areas may impact the tourism economy negatively. The diving areas and the potential diving areas are shown if appendix 7. Though Larantuka strait does not host any major shipping routes, there is a small port in Larantuka city that serves the region and a small amount of ships that pass through the strait to get to the port. The shipping routes of Flores Timur Regency are shown in figure appendix 8. If turbines have any effect on the shipping operations there can be resulting indirect social and economic impacts. However the government has mentioned plans to move the port from its current location in Larantuka to the opposite side of the island, thereby rerouting ship routes away from the strait, omitting the possibilities of negative impacts.

4.1.2 Environmental Impacts of MCEG Based on Literature Survey of MCEG Testing at Various Locations

MCEG turbines have been installed and tested at various locations in the world, such as the UK, the US and Canada. This section will look at the results from previous tidal power environmental monitoring reports to understand the actual impacts of MCEG. Three MCEG projects are discussed in this chapter: SeaGen in Northern Ireland (UK), OpenHydro in Nova Scotia (Canada), and TidGen in Maine (US).

The SeaGen Environmental Monitoring Program (EMP) followed one device with a generation capacity of 2 MW for a period of three years from 2008 to 2011, observing its impact on the marine mammals, benthic ecology and the tidal current flow. Analysis of the data collected during the EMP showed no major impacts of MCEG on the marine mammals. Though there was an initial decline in the number of porpoises during the installation process, no long-term changes in porpoise and seal populations could be attributed to the presence or operation of the turbine. In addition, seals and porpoises were observed to be regularly swimming past the turbine, thereby showing an absence of any barrier effect. The overall number of birds in the vicinity remained stable as well. Changes in the benthic ecology were found to be gradual and in line with natural variation. The tidal flow, measured using Acoustic Doppler Current Profiling (ADCP) showed no significant change in velocity or direction of flow following the installation of the turbine.

OpenHydro environmental monitoring was conducted for around 18 months between 2009 and 2011, observing one turbine of 1 MW generation capacity. While this program did not aim to measure the changes to the tidal current, it observed the impacts of the turbine on seabirds, waterfowls, lobsters, fishes and marine mammals. There were no significant impacts found on any of the species monitored. The turbine was successfully deployed and then recovered without any bio-fouling or other significant damages.

The environmental monitoring program for TidGen is an on-going project in Maine (US), which started in 2012 using one turbine of 150 kW generation capacity. No evidence of any collision between the marine mammals and the turbine were observed. The acoustic impacts were observed to have not exceeded the regulatory levels found to be disturbing to marine mammals. There was also no evidence found pointing towards any disturbance to the benthic ecology, and the seabed characteristics were found to be unchanged. Sea and shorebirds were also unaffected.

While the above three examples of MCEG showed no negative environmental impacts, there is still no evidence that MCEG in Larantuka strait will return the same results. Larantuka strait is situated in tropical waters, composed of a completely different marine environment that the previous studies. Thorough monitoring based on the specific environmental conditions of Larantuka with high importance given to every flora and fauna species is incredibly important for the success of MCEG here.

4.1.3 Potential Environmental Impacts of MCEG Based on Stakeholder Opinion

According to the government officials MCEG may not negatively impact the environment, but may actually positively impact the environment. Corals have recently depleted in Larantuka strait due to destructive fishing methods of dynamite bombing. If MCEG turbines are installed on the sea floor, the foundations of the turbine structures can provide new habitat for coral growth, and could lead to the revitalization of coral populations. The general population also sees no negative impacts of MCEG on the marine environment.

The NGOs and the academics however are not as optimistic as the government officials and general public. Academics from the Faculty of Marine Science and Fisheries from Nusa Cendana University feel that the seaweed cultivation can be affected if the characteristics of currents change due to the operation of the turbines. They also feel that the metabolism of fish can also be affected due to the same reason. There could be other impacts on marine life too according to these stakeholders. Academics and NGO workers pointed out that Larantuka strait is a path for whale migration and that around 18 species of whales, including blue whales, are found in the surrounding seas. There are also dolphins, turtles and dugongs found in the nearby areas. If these mammals move in groups through the narrow straits with large turbine structures, academics and NGO workers feel that collisions can occur. Their prime concern however is the sound of the turbines during their installation, operation and maintenance. As many mammals depend on sonar waves for navigation, the turbine noises could interfere with these sonar waves and cause mammals to lose their sense of direction and become stranded. Academics and NGO workers believe that the turbine structures can act as barriers and create a sound wall, which may eventually lead to the mammals avoiding the strait altogether. They stress that the larger the size and the greater the number of turbines, the greater these impacts could be.

4.1.4 Potential Economic Impacts of MCEG Based on Stakeholder Opinion

According to all the stakeholders, 3 MW of additional electricity will have a positive impact on the local living conditions. The government stresses that eco-tourism development can be extensively aided by cleanly produced electricity, and that clean energy will positively impact the economy. The government as well as the academia believes that more electricity can also help in the development of small industries, such as mechanical and carpentry workshops. The owner of the biggest private company in Flores Timur Regency, Okishin Flores Fishing Company, pointed out that large-scale industries may not operate in the regency due to the lack of resources. However, smaller businesses, such as cashew nut, areca nut and coconut processing businesses can are thought to have the potential to thrive. Academics from Nusa Cendana University also believe that clean energy development will lead to new opportunities for women. Women, who are currently mostly housewives, can help the economy by making traditional fabrics unique to the area, using electrically operated machines. The local people also envisioned some benefits for the fishermen, as currently many fishermen are forced to discard the extra fish, but with more availably electricity, will be able to freeze and process the fish.

Academics from the social sciences, however, warned that people might reject MCEG if the electricity tariff from MCEG is more than the present tariff for electricity from diesel generators. The cost of energy from initial tidal current farms has been estimated in the range of US$0.11–0.22 per kWh (Esteban and Leary, 2011). The latest estimated figures from Ocean Energy Systems (OES), a part of International Energy Agency (IEA) are shown in the table 4.1.4.1.

Table 4.1.4.1 Estimated cost of MCEG based on deployment stage and capacity

Source: Made by author based on data from International Levelised Cost Of Energy (LCOE) for Ocean Energy Technologies, a study by OES

Deployment Stage	Variable	Minimum	Maximum
First Array	Project Capacity (MW)	0.3	10
Second Array	Project Capacity (MW)	0.5	28
	Tariff ($/kWh)	0.21	0.47
Commercial Scale Project	Project Capacity (MW)	3	90
	Tariff ($/kWh)	0.13	0.28

Currently Flores Timur uses electricity generated from diesel, which is imported from Surabaya city by two ships every fortnight. While the present electricity tariff in Flores Timur is US$0.07 per kWh, the production cost is much higher at US$0.23 per kWh with the remaining cost subsidized by the government. Government officials say that MCEG may have to depend on government subsidy or a relatively higher Feed-in Tariff (FIT), for the initial years at least, to provide electricity at an affordable price that can compete with the current prices for electricity produced by diesel generators.

4.1.5 Potential Social Impacts of MCEG Based on Stakeholder Opinion

Local academics stress that more electricity can reduce the number of isolated areas and improve social connectivity among the people. According to academics from the faculty of business and economics, Flores Timur Regency has one of the highest rates of migration of people to neighboring foreign countries of Malaysia and Singapore, a phenomenon that can be curbed with local economic development. The government points out that if rural areas can sustain life in their communities, the huge flow of people from rural areas into the urban areas can be stopped. Regardless of this potential for development, most of the stakeholders expressed concern that the local fishermen can be impacted negatively if they are not allowed to fish in certain areas near the turbines. However, during the interviews, all the fishermen expressed no concerns and were willing to fish in other areas if the whole community benefits from MCEG.

While the government and locals foresee mostly positive social impacts, the NGO and Academics could cite some possible negative impacts. If the project has a conflict of interest with locals, locals may cause damage to the project. Academics from the faculty of science and engineering mentioned a case in the past when some locals vandalized a wind energy project in the province, as the project was affecting a local fossil fuel importing business. If local people are not sensitized properly about the MCEG project they may reject the project completely, rendering all efforts useless. Social scientists from Nusa Cendana University evidenced this previously when locals rejected a coal power plant project in the province, which was built for the direct benefit of locals as they were not provided with the necessary awareness regarding the project. The necessity of sensitization can also be seen in a past solar photo-voltaic (PV) project in the area. Due to lack of knowledge about the use and maintenance of solar panels, many solar panels now lie in a dilapidated state. The unintended effects of potential change in lifestyle that increased electricity can bring are another issue stressed by the social scientists. People in Flores Timur lead a very simple and traditional life, going to bed early and waking up early. Academics state that additional electricity can lead to changing lifestyle patterns, such as people staying up later at night, increased alcohol consumption, and even loss of traditions. Another interesting impact envisioned by the social scientists during the interview dealt with the presence of certain communities in the regency that have based their traditions and lifestyles on whales for centuries. They practice sustainable fishing of whales – not more than 6 whales every year – and use every part of the whale for their sustenance. If the MCEG project causes disturbances to whale behavior, the local wisdom and traditions of the whole communities can be affected indirectly.

4.2 Results of MCDA 1

After considering the potential impacts of additional electricity for the regency, it is necessary to select the best scenario for future electricity generation. MCDA using AHP is an ideal way of making that decision. AHP is not a statistically based methodology and a ‘sample size’ of one is enough to implement the AHP methodology (Duke et al., 2002). AHP was originally developed to enable a single decision maker to select an alternative among multiple choices. The methodology has since been extended to enable the use of AHP in group decision making where the ‘single’ decision maker is actually a group of N people. In this research AHP is conducted with five different stakeholder groups. The number of participants in each of the stakeholder group is presented in table 4.2.1.

Table 4.2.1 Number of participants from each stakeholder group

Source: Made by author

Stakeholder	Number of Participants
Academia	8
NGO	3
PT PLN Electricity Company	2
Local Government	10
Local Population	100

For the selection of a sample group, the key issue is not whether there are enough observations for using AHP but whether there are enough observations in the sample to accurately represent the group of stakeholders. Academics from different faculties act as decision makers to accommodate the variety of opinions. Government officers from six different departments participated in MCDA 1 to gather the diverse views.

In the context of this research, the ideal ‘group’ to represent the local population would be all residents of Flores Timur. Population demographics according to occupation and sex provided by the local government is used in this research to get an accurate representation of the people of Flores Timur. The composition of the population of Flores Timur Regency is presented in table 4.2.2.

Table 4.2.2 Population composition of Flores Timur Regency according to occupation and sex

Source: Flores Timur in Figures, BPS Statistics of Flores Timur Regency 2012

Occupation	Male (%)	Female (%)
Self-employed	12.54	16.26
Self-employed with family assistance	45.03	18.59
Employer	2.06	0.35
Employee	17.86	16.65
Agricultural worker	1.94	0.50
Unpaid worker	20.21	47.44

MCDA has been applied to this research using the web-HIPRE software designed by Aalto University, Finland. The results for each group of stakeholders through MCDA 1 are presented in the following sections.

4.2.1 Academia

Public Acceptance and Disturbance to Bio-Diversity are the two indicators given the most importance by the academics while Electricity Tariff is considered the least important indicator. The academics also consider scenario 3 (only MCEG) as the most appropriate scenario for future electricity generation; it is more than twice as preferred as the next alternative, which is scenario 2 (electricity from diesel and MCEG combination). Scenario 1, where all electricity comes from diesel, is the least preferred option.

The results denoting the most important indicators and the most preferred scenario according to the academia from Nusa Cendana University are shown in figure 4.2.1.1.

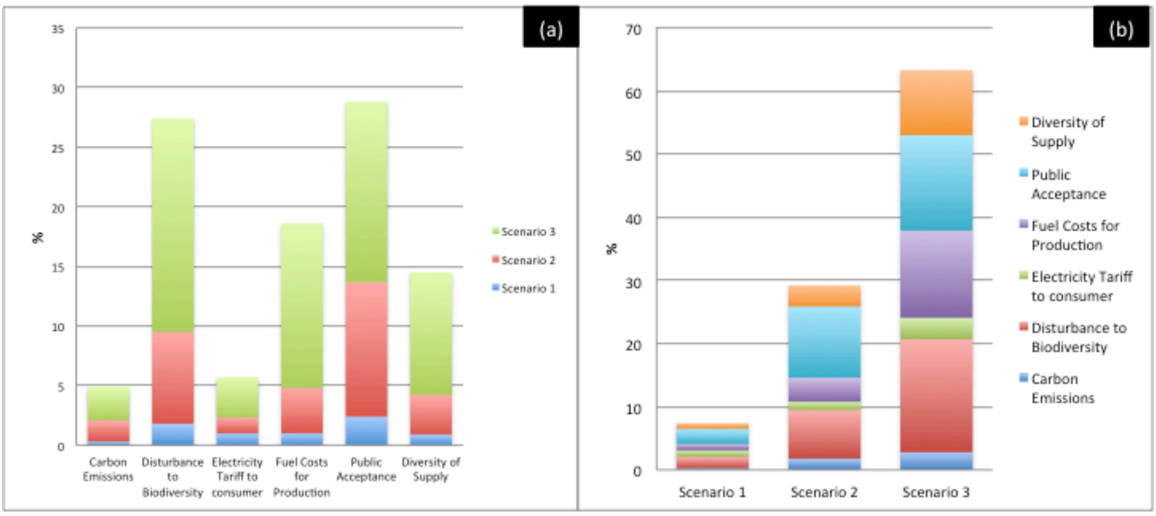


Figure 4.2.1.1 (a) Importance of sustainability indicators according to the academics (b) Scenario preferences for future electricity generation according to the academics

Source: Made by author

4.2.2 NGOs

Public Acceptance is the most important indicator for the NGO workers followed by Carbon Emissions. Electricity Tariff is of least importance to them. NGOs are unique among the different stakeholders groups because they have almost equal preference for scenario 3 (only MCEG) and scenario 2 (diesel and MCEG combination). Scenario 1 consisting of only diesel electricity is the least preferred option.

Figure 4.2.2.1 shows the results for the NGOs indicating the most important indicators and the scenario preferences for future electricity generation.

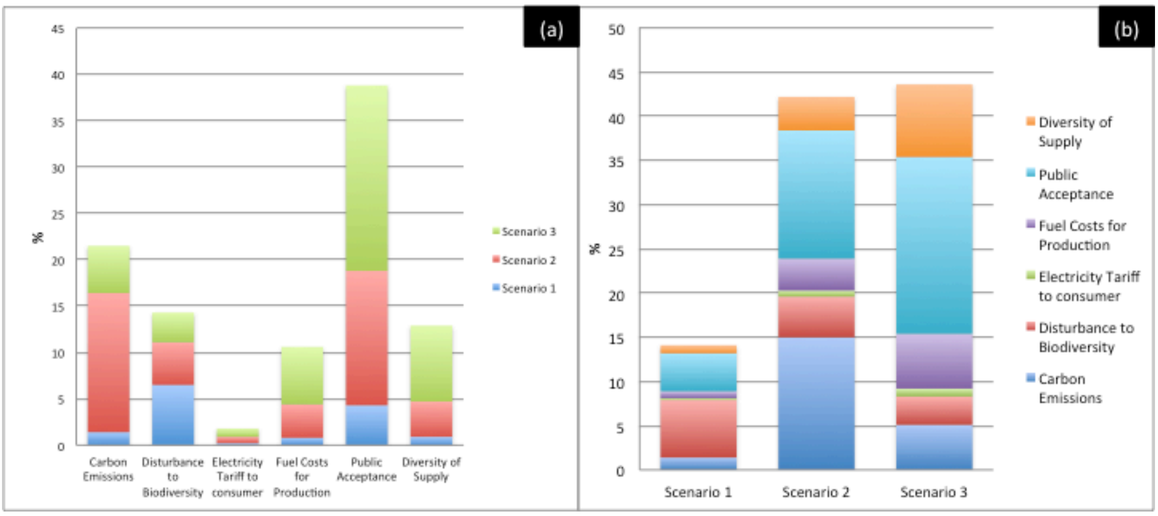


Figure 4.2.2.1 (a) Importance of sustainability indicators according to the NGOs (b) Scenario preferences for future electricity generation according to the NGOs

Source: Made by author

4.2.3 PT PLN Electricity Company

Officials from the government-owned electricity company PT PLN give high and equal importance to both the social indicators – Public Acceptance and Security and Diversity of Supply – closely followed by Disturbance to Bio-Diversity. Electricity Tariff is the least important criteria for PT PLN officials. Amongst all of the stakeholder groups, PT PLN have expressed the highest preference for scenario 3 (only MCEG) and the lowest preference for scenario 1 (only diesel).

The electricity company PT PLN's most preferred scenario and the most important indicator are illustrated in figure 4.2.3.1.

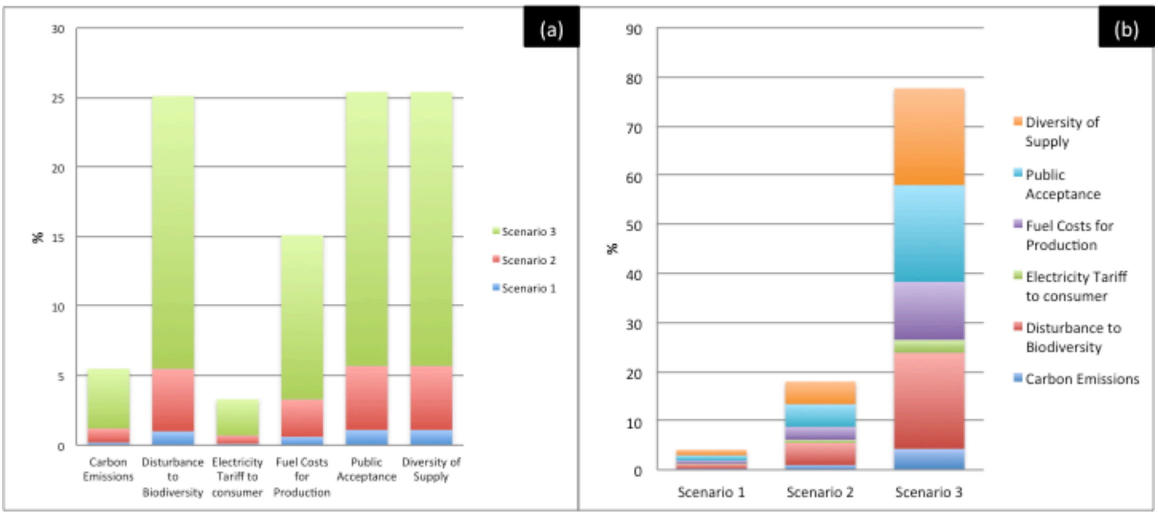


Figure 4.2.3.1 (a) Importance of sustainability indicators according to the government electricity company PT PLN (b) Scenario preferences for future electricity generation according to the government electricity company PT PLN

Source: Made by author

4.2.4 Local Government

The local government prioritizes Electricity Tariff as the most important indicator for sustainable energy followed by Fuel Costs for Production and Disturbance to Biodiversity. Security and Diversity of Supply is of least importance. Like most of the other stakeholder groups, their preference for scenario 3 (only MCEG) is quite high while scenario 1 (only diesel) is the least preferred.

The importance of various indicators and preferences for the scenarios according to the local government are shown in figure 4.2.4.1.

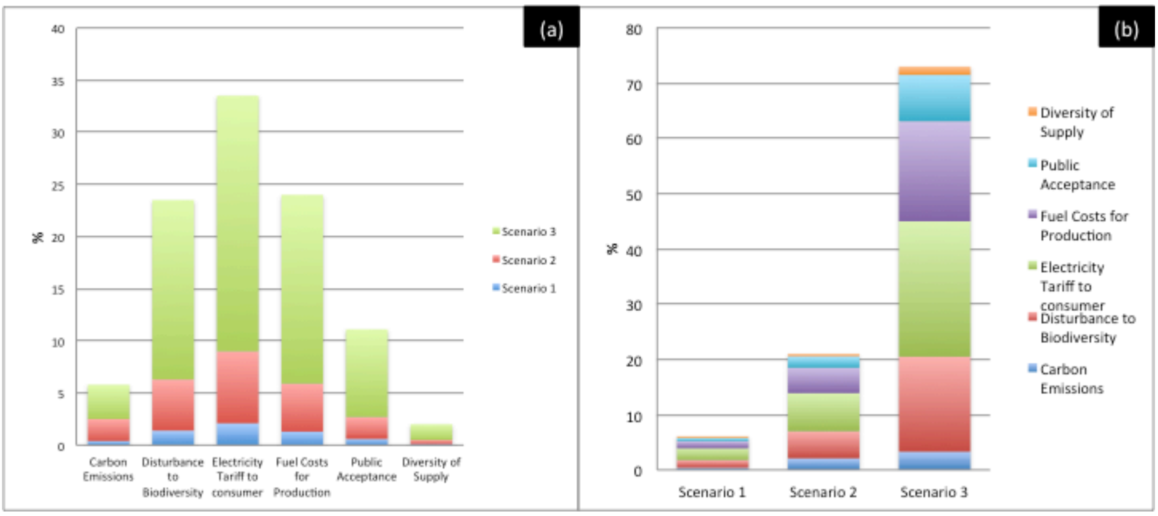


Figure 4.2.4.1 (a) Importance of sustainability indicators according to the local government (b) Scenario preferences for future electricity generation according to the local government

Source: Made by author

4.2.5 Local Population

The local population considers Disturbance to Bio-Diversity as the most important criteria, with Electricity Tariff a close second. They rank Diversity of Supply as the least important indicator. The local population clearly prefers scenario 3 for their future energy generation. Though the local population does not favor scenario 2 very highly, they still prefer it twice as much as scenario 1.

The results for the most important indicator and the most preferred scenario according the to the local population are shown in figure 4.2.5.1.

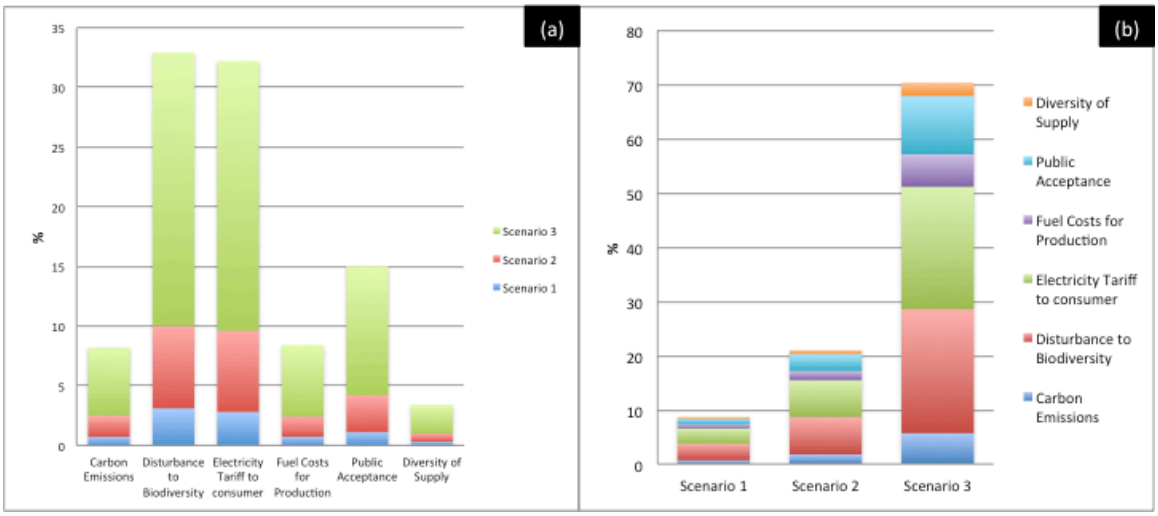


Figure 4.2.5.1 (a) Importance of sustainability indicators according to the local population (b) Scenario preferences for future electricity generation according tot he local population

Source: Made by author

All the above results show a CM greater than 0.2, which necessitates MCDA 2 and MCDA 3 to rectify the error.

4.3 Results from MCDA 2

MCDA 1 using stakeholders' experience and judgment effectively captured the public opinion. However the results from MCDA 1 lack analysis using scientific data. For this reason the author acts as a decision maker and objectively conducts another MCDA (MCDA 2). In MCDA 2 all the criteria are considered equal, setting environmental, economic and social aspects to be of equal importance for sustainable energy. All of the related sub-criteria, the six indicators, are also considered to be of equal importance. With the weights set equally, the best alternative, based on each of the indicators, is obtained using scientific data.

The result showing the most preferred scenario for future electricity generation derived from MCDA 2 with the author as the decision maker is shown in figure 4.3.7.1.

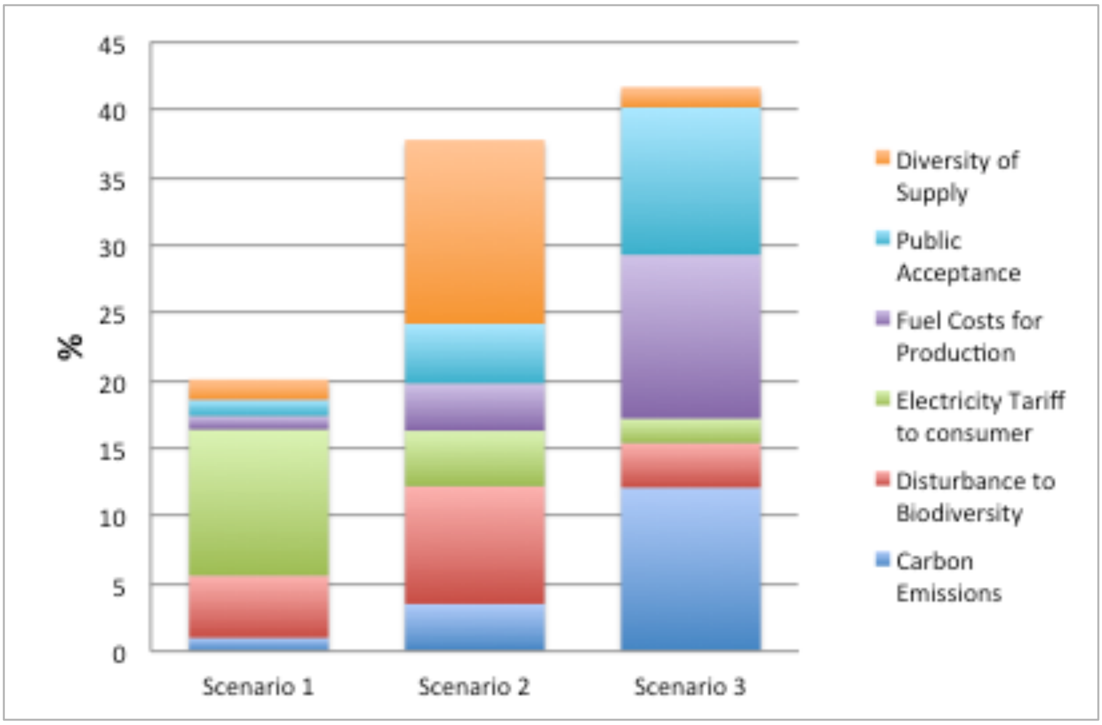


Figure 4.3.1.1 Scenario preferences for future electricity generation derived from MCDA 2 with the author as decision maker

Source: Made by author

As shown in the figure 4.3.1.1, the most preferred scenario for future electricity generation is scenario 3 at 42% preference. Scenario 2 follows with 38 % preference and scenario 1 has 20% preference. Scenario 3 is highly preferred mainly because it is devoid of any emissions as well as requiring no costs for fuel. High public acceptance also helped in the selection of scenario 3. Scenario 2 is desired for its better performance for the Security and Diversity of Supply and Disturbance to Bio-Diversity indicators. Scenario 1 performs poorly on most indicators except the Electricity Tariff indicator. It can be seen from the results that the scenarios are in the same order of preference as those derived by the stakeholder groups in MCDA 1, however the degree of preferences is different.

4.4 Results from MCDA 3

MCDA 2 is conducted using equal weights for every criteria and sub-criteria, which is ideal for sustainability. However, in reality, the importance of each criterion is not the same for the stakeholders. While some stakeholders might consider the environment to be of prime importance, others might think the economy deserves more weight. It is for this reason that the final MCDA 3 involves combining the previous two methods. The results of MCDA 1 will be used to define the weights of each criterion and sub-criterion. The objective analysis conducted earlier for MCDA 2 will be employed again in MCDA 3. In this way, using the weights provided by stakeholders and combining it with objective analysis, a final decision that is both scientific and captures the voice of the people, can be reached.

The weights extracted from the stakeholder groups for each criterion using AHP are shown in table 4.4.1

Table 4.4.1 Weights extracted from stakeholder groups for each criterion using AHP

Source: Made by author

Criteria	Weight (%)				
	Academia	NGO	PT PLN	Local Government	Local Population
Environmental	32.3	35.9	30.6	29.3	41
Economic	24.3	12.4	18.6	57.5	40.7
Social	43.4	51.7	50.8	13.2	18.3

Table 4.4.2 shows the weights extracted from the stakeholder groups for each sub-criterion using AHP.

Table 4.4.2 Weights extracted from stakeholder groups for each sub-criterion using AHP

Source: Made by author

Sub-criteria	Weight (%)				
	Academia	NGO	PT PLN	Local Government	Local Population
CO_2 Emissions	4.9	21.6	5.5	5.8	8.1
Disturbance to Bio-diversity	27.4	14.3	25.1	23.5	32.9
Electricity Tariff	5.7	1.8	3.4	33.5	32.3
Fuel Cost for Production	18.6	10.6	15.2	24	8.4
Public Acceptance	28.9	38.8	25.4	11.2	15
Security and Diversity of Supply	14.5	12.9	25.4	2	3.3

Using these weights from MCDA 1 as shown in table 4.4.1 and table 4.4.2, and the analysis using scientific data from MCDA 2, the final results are derived. These results are shown in figure 4.4.2.1.

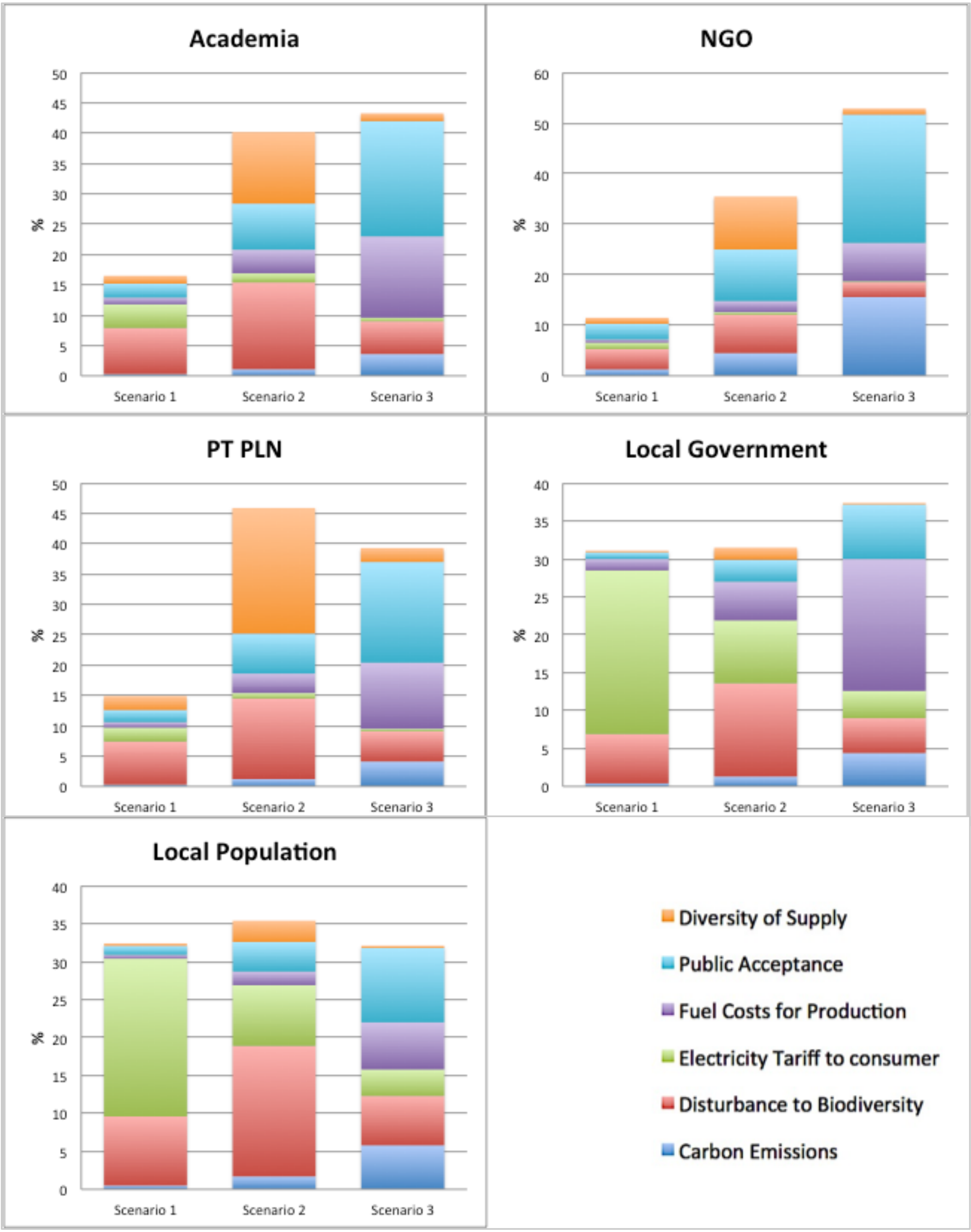


Figure 4.4.2.1 Final result showing the scenario preferences derived from MCDA 3 using stakeholder weights and scientific data

Source: Made by author

These results from MCDA 3 show that majority of the groups prefer scenario 3 for future electricity generation. However two groups show a preference for scenario 2, which is a mix of electricity from diesel generators and MCEG. This result is different from MCDA 1 and MCDA 2 where scenario 3 was always the most preferred scenario. Scenario 1, however, remains as the least preferred option for all the stakeholder groups, as it was in MCDA 1 and MCDA 2.

4.5 Discussion of the Results From MCDA 3

The discussion related to these final set of results from MCDA 3 and their significance follows in the next sections.

4.5.1 Influence of the Criteria and Sub-Criteria

Both the criteria and sub-criteria, and their weighting, have major influence on the final results. This section will look at the influence of the particular criteria and sub-criteria for each group of stakeholders and how these indicators lead to the final results.

4.5.1.1 Academia

The academics prefer scenario 3 by 43.3% compared to 40.2% preference for scenario 2 and 16.5 % preference for scenario 1. According to the academics, social factors have 43.3% importance compared to 32.2% importance for economic aspects. Economic factors with 24.4% importance are considered the least important factor. The preferences of academia for the future electricity generation scenarios can be seen in figure 4.5.1.1.1.

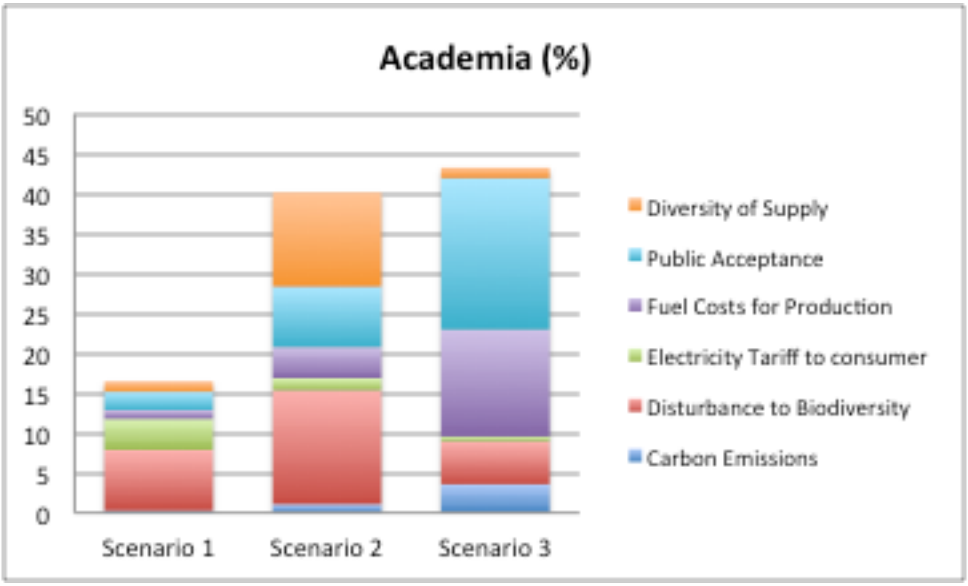


Figure 4.5.1.1.1 Scenario preferences for future electricity generation according to the academia

Source: Made by author

The high public acceptance rate for scenario 3 is the driving factor that led the academics to choose scenario 3 as their preferred choice. Cost of fuel for production is the second highest contributor towards the selection of scenario 3. Electricity from diesel generators is comparatively cheaper and hence scenario 1 should have an advantage. However, electricity tariff is of very low importance to the academics the preference for scenario 1 remains very low. Disturbance to Bio-Diversity is the second most important sub-criterion for this group of stakeholders. Since the disturbance to bio-diversity is relatively unknown for scenario 3, it is not the overwhelmingly preferred result in terms of this indicator. As social aspects are considered the most important for academics, Security and Diversity of Supply – a social indicator – helps scenario 2 gain more prominence. A better performance of the sub-criterion Disturbance to Bio-diversity also aids in the high preference for scenario 2 than scenario 3. Scenario 1 fares inadequately in all the social and environmental factors and hence is very low in preference amongst the academics. Carbon Emissions, one of the biggest drivers for renewable energy, unfortunately, are not considered very important by the academics. If the significance of emissions is realized, the preference for scenario 3 will increase greatly amongst the academics. The preference for scenario 2 will also improve to some extent when placing greater emphasis on emissions.

4.5.1.2 NGOs

The preferences for future electricity generation scenarios for the NGO are shown in figure 4.5.1.2.1.

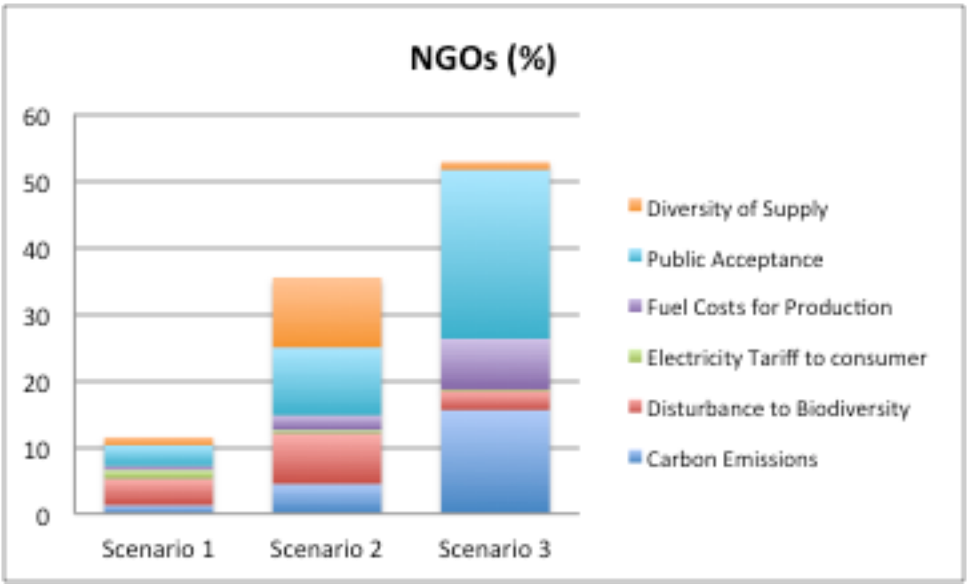


Figure 4.5.1.2.1 Scenario preferences for future electricity generation according to the NGOs

Source: Made by author

NGOs have the highest preference for scenario 3 at 52.8% followed by scenario 2

(35.6%) and scenario 1 (11.6%). The NGO officials consider social aspects (51.5%) to be more than four times as important as economic aspects (12.4%). Also the environmental factors (36.1%) are nearly three times more important than the economic factors. The preference of scenario 3 amongst NGO officials is mainly due to the high importance placed on the Public Acceptance and Carbon Emissions indicators, amplified by the high importance given to the social and environmental criteria. Though scenario 3 reflects poorly on the Electricity Tariff sub-criterion, its impact is low due to the low importance NGO officials place on economic aspects for the NGO officials. However, despite the low importance attributed to economic aspects, the Fuel Costs for Production make a contribution to scenario 3 gaining the highest preference amongst NGO officials. Scenario 2 is helped by the sub-criterions Public Acceptance, Diversity of Supply, and Disturbance to Bio-diversity to gain second place in preference. Scenario 1 fares poorly in all the indicators, making it the least preferable option.

4.5.1.3 Electricity Company PT PLN

Scenario 2 is the most preferred scenario for this group of stakeholders, at 45.8% preference. Scenario 3, at 39.3%, and scenario 1, at 14.9%, follow. Like the academics and the NGO officials, the representatives of the electricity company also consider social aspects (50.5%) to be of most importance. Environmental factors at 31% importance are the second most important followed by economic factors at 18.5% importance. Figure 4.5.1.3.1 shows scenario preferences of the officials representing the energy company PT PLN for future electricity generation.

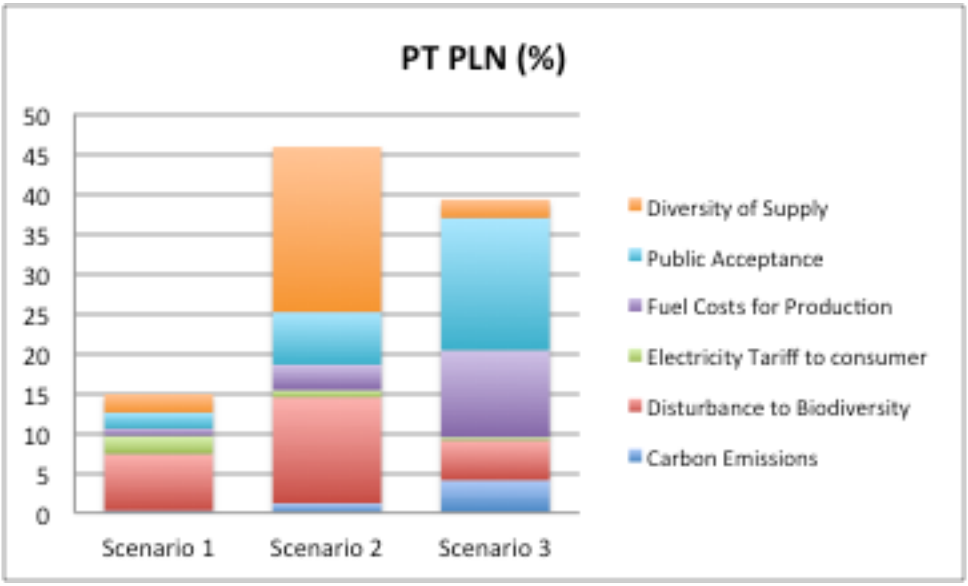


Figure 4.5.1.3.1 Scenario preferences for future electricity generation according to the electricity company PT PLN

Source: Made by author

The high importance for social factors amplifies the importance of the sub-criterion Diversity of Supply, thereby allowing this sub-criterion to contribute greatly towards the selection of scenario 2 as the most preferred. Disturbance to Biodiversity is the other indicator that has strengthened the preference for scenario 2. High public acceptance and zero costs of fuel for generating electricity were not enough to elevate scenario 3 to the highest preferred scenario. The lack of complete knowledge about the effects of MCEG on biodiversity, and the extremely low importance placed on emissions have led to scenario 3 taking the second place in preference. Despite causing relatively low disturbance to the bio-diversity, scenario 1 has been chosen as the least preferred scenario for generating electricity in future.

4.5.1.4 Local Government

Scenario 3 is the most preferred scenario with 37.4% preference. Scenario 2 with 37.5% preference and scenario 1 with 31.1% are close behind. Compared to all other stakeholder groups, the local government gives the highest importance to economic aspects. They consider economic aspects to be of 57% importance compared to environmental aspects at 29.5% and social aspects at 13%. The scenario preferences for future electricity generation according to the local government are shown in figure 4.5.1.4.1.

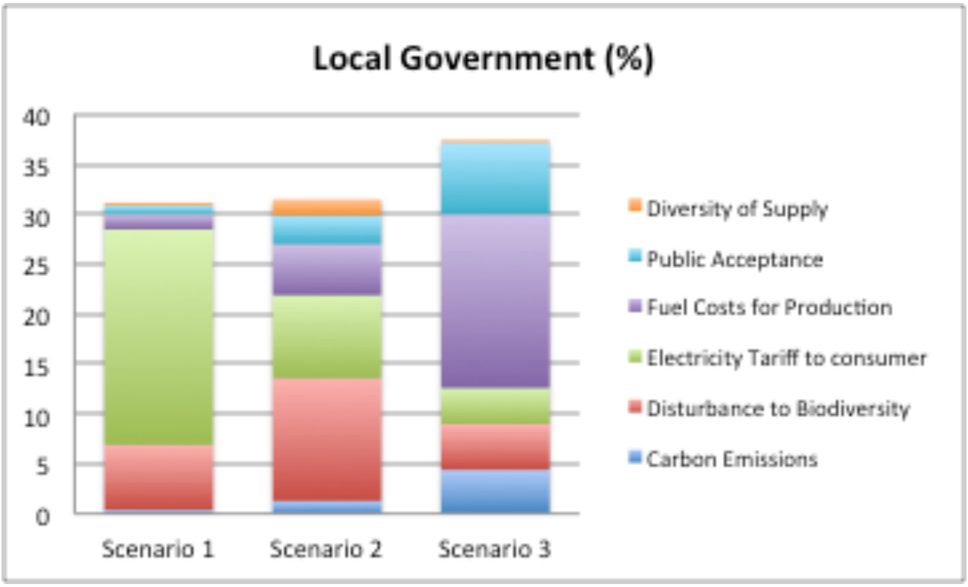


Figure 4.5.1.4.1 Scenario preferences for future electricity generation according to the local government

Source: Made by author

The relatively lower preference for scenario one, compared to the other stakeholder groups is mainly because electricity tariff is the most important indicator for the government. Electricity is considered more than three times as important as Public Acceptance and nearly five times as important as Carbon Emissions. However zero fuel costs for production of MCEG allowed scenario 3 to be selected as the most preferred option. Scenario 2 narrowly surpassed scenario 1 due to its lower impact on the surrounding bio-diversity. Scenario 1 has a higher preference compared for the local government compared to other stakeholder groups because of the government's greater emphasis on economic aspects. This economic emphasis in turn magnified the impact of the lower electricity tariff from diesel generators than the expected tariff for MCEG.

4.5.1.5 Local Population

Figure 4.5.1.5.1 shows the preferences for future electricity generation scenarios in the opinion of the local population.

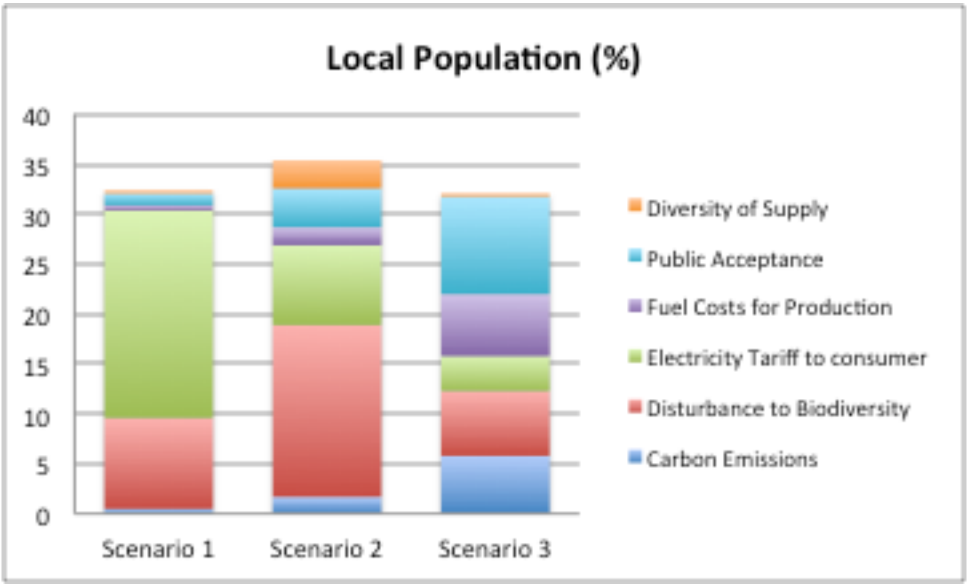


Figure 4.5.1.5.1 Scenario preferences for future electricity generation according to the local population

Source: Made by author

Scenario 2 at 36% preference is the most preferred scenario by the local people. Scenarios 1 and 3 each have 32% preference. The locals consider environmental and economic aspects to be of equal importance at 40.8% importance and social factors to be less than half as important at 18.4% importance. The selection of scenario 2 as the most preferred option is aided by the lower disturbance to diversity caused by MCEG and the comparatively lower electricity tariff. Scenario 1 has the highest percentage of preference amongst local people compared to other stakeholder groups, due to the low electricity tariff and relatively lower disturbance to biodiversity. Higher electricity tariff and inadequate information about disturbance to bio-diversity is what has made scenario 3 have the lowest preference amongst local people compared to the other stakeholder groups.

4.5.2 Significance of MCDA 3

MCDA 3 is not only significant but also necessary. MCDA 1 was vital to capture the experience, judgment and opinion of the stakeholders about given criteria and sub-criteria, while MCDA 2 was essential to the process as it involved the use of scientific data. MCDA 3 using stakeholder opinion and scientific data gives the most realistic results after removing the possible errors. Results of MCDA 1 show some error compared to the criteria and sub-criteria the stakeholders considered most important. Significance of each criteria and sub-criterion can be based on personal opinion and experience and can be subject to personal judgment. However the analysis of each alternative based on the sub-criteria cannot be based on personal opinion and experience, but on facts and data. The impacts of each indicator are ideally known facts, and ideally measurable. Analysis with limited knowledge of the potential impacts can lead to errors, as noticed in MCDA 1. These errors may have been due to lack of knowledge of the impact of each scenario on the specific indicators, or due to misunderstandings of the AHP process. The following sections will try to explain the some of the errors for each stakeholder group by comparing the results from MCDA 1 and MCDA 3.

4.5.2.1 Academia

For the academics, Disturbance to Bio-Diversity is of great importance. However that was not reflected in their analysis of the scenarios, as scenario 3 is better than scenario 2 when concerning disturbance to biodiversity. As explained earlier, scenario 3 is likely to cause higher disturbance to diversity considering the larger number of turbines involved. For the ease of explanation results from MCDA 1 and MCDA 3 according to the academia are compiled and shown in figure 4.5.2.1.1

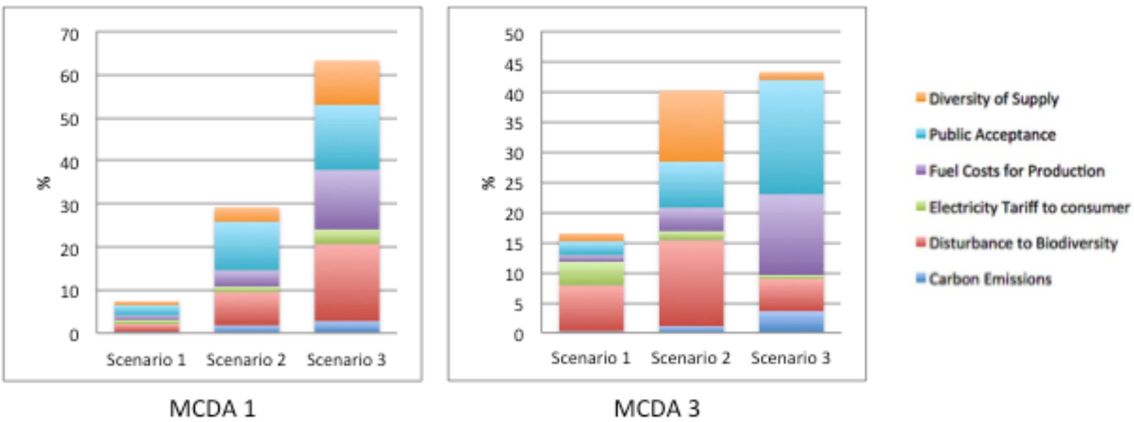


Figure 4.5.2.1.1 Scenario preferences according to the Academia using MCDA 1 and MCDA 3

Source: Made by author

Also in MCDA 1, the scenario 3 reflected a situation with lower electricity tariffs than scenarios 1 and 2, although according to present estimates, MCEG may be the more expensive option. Scenario 2, consisting of two technologies should score higher for the indicator Diversity of Supply, but this is not reflected in MCDA 1. Due to these errors, analysis using scientific data is necessary, and so it the understanding of the process. After rectifying these errors in MCDA 3, though the order of preference remains the same, the preference for scenarios 1 and 2 increase significantly.

4.5.2.2 NGOs

In order to understand the possible errors, results showing the most preferred scenarios from MCDA 1 and MCDA 3 according to NGOs are compiled and shown in figure 4.5.2.2.1.

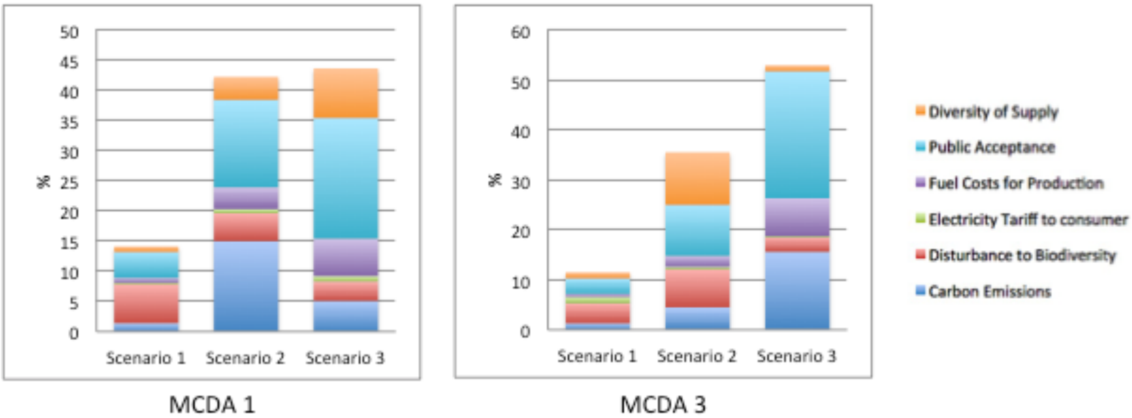


Figure 4.5.2.2.1 Scenario preferences according to the NGOs using MCDA 1 and MCDA 3

Source: Made by author

For the NGOs public acceptance is the most important indicator. This is reflected in MCDA 1 and MCDA 2, suggesting a lack of error. However, there is some error noticed in other indicators. Considering NGOs deem CO_2 Emissions to be the second most important indicator, scenario 3, a scenario with only MCDG and thus the least emissions, should have had a greater contribution from the Carbon Emissions indicator towards its selection as the most preferred scenario in. In MCDA 1 it is seen that scenario 2 was a better option than scenario 3 as far as CO_2 emissions are considered. This is theoretically incorrect as scenario 2 also includes diesel generators, which have significant emission. Also scenario 3 performed better in the indicator Diversity of Supply though scenario 2 should have the best performance in this indicator, as it includes two methods of electricity generation instead of just one. Through addressing these errors, the preference of scenario 3 has risen significantly in MCDA 3 because of its low carbon emissions.

4.5.2.3 Electricity Company PT PLN

MCDA 1 and MCDA 3 results showing scenario preferences of PT PLN are shown in figure 4.5.2.3.1.

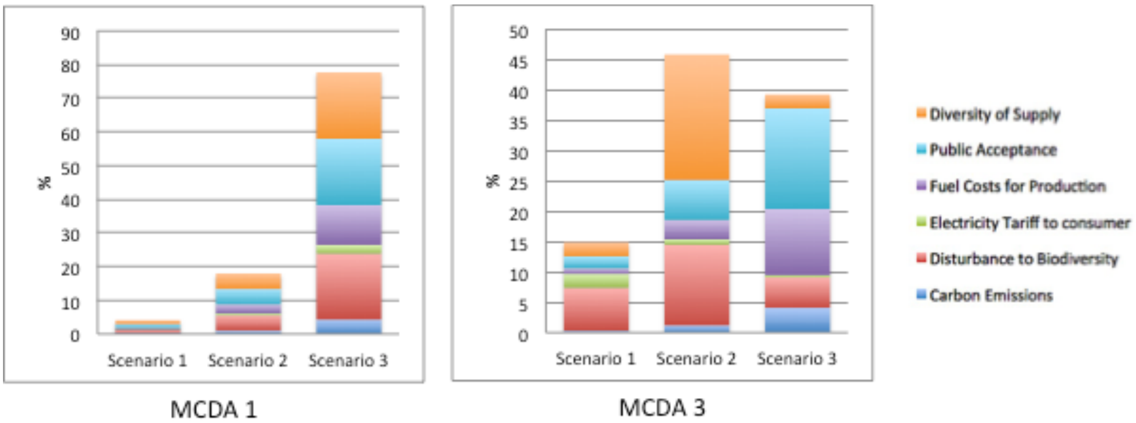


Figure 4.5.2.3.1 Scenario preferences according to the electricity company PT PLN using MCDA 1 and MCDA 3

Source: Made by author

PT PLN gives high and equal importance to both the social indicators, i.e. Public Acceptance, and Security and Diversity of supply. Disturbance to Bio-Diversity comes in a close second in importance. However the preferred future electricity generation scenario choice of PT PLN based on the individual indicators seems skewed. Given the better performance for scenario 2 as far as Diversity of Supply and Disturbance to Bio-diversity is concerned, scenario 2 should be the most preferred scenario. However in MCDA 1 scenario 3 performed better on all the indicators, which points to some error, either in appreciating the significance of the impacts or in understanding the process. Using the weights obtained in MCDA 1, MCDA 3 provides better analyses to overcome these errors and identify scenario 2 as the most preferred scenario.

4.5.2.4 Local Government

The scenario preferences for the local government using MCDA 1 and MCDA 3 are shown in figure 4.5.2.4.1.

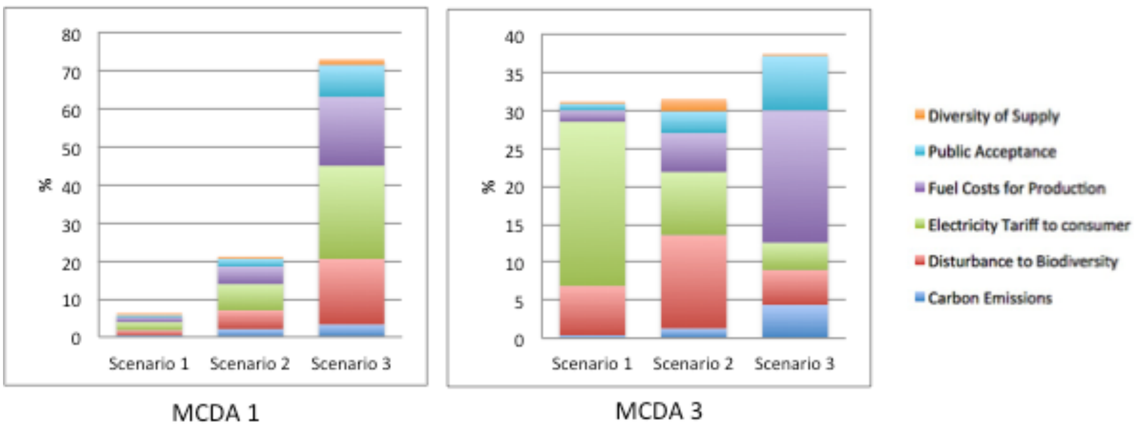


Figure 4.5.2.4.1 Scenario preferences according to the local government using MCDA 1 and MCDA 3

Source: Made by author

The local government considers Electricity Tariff, by far, the most important indicator for selection of a future energy source. Since diesel energy is currently much cheaper than MCEG, scenario 1 should have a significantly higher preference than the extremely low preference obtained in MCDA 1. In MCDA 1 it was observed that scenario 3 was the best performing scenario as far as electricity tariff is concerned, followed by scenario 2. This can be identified as a major source of error. Using the stakeholder weights and analyzing the indicators using actual data, in MCDA 3 the preference of scenario 1 rises from 5.8% to 31.1% taking it exceedingly close to the preference level for scenario 2.

4.5.2.5 Local Population

MCDA 1 and MCDA 3 results showing the scenario preferences of the local population are shown in figure 4.5.2.3.1.

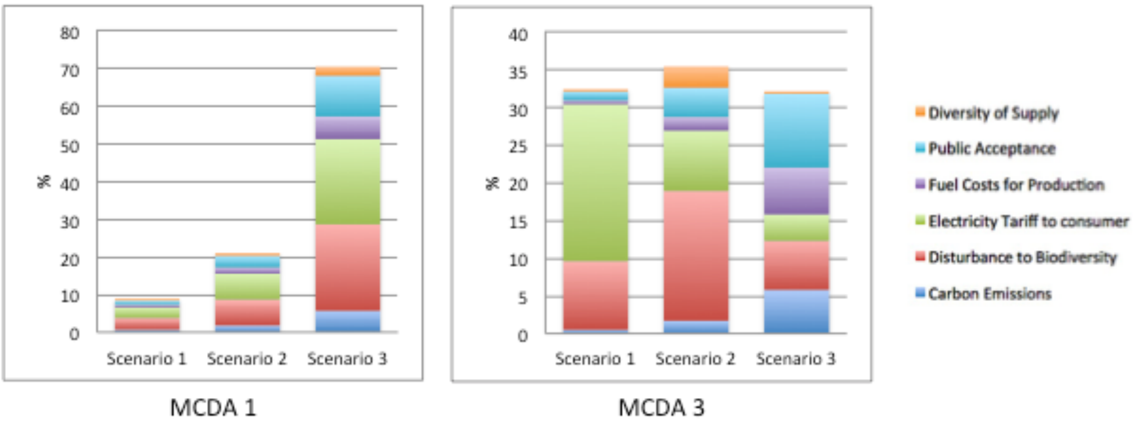


Figure 4.5.2.5.1 Scenario preferences according to the local population using MCDA 1 and MCDA 3

Source: Made by author

The local public considers Disturbance to Bio-Diversity and Electricity Tariff as the most important indicators for sustainability. Considering this information, scenarios 1 and 2 should have very high preference, considering the cheap electricity tariff from diesel generators and the lower disturbance to surrounding bio-diversity of scenario 2. But in MCDA 1, scenario 3 performed better than the other two scenarios in both the indicators. As a result, in MCDA 1, scenario 3 was preferred more than seven times to scenario 1 and almost 3.5 times to scenario 2. Using scientific data and analysis to rectify this error, MCDA 3 reflects completely different results. Now scenario 3 is slightly more preferred than both the other scenarios. This is mainly due to its low impact on bio-diversity and relatively cheaper electricity tariff. The importance of cheap electricity tariff to the local public has propelled scenario 1 from less than 10% preference in MCDA 1 to 32% preference in MCDA 3.

Analyzing the results from each stakeholder group exemplifies the significance and necessity of MCDA 3 and using both stakeholder weights and scientific data to obtain final results. It also shows the great importance of possessing thorough knowledge about the various impacts of the technologies in discussion. The lack of knowledge of impacts can lead to an error in judgment, as explained above, or lead a lower preference – as exemplified by the lack of knowledge of the impacts on bio-diversity from MCEG – and both these outcomes are undesirable.

5. Conclusion

The following sections discuss the implications of this research and offer possible recommendations for deployment of sustainable energy technology in the future. The limitations of this research are also discussed.

5.1 Implications

The arithmetic mean of the most important sustainability indicators for all groups of stakeholders is shown in figure 5.1.1

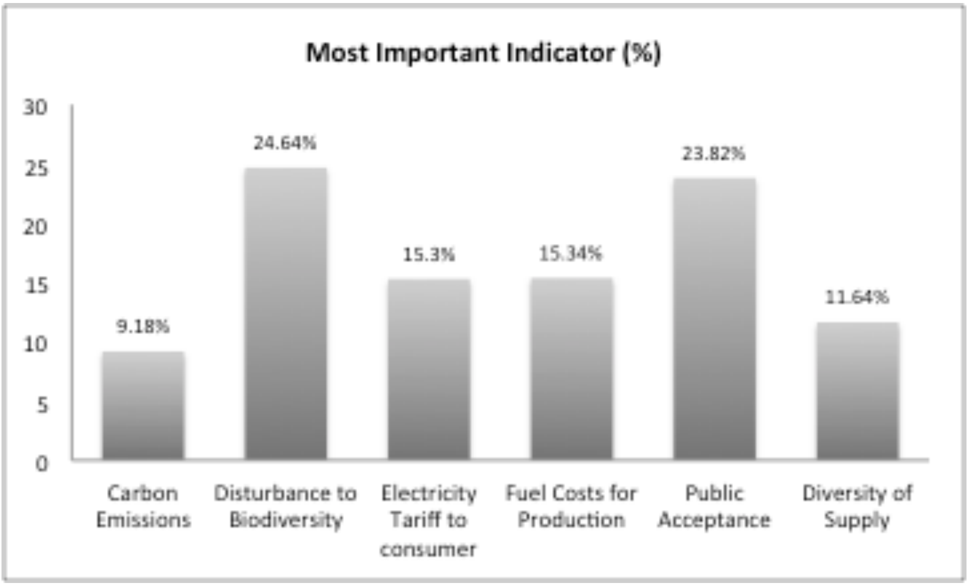


Figure 5.1.1 Importance of indicators according to all the stakeholders

Source: Made by author

On average, Disturbance to Bio-Diversity is considered the most important indicator for sustainability, followed by Public Acceptance. Higher public acceptance has helped scenario 3 to be selected as the most preferred option for three of the five stakeholder groups. The third most important indicator, Fuel Costs for Production, also helped scenario 3 take the lead preference in three of the stakeholder groups. The relatively lower disturbance to biodiversity caused by a mix of MCEG and diesel generators has helped scenario 2 being selected as the most preferred scenario for two of the stakeholder groups.

Since disturbance to biodiversity is the most important indicator for all stakeholders, more consideration has to be given to this aspect for future deployment of sustainable energy technologies. If it could be proven that MCEG has low or no negative impact on the surrounding biodiversity, scenario 3 would have been the most preferred scenario for all stakeholder groups.

Even though developing countries may have no tradition of public engagement while deciding on energy issues, it is surprising to see that public acceptance is considered as one of the most important indicators by the stakeholders. If there were low public acceptance for MCEG, the results would have differed greatly, with scenario 2 becoming the most preferred scenario for most stakeholders and with some groups even opting for scenario 1. This shows whatever may be the technology its selection can be greatly influenced by general public opinion.

Based on current estimates, electricity generated from MCEG is not the cheapest option for consumers. If the electricity tariff for MCEG could be as economical as that for diesel, scenario 3 would be the overwhelming favorite of the local government and the local population, the major users of electricity in Flores Timur Regency.

One of the main advantages drivers of renewable energy technologies all over the world is the need for electricity sources that produce low CO_2 emissions over its life cycle compared to conventional fossil fuel technologies. Unfortunately the local stakeholders consider CO_2 Emissions as the least important indicator. If the people had considered CO_2 emissions as an important factor, scenario 3 would have been the most preferred choice for all the stakeholders and scenario 1 would have been of extremely low preference.

It can be thus concluded that all the indicators play a different yet significant role in the selection of future technology, and can play an important role in the decision-making process by influencing the preferred outcomes.

5.2 Recommendations

Based on the findings a set of recommendations is derived that can contribute to the successful deployment of MCEG in Indonesia.

Conducting an Environmental Impact Assessment (EIA) for all new technologies is a norm these days. But, for a technology such as MCEG, the EIA is more difficult, not just physically, as it involves under-water activities, but also economically, as it can be expensive. Moreover, MCEG is a new technology and there are not many precedents. However, the local stakeholders in Flores Timur Regency consider the Disturbance to Bio-Diversity to be a prime concern and therefore EIA is necessary for successful deployment of MCEG. EIA will identify all the mammals, fishes, birds and other marine creatures that can be impacted. The conditions of the sea floor and the effect on the tidal currents will also be noted. In addition to an EIA, monitoring of the environmental conditions for a prolonged period of time, such as a few years, using an EMP is vital. Previous examples of similar activities in UK, US, and Canada should also be studied in detail and the methods used in these activities can be adjusted or adapted for Indonesian conditions to optimize the results. A successful EIA and EMP report will allay the concerns of the academics and the environmentalists and will be a critical tool for sustainable deployment of MCEG in Indonesia.

As public acceptance has also been deemed to be a major factor for development of sustainable energy projects, it is essential to at least have a basic consultation process open to the public to inform them and engage them about MCEG technology. The academics and the public also stressed the necessity of local engagement in all steps of MCEG deployment, be it environmental monitoring, installation, operation, or maintenance. The fishermen are open to lending out their boats for the various functions required for MCEG and their help can be vital in making the community feel as part of the project. Local communities should also be provided employment in the various stages of the project in order to gather local support. The head of the Department of Informal Education of Flores Timur Regency informed the author about the availability of people willing to work on such projects and the existence of facilities to train them. In this way, involving the locals will create a sense of ownership of the project within the community, which will contribute towards the long-term sustainability of the project.

One of the main reasons for skepticism towards MCEG worldwide is the estimated high electricity tariff. Efforts must be made to reduce the cost of electricity to the customer by making the technology cheaper. The Managing Director of IHL (BPPT) provided information about the efforts being made to develop a cheap turbine that can efficiently provide electricity economically. An effective FIT can also help in providing electricity to the customer at inexpensive rates. If MCEG can obtain FITs similar to solar PV in Indonesia, MCEG can become an affordable option for electricity generation. The FITs in Indonesia for different technologies are listed in table 6.2.1.

Table 5.2.1 FIT for various sources of renewable energy in Indonesia

Source: Made by author based on MEMR Regulation 12/2012 and MEMR Regulation 4/2012

Source	FIT	Conditions
Mini and micro hydro	Rp 656-1506/kWh	<10 MW; depends on location and whether it is connected to a low- or medium-voltage network.
Biomass	Rp 975-1722.5/kWh	<10 MW; depends on location and whether it is connected to a low- or medium-voltage network.
City waste	Rp 850-1398/kWh	<10 MW; depends on technology utilized and whether it is connected to a low- or medium-voltage network.
Geothermal	US cent 10-18/kWh	Depends on location, and whether it is connected to a high- or medium-voltage network.
Solar PV	Upto US cent 25/kwh	Depends on location, and whether it is connected to a low- or medium-voltage network.

The costs to the customer can also be reduced by availing subsidies similar to those enjoyed by the fossil fuels, which are what allow technologies such as diesel generators to produce electricity at a much cheaper rate.

The importance of low emission energy technologies can never be under-estimated in the fight against climate change. Nonetheless, the local stakeholders jointly consider CO_2 emissions to be of least importance. Interviews with the local people showed a deep knowledge about local environmental problems like coastal erosion and fish stock reduction. However, there a distinct lack of knowledge was noticed when it came to global environmental problems, such as ozone layer depletion, climate change and global warming. It is essential for the public to be not only educated in regional environmental issues, but also educated in global environmental issues, their causes and the ways to mitigate them.

The long-term benefits of renewable energy have to be explained to the local public not just in environmental terms but also in economic terms. While millions of dollars will need to be spent in fuel costs for diesel generators, MCEG will require none. Moreover, people have to be informed that the volatile prices of the oil, and their decreasing availability make diesel generators an unattractive energy source in the long-term. Spreading awareness about the harmful effects – economical and environmental – of the fossil fuels and the benefits of MCEG is as important as the technology itself for its successful sustainable deployment.

These courses of actions can help towards sustainable deployment of MCEG in Indonesia in future, and the deployment of a renewable energy source to quench the growing need for electricity in developing countries.

5.3 Limitations of Research

This research focuses on a renewable energy technology that is currently at the research and testing stage, instead of the commercial deployment stage. The various impacts of this technology, though carefully estimated, have no precedence in real life scenarios. This limits the scope of showing the exact impact of MCEG. Based on the current information available, it is impossible to select an exact solution, but it is possible to select the most favorable course of actions. In a real life situation, many other factors not considered in this research, such as local religion, local politics, national politics, foreign influence, corruption, etc. may also contribute toward the selection of a future energy technology. This study does not address the influence of these other factors.

This research involves the participation of local stakeholders including fishermen and farmers, many of whom are illiterate, to conduct the MCDA. Thus, in order to make the MCDA process simple enough to understand – a necessity – only six indicators of sustainability were used. Though six indicators are enough for a sustainability assessment, it forced the scope to be somewhat limited compared to an assessment using many more indicators.

While the environmental, economic and social impacts of all the three scenarios were looked at, this research does not address the technical feasibility of each of the three scenarios, and assumes that all the scenarios are possible in the future.

While there are five groups of stakeholders included in this research, the relative influence and importance of each group is unknown. The academia and NGOs may be the most knowledgeable about potential impacts but the electricity company may be the most informed about production and distribution of the electricity. While the local public may be the major users of electricity, the government officials may be the final decision makers. This research gives equal importance to all groups of stakeholders and this may restrict the applicability of the final results and recommendations.

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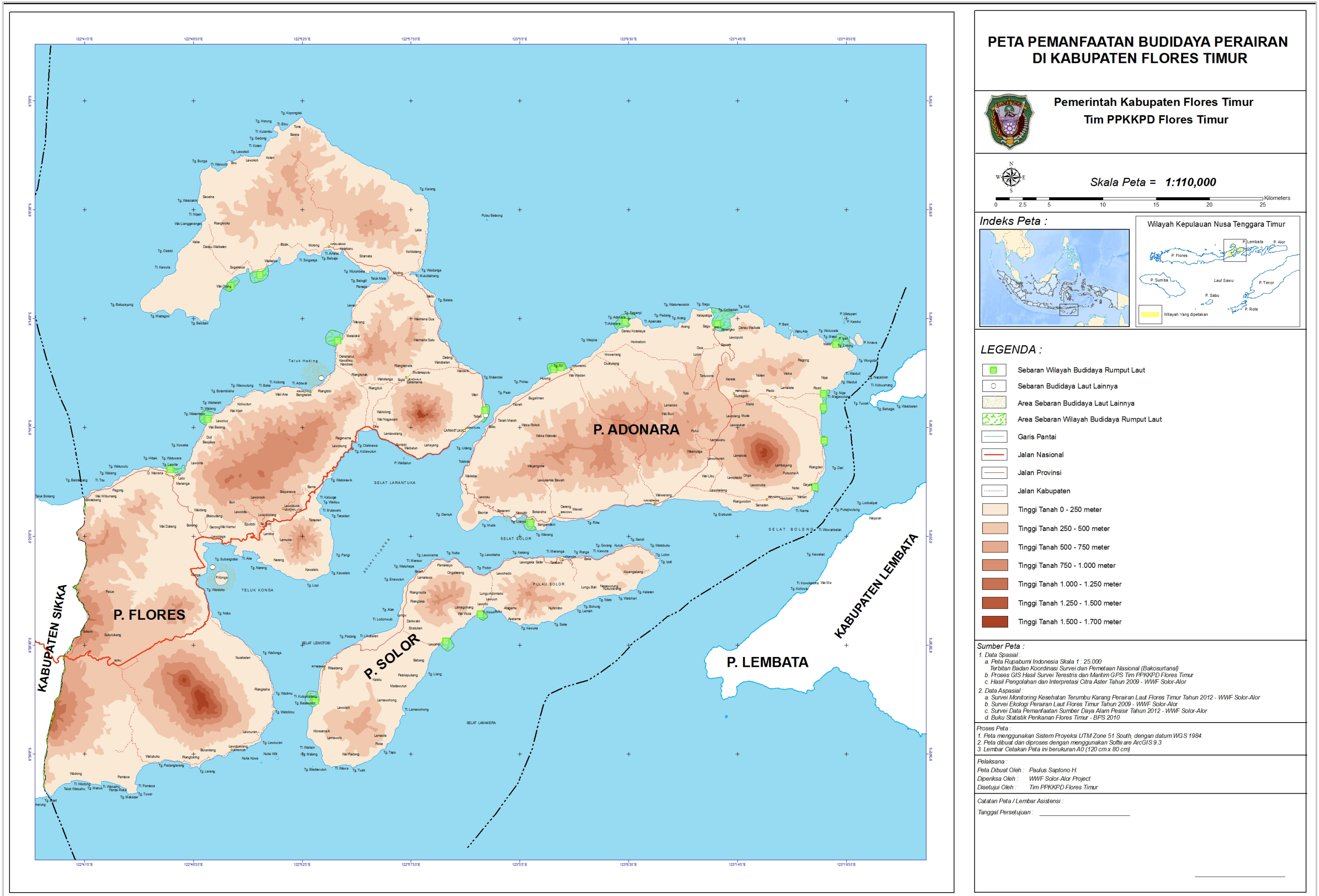
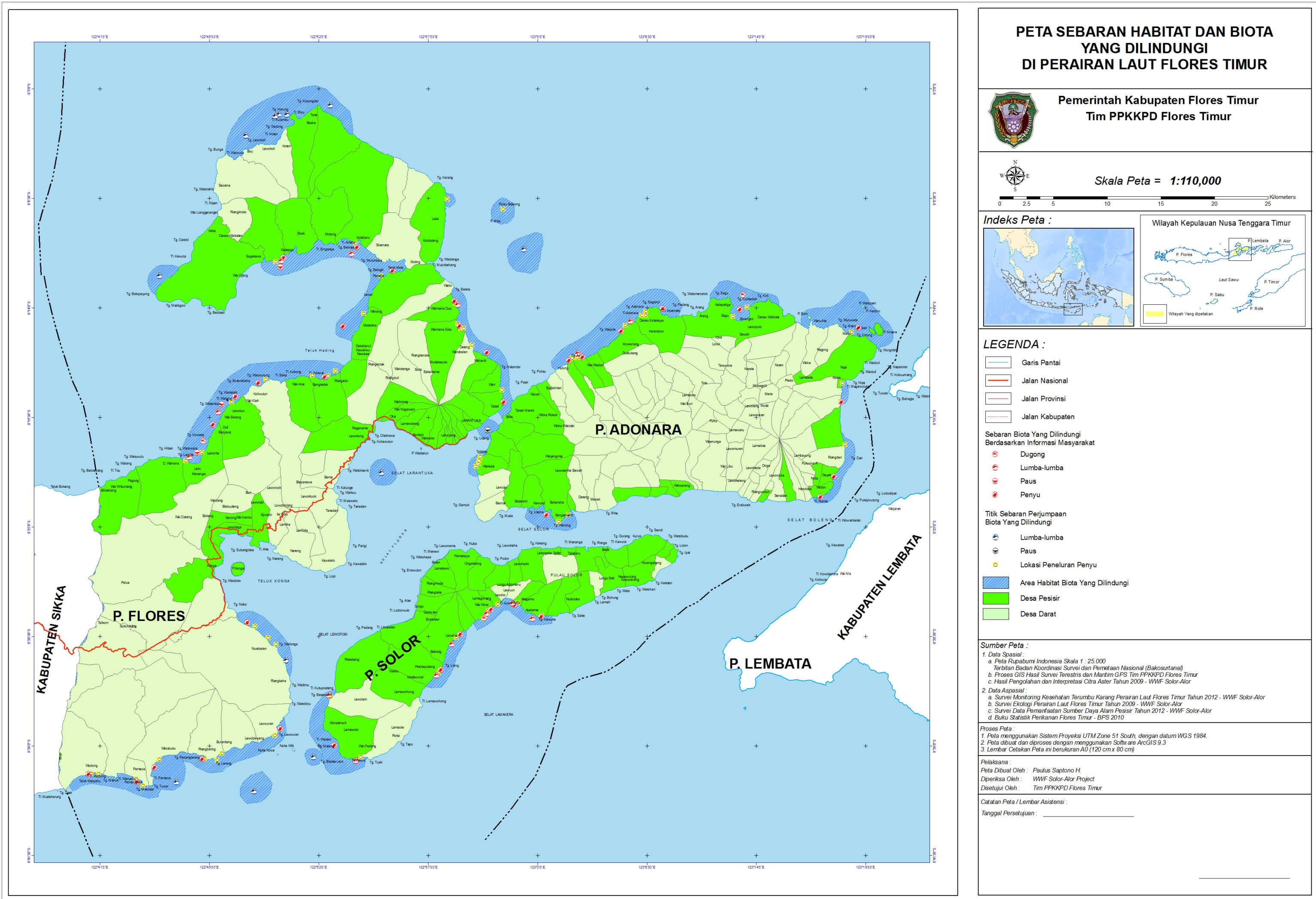
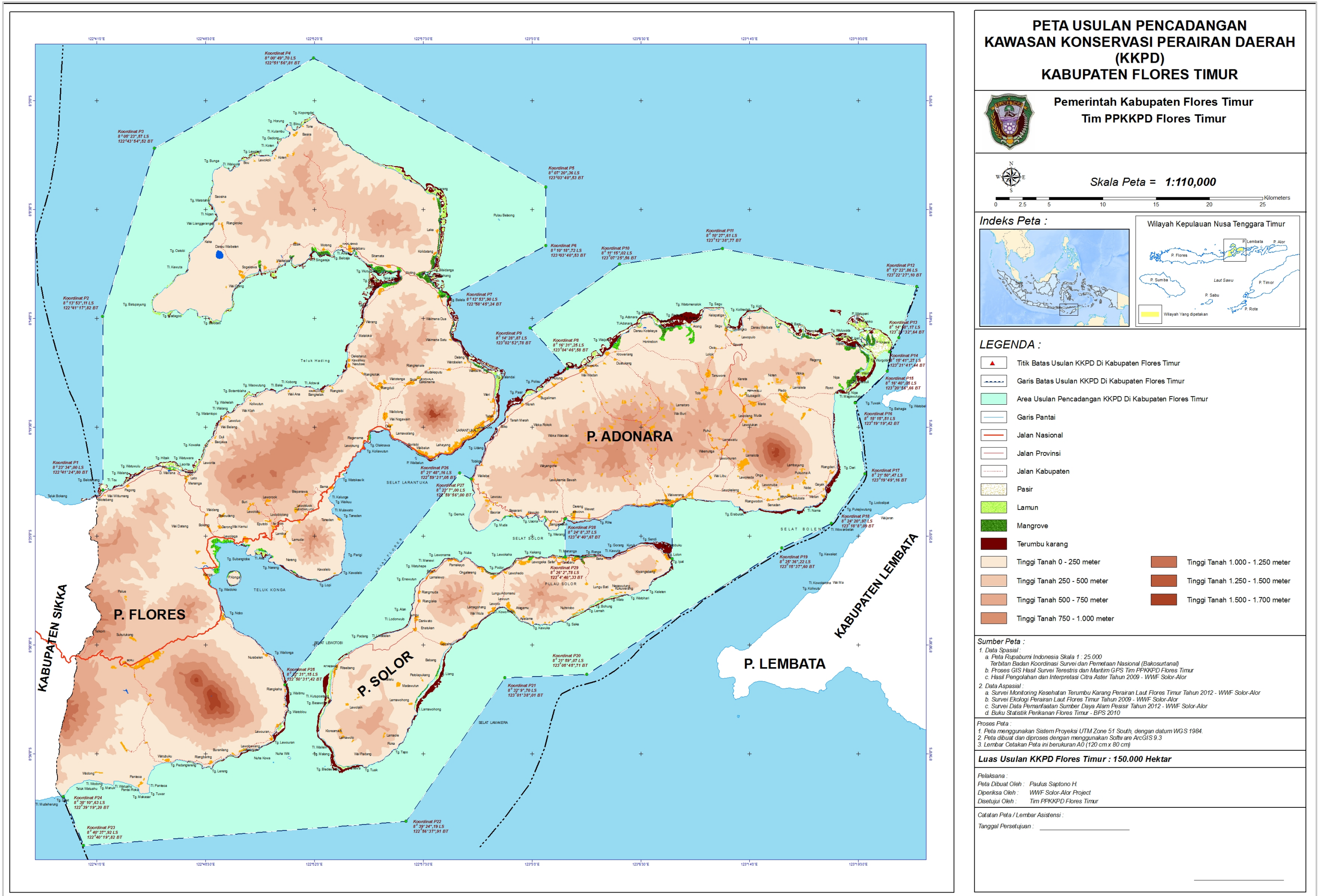


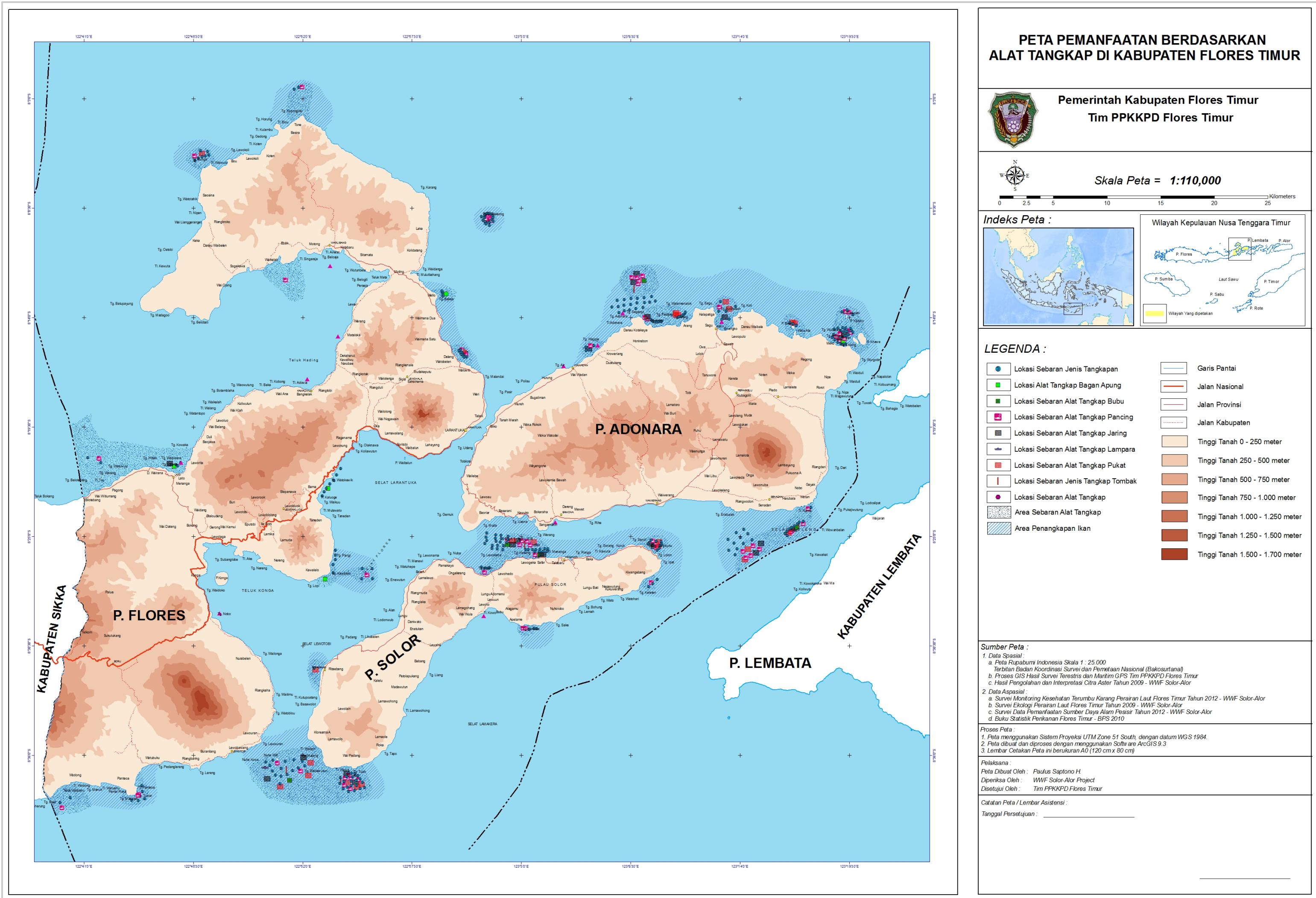
Appendix 1: Map displaying the areas where aquaculture is practiced in Flores Timur Regency
Source: KKPD, Local Government of Flores Timur Regency



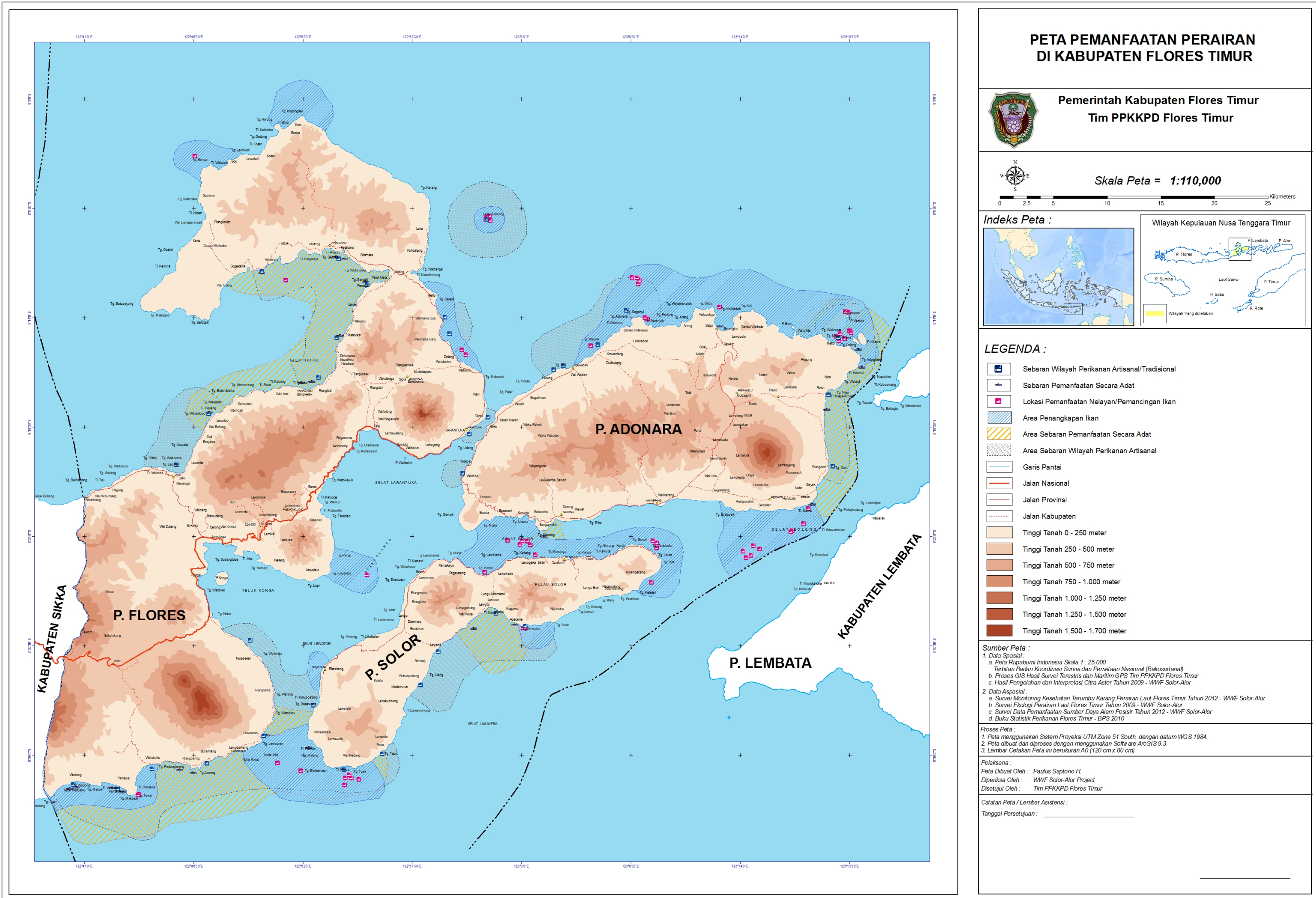
Appendix 2: Map displaying the areas with marine biota in Flores Timur Regency
Source: KKPD, Local Government of Flores Timur Regency



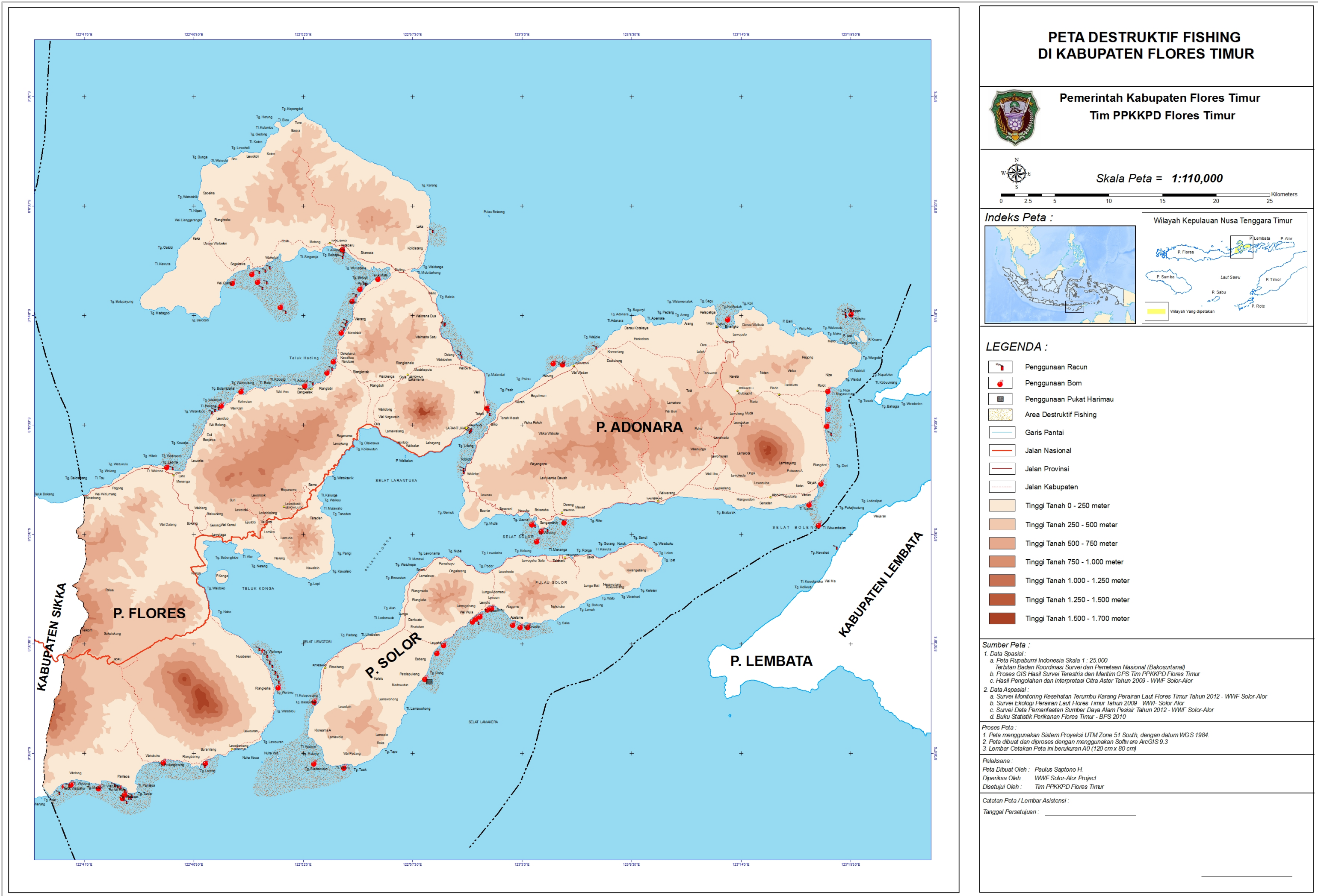
Appendix 3: Map of proposed marine conservation area in Flores Timur Regency
Source: KKPD, Local Government of Flores Timur Regency



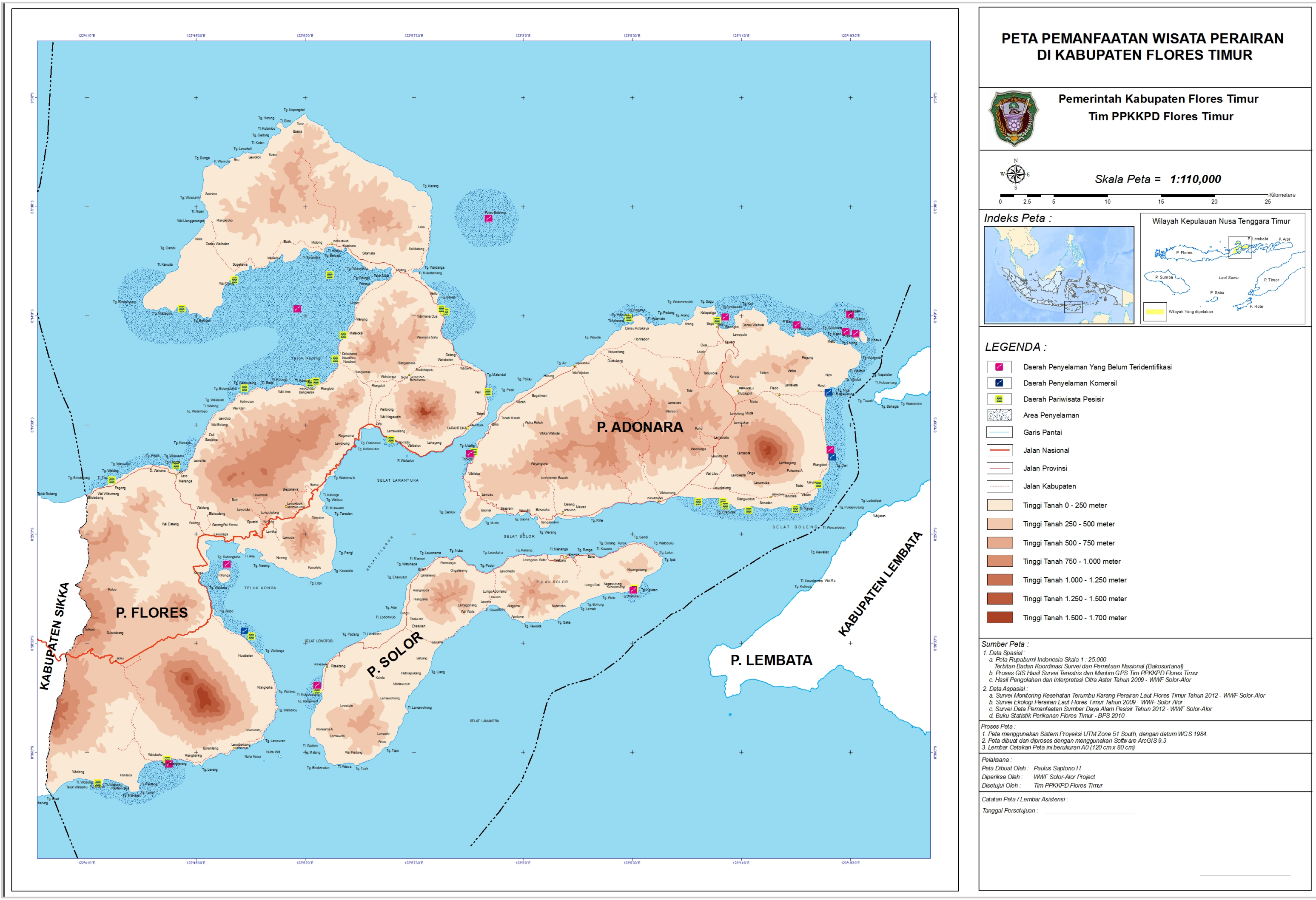
Appendix 4: Map of major fishing areas based on the type of fishing methods in Flores Timur Regency
Source: KKPD, Local Government of Flores Timur Regency



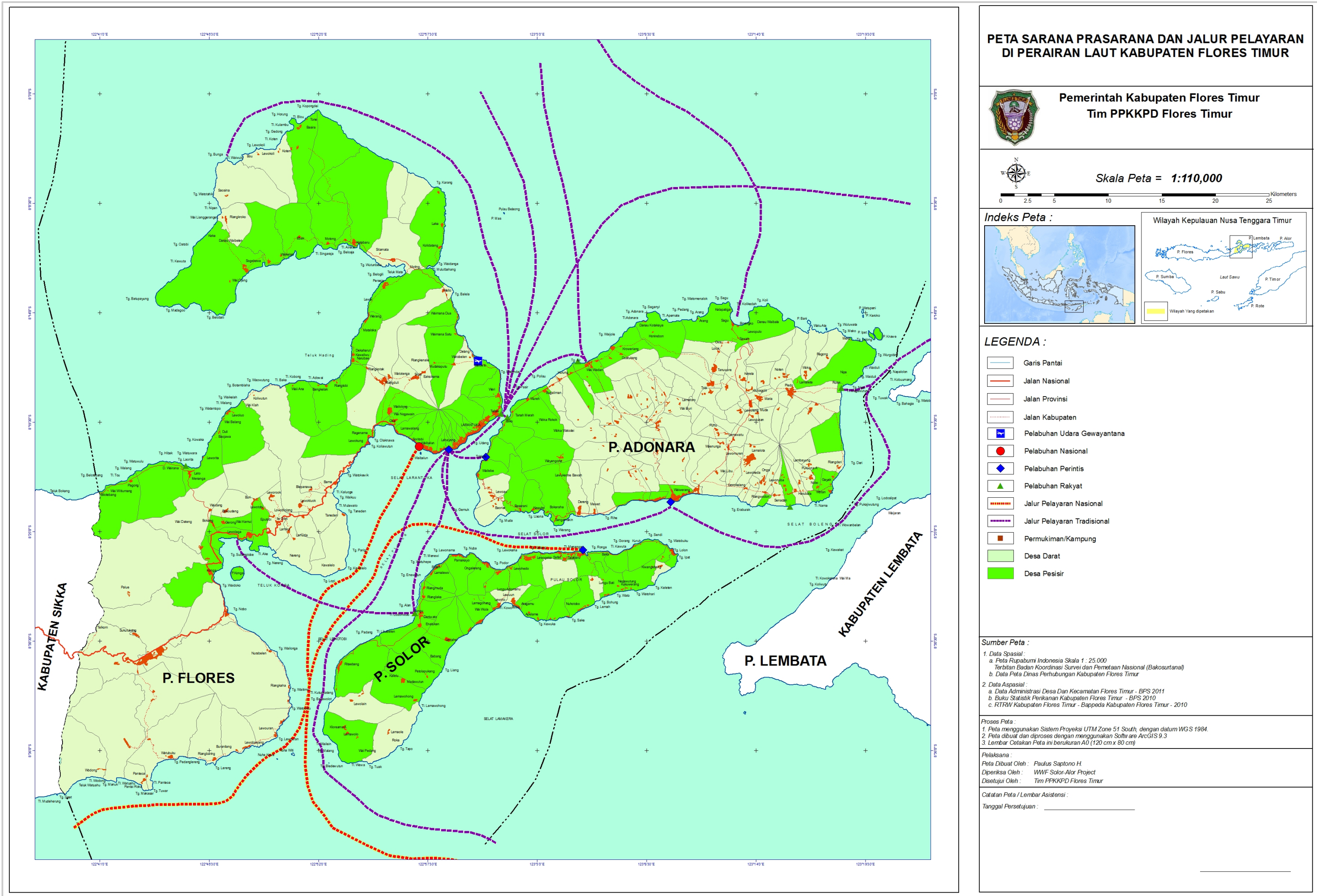
Appendix 5: Map showing areas where artisanal fishing methods are practiced in Flores Timur Regency
Source: KKPD, Local Government of Flores Timur Regency



Appendix 6: Map showing areas where destructive fishing methods are used in Flores Timur Regency
Source: KKPD, Local Government of Flores Timur Regency



Appendix 7: Map of current diving areas and potential diving areas in future
Source: KKPD, Local Government of Flores Timur Regency



Appendix 8: Map of shipping routes of Flores Timur Regency
Source: KKPD, Local Government of Flores Timur Regency