SERG 5002

Cebu Island Final Report

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1.0 Introduction

The Island of Cebu is located in the Philippines. It has a large industrial sector and an overall population approximately 3 million residents [1]. Currently the Island is supplied energy from large geothermal resources as well as fossil fuels. This report reviews the current electricity needs for Cebu Island and analyzes the most renewable and cost effective sources for meeting the island's electricity demand.

2.0 Location and Population

Cebu is an island province in the Philippines. It is a largely industrialized province with 41% of its population residing in metropolitan areas [1]. Cebu is not located in an earthquake zone nor is it in a typhoon belt [2]. Its advantageous location, as seen in Figure 1, provides stability to industries and has helped Cebu not only become host to 80% of the inter-island shipping, but has also helped it grow a large manufacturing and tourism sector [2]. One key component in Cebu's success has been its reliable source of electricity. A secure supply of electricity has enabled Cebu to industrialize and attract a variety of industries therefore, any source of electricity chosen for Cebu must account for the islands economic dependence on stable electricity supply.

The average population density in Cebu is noted to be 530 per square kilometer. The Population density is highest around the metropolitan area, approximated at 750 people per square kilometer, see**Error! Reference source not found.**. In addition to industries, 87 ercent of Cebu households consume electricity [3]. The average household electricity consumption in Cebu has also increased by 27% [3].

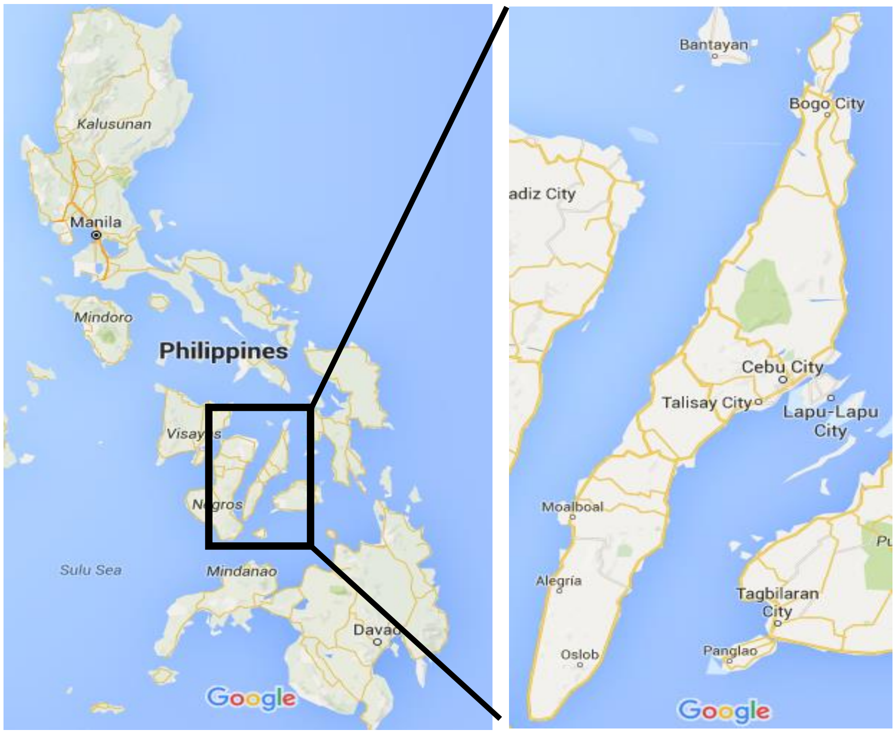


Figure 1 Cebu location in the Philippines

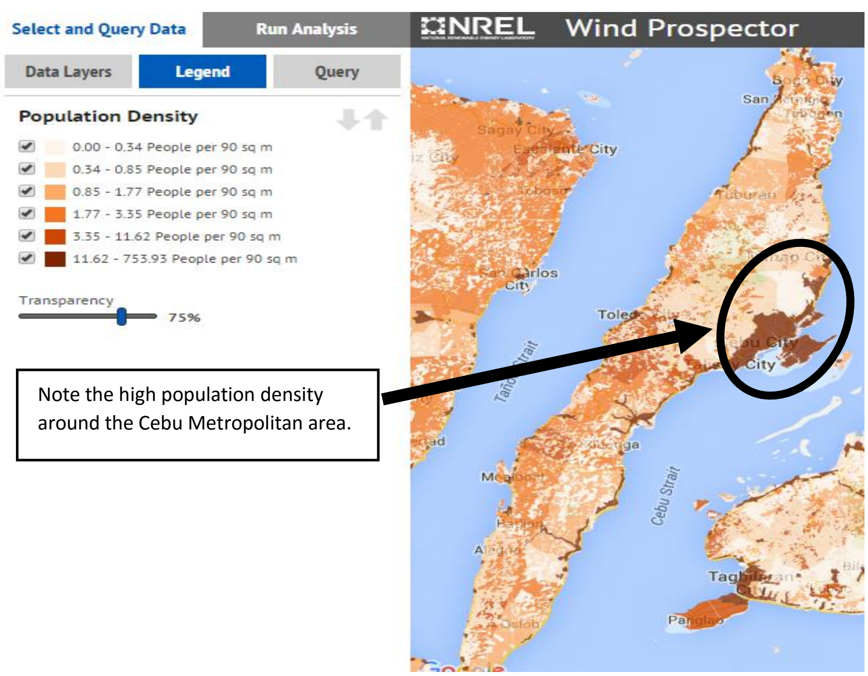


Figure 2 Cebu population density

3.0 Electricity Generation

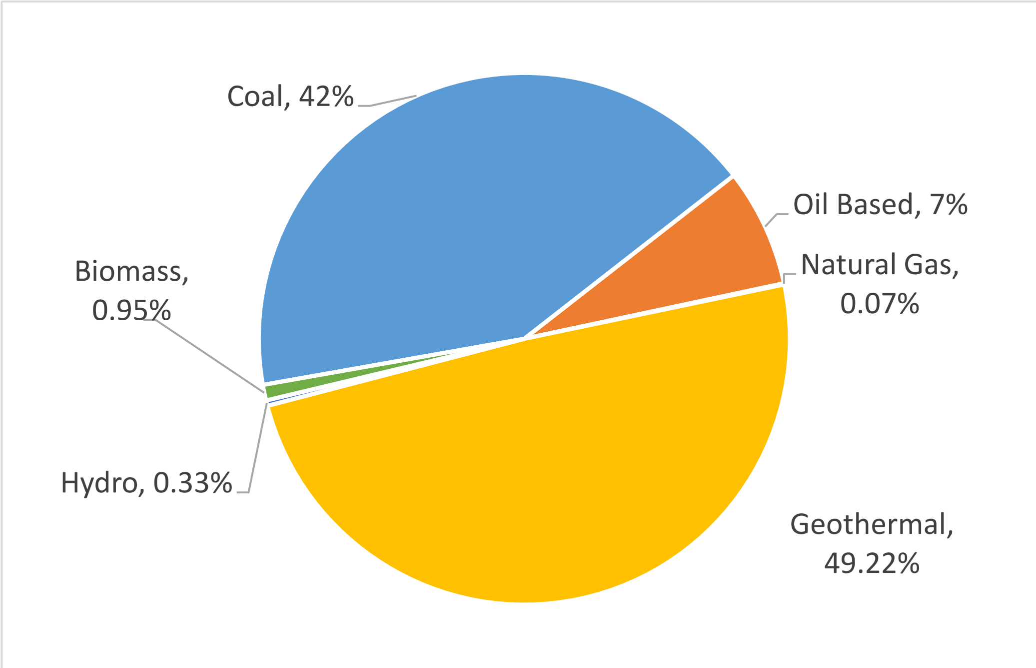


Figure 3 Visayas electricity supply by fuel source

Cebu receives its power supply from the Visayas power grid which consists of 4 main sub-grids, Cebu, Negros, Panay, Bohol and Leyte- Samar. The Cebu sub-grid accounts for 41.25% of the dependable capacity to the Visayas power grid [4] generated from fossil fuels. The total dependable capacity generated by the Cebu grid is 867 MW. The largest amount of geothermal energy is supplied by the Leyte- Samar grid at 29% is 588 MW. The total Visayas grid has a gross power generation capacity of 11099 MWh [5], with geothermal accounting for 49% of total installed capacity and 42% coal, the remainder being a mix other sources such as diesel, natural gas and hydro, see Figure 3 for breakdown by source and Table 1**Error! Reference source not found.** for generation capacity by sub grid.

Table 1 Visayas generation capacity for 2012 by province

Visayas Sub Grid	Dependable Capacity (MW) [4]	Generation (MWh) [5]	% of Total Capacity	% Total Generation	Main Fuel Source
Cebu	868	4158028	41	36	Coal
Negros	209	1600241	10	14	Geothermal
Panay	414	1266377	20	11	Coal
Bohol	23	44833	1	0.4	Hydro
Leyte-Samar	588	4358357	28	38	Geothermal
Net	2103	11427835			

4.0 Electricity Consumption:

The Visayas electric grid provides electricity to residential, commercial and industrial sectors. The total amount of electricity consumption from the Visayas electricity grid in 2012 is 10,072 GWh [5]. The total power consumption by the Visayas grid can be broken down by as shown in Figure 4. Of the total amount of consumed by the Visayas grid, 75% was sold while 25% was either used for operating the grid or was lost to system losses. Of the electricity that was sold a large amount of the electricity went to support economic development in the industrial and commercial sectors (58%). The two largest consumers of electricity were residential and industrial consumers reflecting 40% and 35% of electricity sold. The exact amount of electricity consumed in 2012 by sector is shown in Table 2.

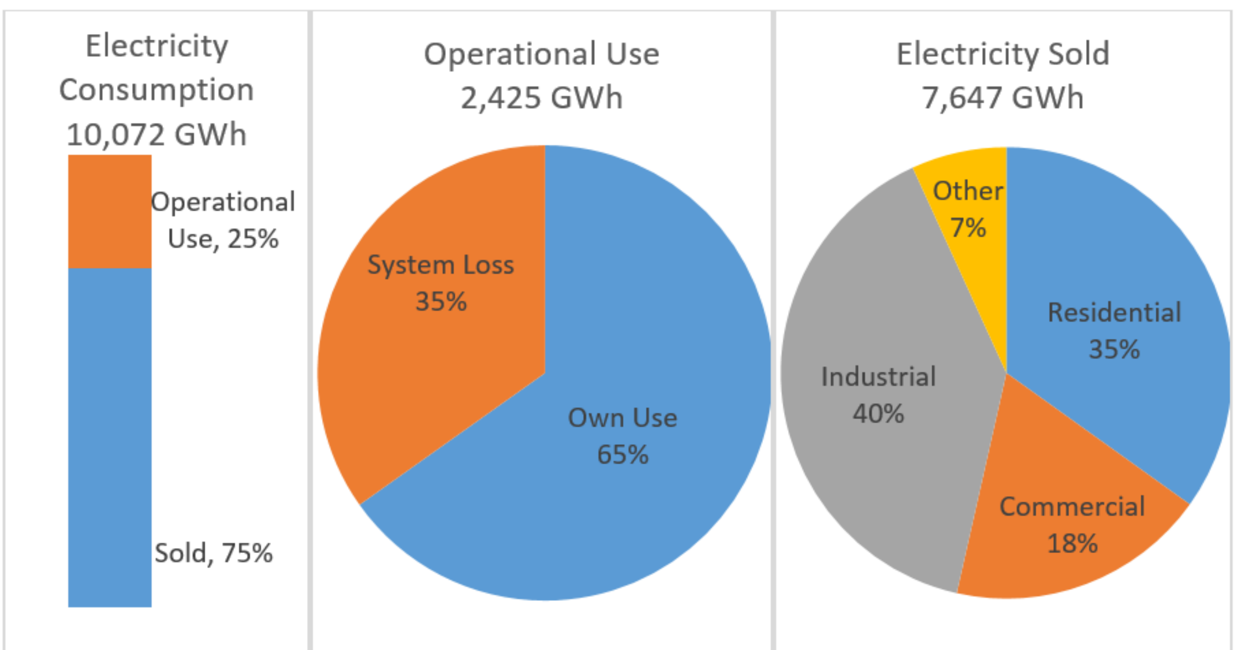


Figure 4 Visayas electricity consumption

Table 2 Visayas electricity consumption by sector

Consumption	MWh [2]	% Total
Electricity Sold	7646700	76%
Residential	2668062	26%
Commercial	1425684	14%
Industrial	3031684	30%
Other	521270	5%
Operational Use	2425302	24%
Own Use	1092227	11%
System Loss	1333075	13%
Total	10072002	

The two main suppliers for Cebu are Visayas Electric Company (VECO) and Cebu II Electric Company Inc (CEBECO). VECO is responsible for providing power to 61% of the Cebu metropolitan area and CEBECO provides power to the remainder [1]. The demand for Cebu in 2012 saw a peak at 747 MW while the Visayas grid peak was recorded at 1551 MW [5]. It is noted that while Cebu's reliable generation capacity is at 867 MW is greater than its peak demand, Cebu's main source of energy production is through fossil fuels which are emission intensive resources.

As Cebu continues to grow the demand for power supply is also expected to grow. Currently the government has plans to bring additional coal powered plants on line to meet this demand [4] while also exploring additional renewable energy solutions [6]. A new Renewable Energy law has been introduced by the government in the Philippines to promote the development of renewable energy projects. This government is trying to incentivise the development of new projects through income tax holidays for renewable projects for the first 7 years of the their commercial life followed by reduced corporate taxes after the 7 year period. Additionally, the government is introducing duty free imports for renewable energy equipment and machinery, reduced taxes on equipment's, tax exemption on the sale of carbon credits and priority in sale for energy generated through renewable sources [6]. The government is also facilitating the market for renewable energy supply by providing a FIT rate for various sources of renewable power, see Table 3 for the rate [6].

Table 3 FIT prices introduced to promote renewable energy

Energy Source	Fit Rate (Php/kWh)
Wind	8.53
Biomass	6.63
Solar	9.68
Hydro	5.9
Average non FIT price (CEBU)	6.04

5.0 Transmission Grid

Cebu's transmission grid is part of the Visayas grid. It connects to Leyte on the north side and Negros on the South side. The existing transmission grid is shown in Figure 5.

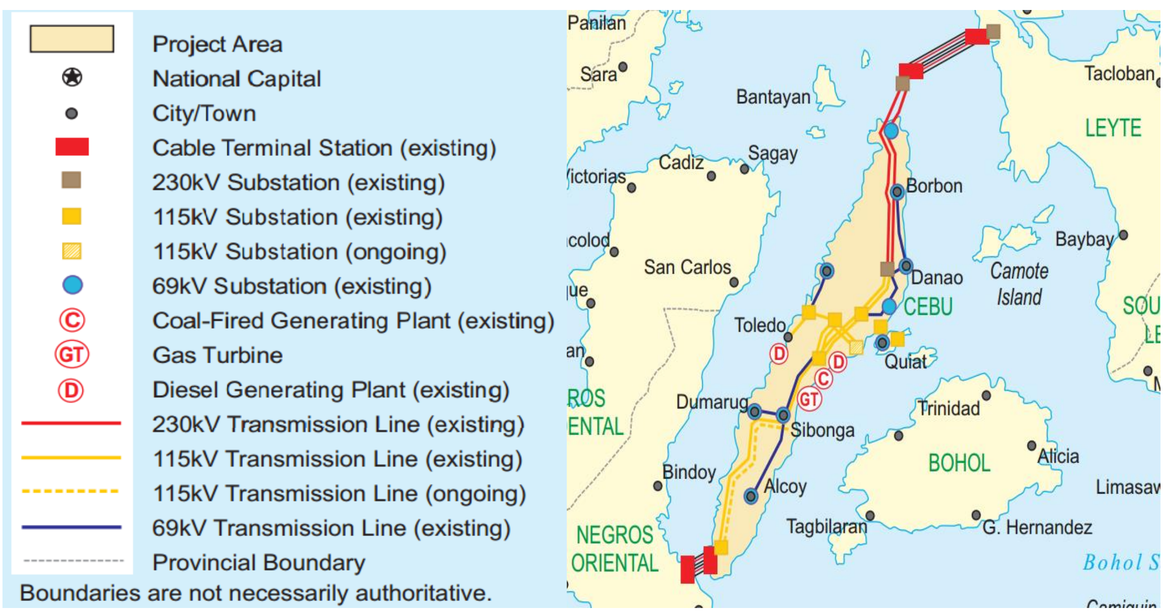


Figure 5 Existing Cebu transmission grid

The existing transmission grid is optimized to distribute the electricity from where it is generated to where the demand is located. Leyte has a high amount of generation capability relative to its demand, therefore it serves as a net exporter of energy. Excess energy from Leyte flows either to Cebu or Bohol. Additionally as Cebu also has a number of generation resources it can also export electricity. The excess electricity generally flows from Cebu to Negros [9]. Cebu's central location in the Visayas grid makes it a connecting point for the overall transfer of electricity.

6.0 Alternative Electricity Generation Sources

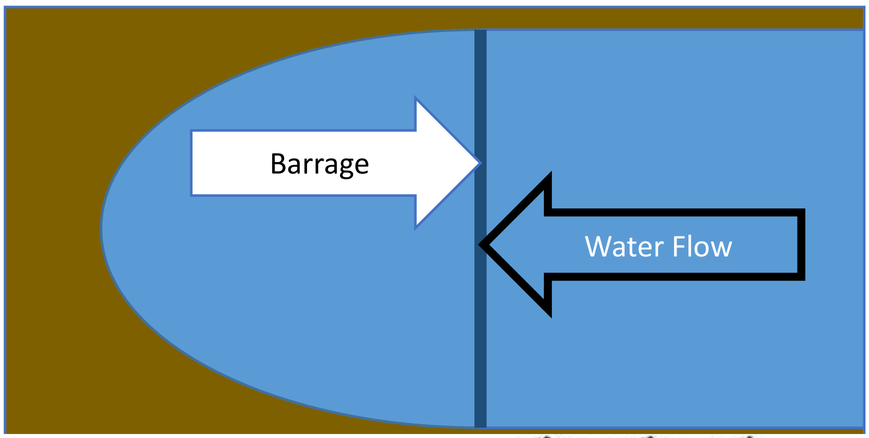
Currently Cebu's local generation of electricity is largely from Coal and Carbon intensive sources. To move Cebu towards a more sustainable path alternatives to its existing energy base will be considered. These alternatives will be analyses for their feasibility along with their environmental impact.

7.0 Hydro Energy

The total untapped potential for hydropower in the Philippines is estimated to be at approximately 13097 MW [10]. This is divided into small, medium and large scale hydro projects. While hydro plants require a significant capital investment, they hold a strong potential for being a renewable source of energy. The main hydro resources in the area are micro-hydro projects, ocean tidal, ocean thermal and ocean wave. Cebu has natural resources that can be used to develop ocean thermal and ocean tidal energy reserves [10]. Cebu's tidal energy reserves will be explored for electricity generation, see Figure 6 for location of resources.

Figure 6 Location of Tidal Resources Extrapolated from DOE Resource Map [14]

Tidal energy generates electricity by using the kinetic energy of the water waves. Water first flows across the barrage when the tide comes in and then again when the tide goes out. Turbines are installed in the barrage and as the water moves past them, the kinetic energy from the water moves the turbines which then produces electricity, see Figure 7 and Figure 8.



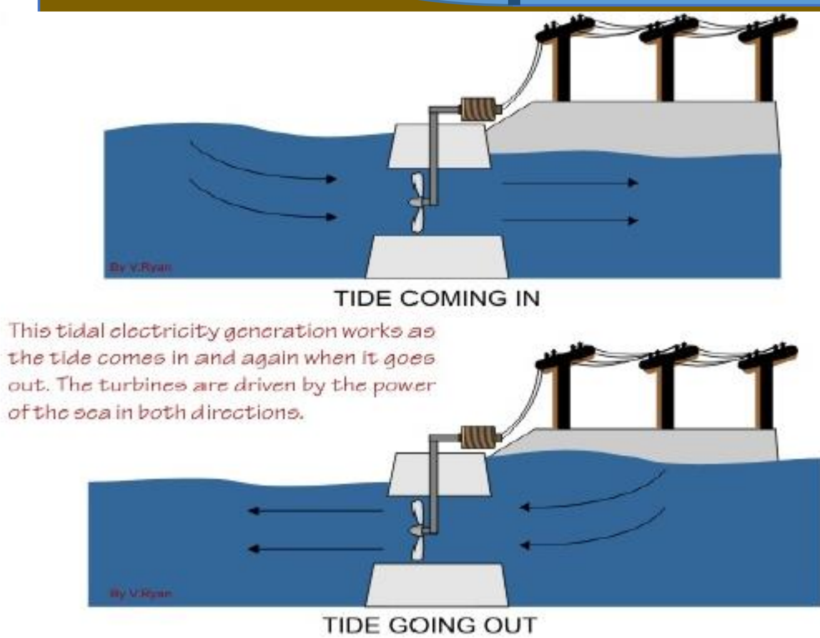


Figure 8 Tidal energy overview

The average height of high tide at Cebu Island is about 1.3 m and the average height at low tide is approximately 0.3 m [12]. For ease of calculation the tide is estimated to be the average of the high tide and the low tide, 1.0 m. The amount of energy in the tide is greater when the tide comes in relative to when the tide goes out, therefore, the amount of electricity produced will also be greater when the tide comes in relative to when it goes out.

The overall peak demand for Cebu is noted to be 747 MW [5].

7.1 Plant Location

To make use of the Tidal resources in Cebu, the plant will need to be located near the Cebu/ Bohol strait. Naga City is currently a location for one of the coal power plants, it also borders the Cebu/ Bohol strait as shown in Figure 9.

Figure 9 Naga city, proposed tidal plant location

7.2 Analysis

The assumptions used for the analysis of the hydro facility are outlined in Table 4. The overall cost of the proposed Hydro facility is reflected in USD millions (MM) in Table 5. The overall environmental impact of the tidal power facility is expected to be negligible.

Table 4 Assumptions used for analysis of Hydro facility

Assumptions Hydro	Value
Investment $/ KW	6250
Production Cost $/ MWh	110
OM cost $ /kWh	85
Tide Height (m)	1
Velocity of tide (m/s)	3
Barrage Length (m)	48000
Theoretical Volume m^3/s	107575
Turbine area(m^2)	1

Table 5 Cost overview of hydro facility

30 Year Hydro Cost Summary	Costs (MM)
Total Cost	$ 53,237
Capital Cost	$ 53,216
O&M	$ 22

7.3 Transmission

The assumptions used to estimate the transmission cost are highlighted in Table 6. The total transmission costs are summarized in Table 7. A general overview of the proposed transmission network is shown in Figure 10.

Table 6 Assumptions used for transmission cost analysis

Cost Assumptions:	Cost
Transmission line AC $/ km	235000
Transmission line DC $/km	2810000
O&M % of line cost	1.5%
Substation $/station	7000000
Transmission life	30

Table 7 Estimated transmission costs for Tidal plant

Transmission Cost	Value
Net km	231
Net Substation	16
Transmission AC line MM	54
Substation MM	112
30 Year O&M MM	24
30 Year Cost MM	191

Figure 10 General overview of transmission network

7.4 Evaluation

While Naga City would be an ideal location due to its abundance of tidal resources, it is close to several main trading ports and an electric facility near this location would have the potential of interfering with economic activity. Therefore while technically feasible a tidal plant would not be the ideal solution for Cebu’s electricity production needs.

8.0 Wind power

Cebu does not have very good wind resources and its high population density creates the additional problem of the necessary land resources needed to place the wind turbines. The southern tip of the Island is one of the few locations where wind speeds are approximately 7.0 m/s.

Wind energy is created by the flow of air over the blade of the wind turbine. As the wind passes over the turbine blade the, the shape of the blade creates forces that make the blade move, spinning a rotor. The rotor in-turn spins the central drive shaft. The motion from the drive shaft is transferred to a higher speed rotation in the driveshaft which uses this energy and converts it to electrical energy in the generator as illustrated in Figure 11.

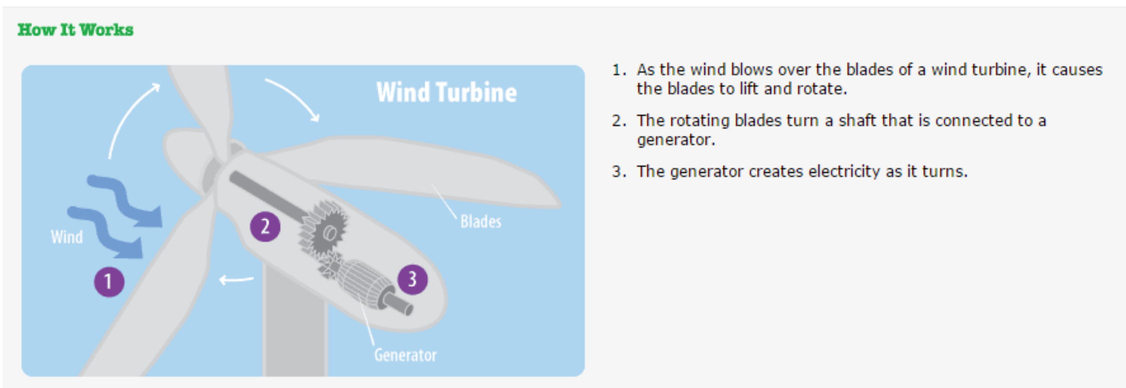


Figure 11 Schematic of wind turbine to illustrate how electricity is produced [12]

Average wind speeds on the island range from 4 m/s to 9 m/s (Labratory, n.d.). The southern part of the island has higher wind speeds, ranging from 7.0m/s- 9.5m/s. The calculations for wind potential are done using an average wind speed of 7.0m/s.

8.1 Location

The best location for wind resources in Cebu is located on the southern tip of the island as highlighted in Figure 12.

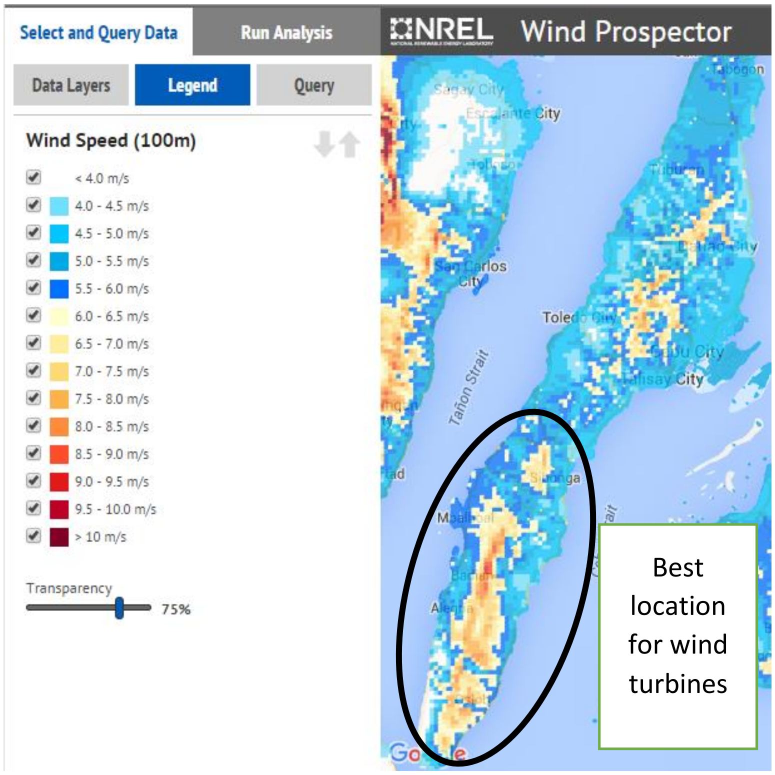


Figure 12 Location for wind turbines

8.2 Analysis

The assumptions used to analyze the potential for wind energy in Cebu are highlighted in Table 8. The overall cost of installing the wind turbines and maintaining them over 30 years is highlighted in millions of USD (MM) in Table 9. The cost is shown as a percentage of total cost in Figure 13. The total environmental impact from using wind power is shown in Table 10.

Table 8 Assumptions used to analyze the potential for wind power in Cebu

Assumptions Wind	Value
Capital Cost $/ Turbine	1036000
Diameter (m)	70
Land needed m/turbine	96211
Land Lease 4/ Turbine	5000
OM cost $ / Turbine/yr	30000
Fatalities/GWeYR	0.0019
Bat death / Turbine	45

Table 9 Cost analysis for wind power over 30 year life

30 Year Wind Cost Summary	Costs (MM)
Total Cost	$ 1,039
Capital Cost	$ 516
O&M	$ 448
Land Lease	$ 75

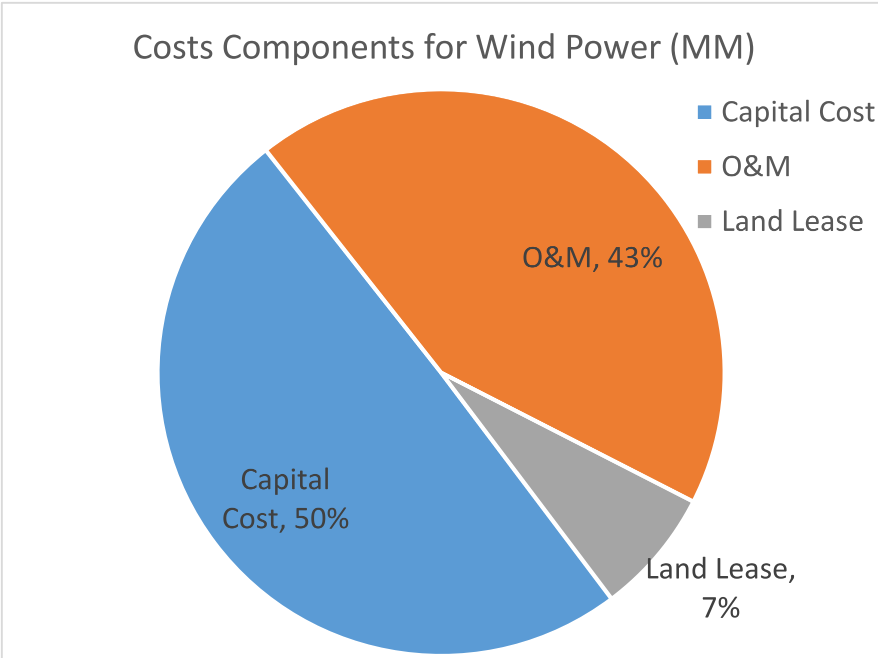


Figure 13 Cost components as percent of total cost for wind power

Table 10 Total environmental impact of wind power

30 Year Environmental Impact	Value
Fatalities	0.02
Bat Deaths	627300
Land (km^2)	48
Displaced People (507/km2)	24292

8.3 Transmission

The transmission network will be similar to the network in Figure 10 but will have two substations at the southern tip rather than the connection in Naga City.

The assumptions for the transmission cost analysis will be the same as those outlined in Table 6. The estimated transmission costs are summarized in Table 11.

Table 11 Estimated transmission cost for wind power

Transmission Cost	Value
Net km	231
Net Substation	17
Transmission AC line MM	54
Substation MM	119
30 Year O&M MM	24
30 Year Cost MM	198

8.4 Evaluation

The overall quality of the wind power potential in Cebu is considered to be moderate, furthermore a look at the population density and location of wind resources highlights a concern regarding human displacement as shown in Figure 14. The displacement of over 24 thousand people, Table 10, is considered to be very high and would likely have a significant impact on the island. Additionally the wind potential is noted to be concentrated on hilly areas of the island. The topography at this region would make placement of the turbines difficult and add additional cost to the estimate provided. Wind is not recommended to be a good resource for electricity production in Cebu.

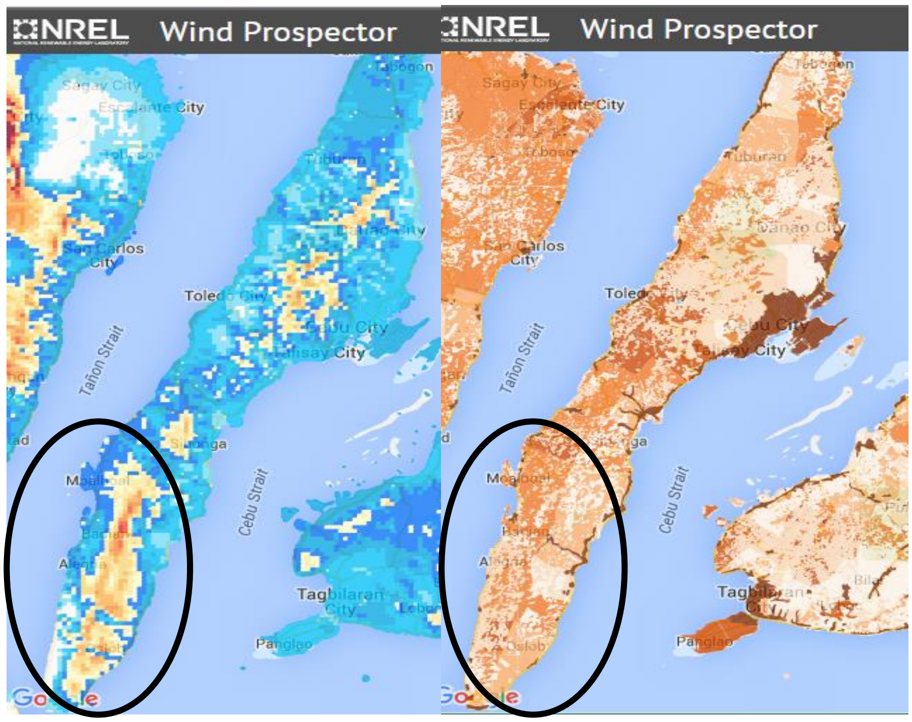


Figure 14 Wind resource quality is best in populated area of the island

9.0 Thermal Power

Thermal power plants generate electricity from heat. A working liquid, often water, is heated to generate steam. This steam is then used to turn a turbine which generates electricity, see Figure 15.

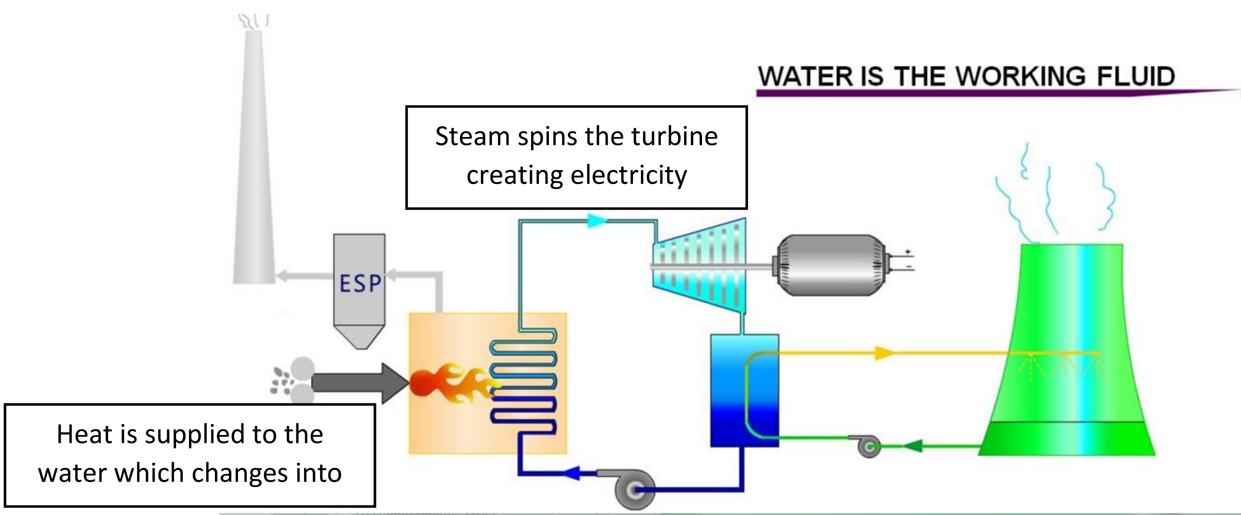


Figure 15 Thermal Power Generation [4]

While the type of fuel used to generate heat for the power plant can vary, all thermal power plants use a similar production method as shown in Figure 15 Different fuels can have different impacts for electricity production. Fuels that are burnt to heat water will generate higher greenhouse gasses when compared to fuels such as nuclear or geothermal. However, sources like nuclear will need additional environmental and safety considerations to be made to mitigate concerns like radioactive nuclear waste. Fuel sources can also have an impact in the efficiency of the production process. This report analyzes the potential for different fuels to be used as inputs for thermal heat production.

10.0 Fossil Fuels

Fossil fuels are non-renewable fuels that can be used in the generation of electricity. Examples of fossil fuels are coal, natural gas and oil. Fossil fuels are energy dense fuels and a convenient source of energy. They can easily be used to provide heat for the production of electricity in a thermal power plant.

Cebu currently has 8 fossil fuel based power plants [5]. The dominant source of fuel being coal but diesel and gas are also used and have a combined generation capacity of 1593 GWh [6]. If Cebu was not connected to the Visayas grid, it would need to generate 3834 GWh of electricity for its yearly consumption, with a peak power output needed of 747 MW.

Cebu has domestic coal reserves estimated at 18% of the world’s reserves at 458 million metric tons [7].

10.1 Fossil Fuel Plant Locations

As Cebu currently has Fossil Fuel powered power plants, the same locations will be used for new generation. These locations are near main ports and allow for the easy transport of the fuel. These locations are Toledo City, Naga, Brgy Colon and Cebu City. The locations are shown in Figure 16.

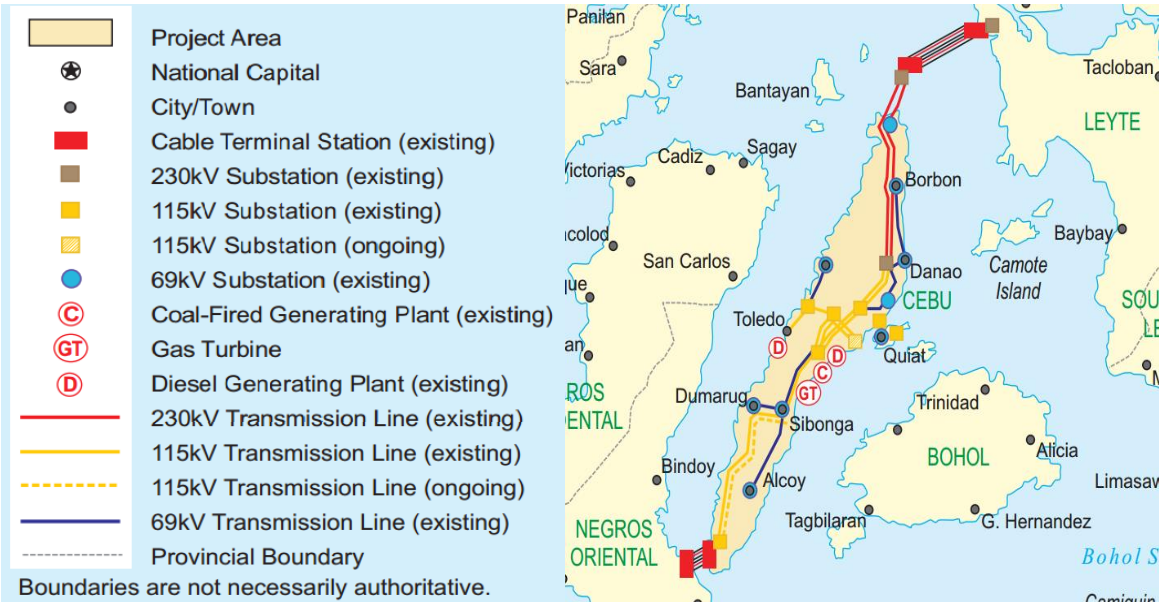


Figure 16 Current location of power plants

10.2 Analysis

The assumptions used for the analysis of fossil fuel plants are summarized in Table 12. The cost analysis is done by using the current market price of coal at $42 USD per Short ton [8] and for natural gas at $2.33 USDMMBtu [9]. The total overall fuel requirement for coal and natural gas is summarized in Table 13 along with a cost summary. The cost of natural gas and coal is also compared in Figure 17. The total environmental impact of fossil fuel plants is summarized in Table 14.

Table 12 Assumptions used for fossil fuel analysis

Assumptions Fossil Fuel	Coal Value	Natural Gas Value
Fuel MJ/kg	17.43	55.5
Cost/ kW	3500	584
CO_2 kg/MWh	1020	515
SO_2 kg/MWh	6	0.05
NO_2 kg/MWh	2.7	0.77
Water l/W/Year	17.6	0
Capacity Factor	64%	42%
Efficiency	30%	60%
Fatalities/GWeYR	0.569	0.115

Table 13 Fossil fuel cost summary

30 Year Fossil Fuel Cost Summary	Coal Value (MM*)	Natural Gas Value (MM*)
Total Cost	6282	2045
Capital Cost	2615	436
Fuel Cost	3667	1608
Fuel Million Metric Ton	79	12

*MM= Million USD

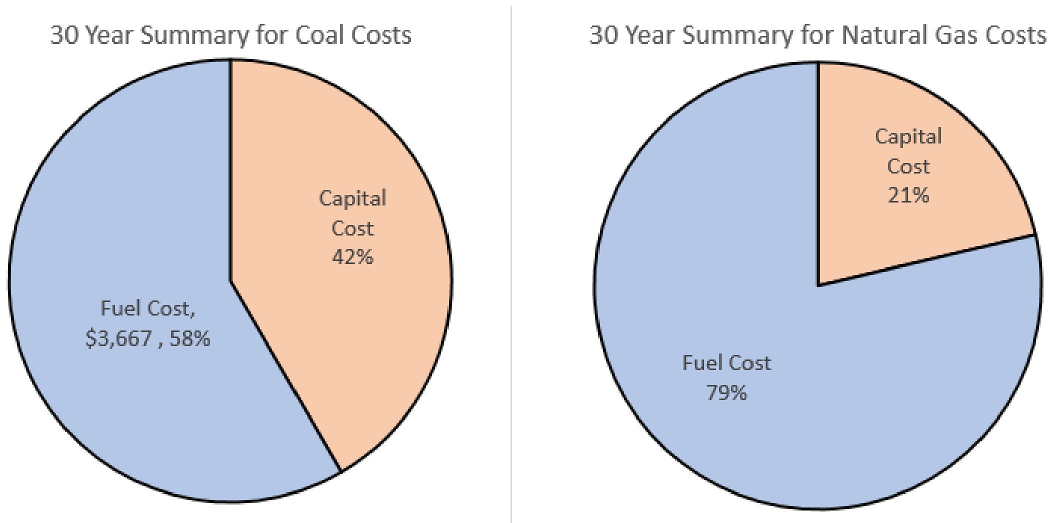


Figure 17 Fossil fuel cost breakdown as percent of total

Table 14 Environmental impact of fossil fuel plats over 30 year operation

30 Year Environmental Impact	Coal Value	Natural Gas Value
CO2 Thousand Metric Tonne	117349	59250
SO2 Thousand Metric Tonne	690	6
NO2 Thousand Metric Tonne	311	89
Water L	2024844	0
Fatalities	7	2

10.3 Transmission

A similar network to the one existing in Cebu is created with additional substations at the locations of the power plants. The assumptions used for the cost analysis of the transmission system are outlined in Table 6 Assumptions used for transmission cost analysis. The total transmission costs for Cebu Island for fossil fuel plants is summarized in Table 15.

Table 15 Transmission cost summary for fossil fuel plants

Transmission Cost	Value
Net km	231
Net Substation	18
Transmission AC MM	54
Substation MM	126
30 Year O&M MM	24
30 Year Cost MM	205

10.4 Evaluation

Fossil fuel power plants have the advantage of being able to supply base and peak load. They can easily be adjusted to manage peak demand for the island. However, fossil fuels come with a large environmental footprint and the advantage of installing coal and natural gas power plants should be measured against their environmental consequences.

11.0 Nuclear Power Plant

Nuclear power plants used radioactive material to provide the energy needed to heat the working fluid. A radioactive material such as Uranium 235 undergoes a process of fission whereby the atom splits apart releasing large amounts of energy. As the atoms split they hit other atoms and cause similar reactions. The energy released through the process of fission is captured and used to heat water which, similar to a thermal power plant, is then used to spin a turbine and generate electricity. Nuclear fuels are very energy dense and a small amount of fuel can release a substantial amount of energy. The nuclear power plant operates very similar to a thermal power plant where heat is added through a nuclear reaction. Figure 18 illustrates the key distinguishing element of a nuclear power plant.

The rate of nuclear reactions cannot be controlled at the speed with which electric demand changes. Therefore nuclear power plants typically provide base load power to an island. The Philippines does have some nuclear power but none exists on Cebu. While nuclear power plants do not release significant greenhouse gasses, the radioactive waste generated from the fission reaction must be carefully stored for years.

The nuclear reactor used for analysis here will be the CANDU reactor.

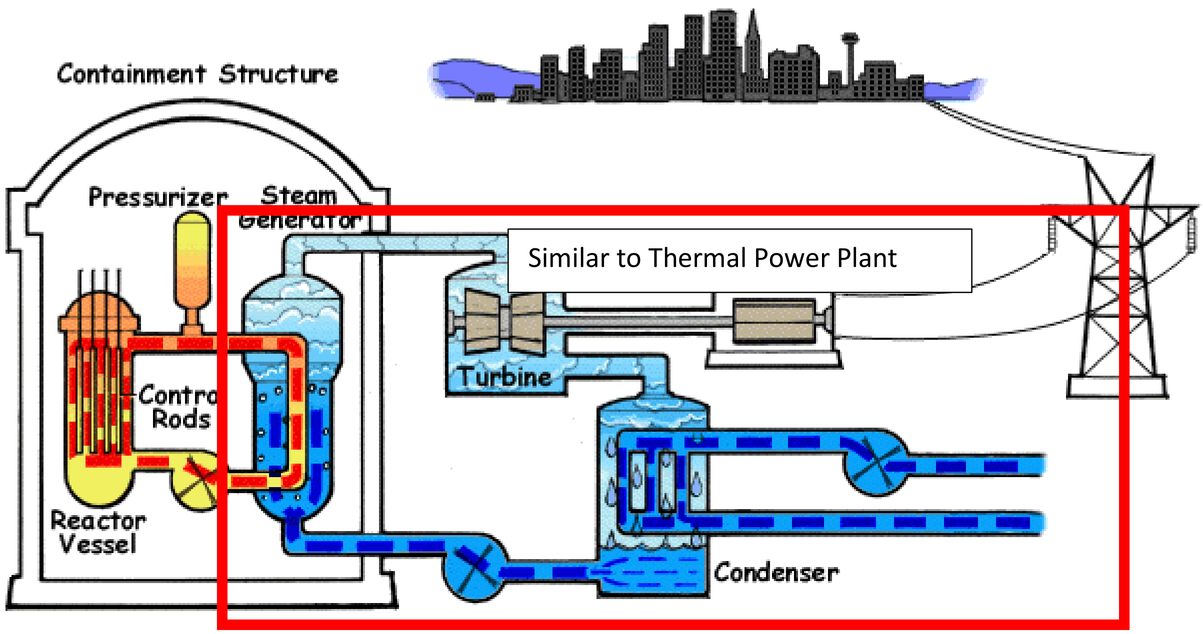


Figure 18 Key difference in nuclear power plants in how heat is added to the system

11.1 Location

A nuclear power facility would need easy access to water. Toledo City and Cebu City both provide ideal water access for nuclear installations. These cities currently have coal fire plants, similar locations can be used for nuclear, see Figure 19.

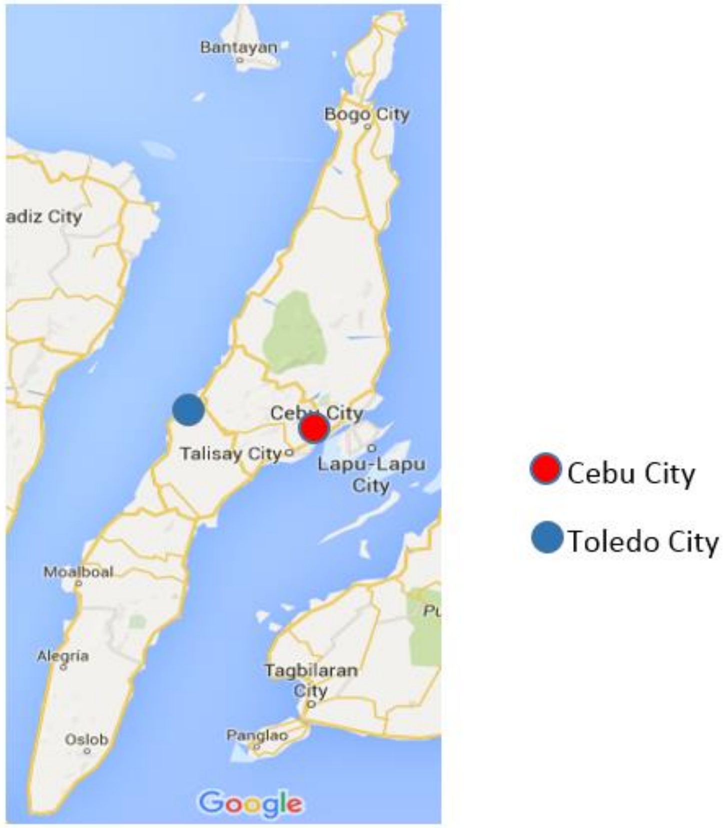


Figure 19 Nuclear power plant locations

11.2 Analysis

The assumptions used for analysis for the reactor are highlighted in **Error! eference source not found.**. The base load demand for Cebu is estimated from the overall power consumption for the year. The total lifetime fuel requirement for the nuclear plant is summarized in Table 18. The overall cost analysis is highlighted in Table 17 and a breakdown of the cost as a percentage of overall cost is shown in Figure 20. The total lifetime environmental impact of the nuclear facility is summarized in Table 19.

Table 16 Assumptions used to analyze nuclear power plants

Assumptions Nuclear	Value
Fuel Cost $/MWh	4
Demand Base MW (calculated)	438
Spent Fuel Cost $/MWh	1.45
Capital cost/ kW	2347
O&M Cost $/MWh/yr	10.85
Capacity Factor	0.9
Efficiency	0.3
Fatalities/GWeYR	0.00726
Mass Uranium kg/MW	45

Table 17 Cost analysis for nuclear power plants over 30 years

30 Year Nuclear Cost Summary	Costs (MM)
Total Cost	32540
Capital Cost	30824
Fuel Cost	460
O&M	1248
End of life	8

Table 18 Lifetime fuel requirement

Nuclear	30 Year
Replacement Fuel (Ton)	438
Amount of Fuel needed (Ton)	66

Table 19 Lifetime environmental impact

30 Year Environmental Impact	Value
Fatalities	0.01

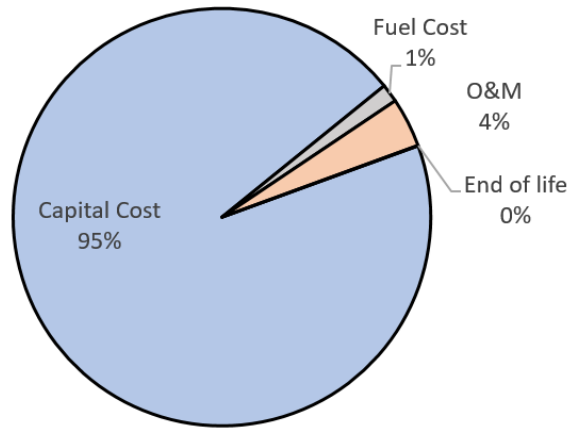


Figure 20 Nuclear cost comparison as percent of total

11.3 Transmission Cost

The transmission line breakdown used would be the same as the transmission structure for fossil fuels. Two nuclear plants of equal capacity would be built, one in Toledo City and one in Cebu city. The total transmission costs are summarized in Table 15 the analysis was conducted using the assumptions as outline in Table 6.

11.4 Evaluation

Nuclear power can be a feasible option to provide Cebu with electricity. The main concerns with nuclear energy would be the nuclear waste that is generated. It should be noted that nuclear waste can be recycled. While countries like Canada do not currently recycle this waste, places like France do and this can have a significant impact on the amount of waste that is generated. New nuclear fuels are also being developed that can help mitigate safety concerns regarding nuclear meltdowns.

12.0 Geothermal Energy

Geothermal energy harnesses the heat from the earth's core. The internal heat in the earth's core comes from gravitational stirring and the radioactive decay of uranium, thorium and other fissile material [13]. Pipes are placed into the ground after it has been drilled to reach a depth at which thermal energy released by the earth can be used to heat water. Water is then sent through the pipes, it is heated and then as it comes back out of the ground and it is used to generate electricity in a manner similar to thermal power plants. Figure 21 illustrates how a geothermal power plant operates.

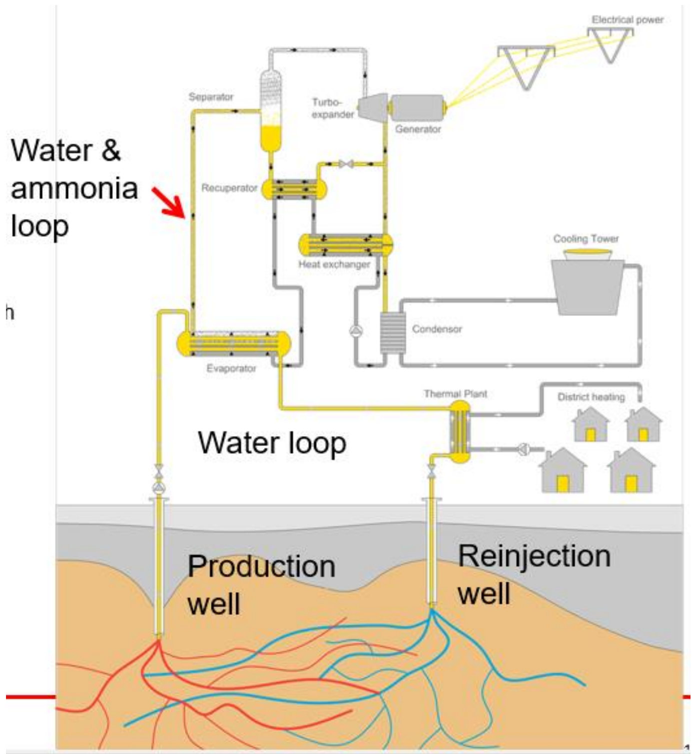


Figure 21 Schematic of geothermal power plant [18]

Geothermal energy is not intermittent and therefore can provide a predictable supply of electricity. This positions geothermal as a good source for base load power supply. The Philippines sits on 'The Ring of Fire' [14] , a region where there is very high geothermal potential at shallower depths (3km). The Visayas grid, of which Cebu is a part, receives approximately 50% of its electricity from geothermal sources [2]. Cebu does not currently have geothermal generation facilities but Toledo city has been recommended for projects for geothermal production [15]. For this assessment it is recommended that Toledo city be used for geothermal power installation. The sites where existing coal power plants are located will be proposed to be used.

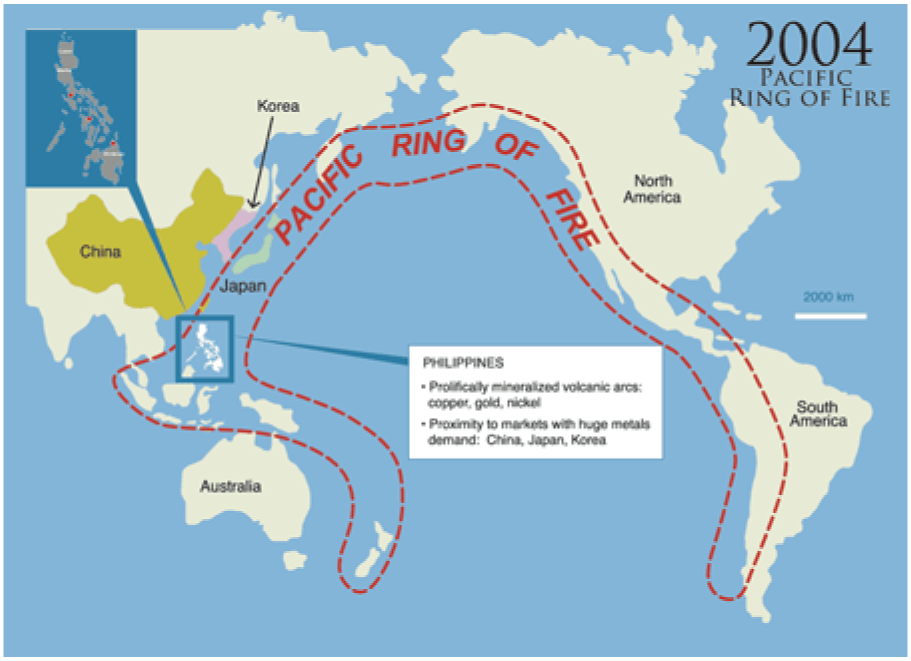


Figure 22 Location of pacific Ring of Fire in relation to Philippines [23]

12.1 Plant location

While most of Cebu has great geothermal resources, Toledo City has been proposed to be the location for a new plant. Toledo City currently has an existing coal fired plant which will be proposed as the location for the new installation. See Figure 23 for proposed location.

Figure 23 Toledo City as the proposed location of new geothermal plant

12.2 Analysis

The assumptions used to analysis for the geothermal plant are summarized in Table 20. The cost analysis is summarized in Table 21 and the cost comparison is illustrated in Figure 24. The overall environmental impact is summarized in

Table 22.

Table 20 Assumptions used for geothermal analysis

Assumption Geothermal	Value

Energy needed (GWh)	3835
O&M Cost cents/kWh	0.68
Cost $/ kW	3550
CO_2 kg/MWh	27
SO_2 kg/MWh	0.16
Land use m^2/GWh	404
Water l/MWh	0.003
Efficiency	20%
Fatalities/GWeYR	0.000762

Table 21 Geothermal cost analysis

30 Year Geothermal Cost Summary	Costs (MM)
Total Cost	2334
Capital Cost	1554
O&M	780

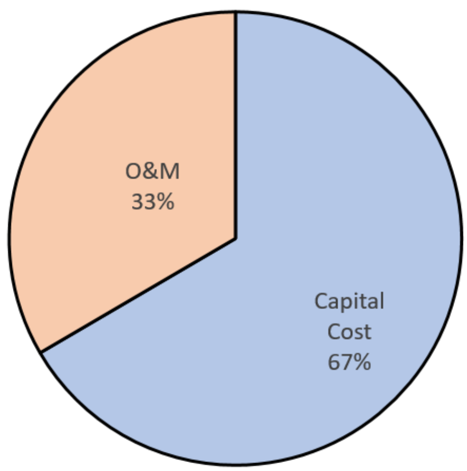


Figure 24 Geothermal cost comparison as percent of total

Table 22 Lifetime environmental impact

30 Year Environmental Impact	Value
CO_2 Ton	3141
SO_2 Ton	18

Water L	345144
Land (km^2)	46
Fatalities	0.02

12.2 Transmission

For geothermal energy only one power plant would be needed. Therefore the main changes to the transmission system would be one less substation. This will change the transmission costs as outline in Table 23. The assumptions used for the transmission analysis are summarized in Table 6.

Table 23 Geothermal transmission analysis

Transmission Cost	Value
Net km	231
Net Substation	17
Transmission AC MM	54
Substation MM	119
30 Year O&M MM	24
30 Year Cost MM	198

12.3 Evaluation

A key consideration for geothermal plants is their life and the amount of land needed to provide the energy. Preliminary calculations show that the geothermal source would provide the needed supply of energy for over 150 years. As such, the land needed to supply this amount of energy in the first year is only 1.5 km^2. It is estimated that the calculation of 46 km^2 is too conservative and does not accurately reflect the potential of geothermal source in Cebu. The land requirement for Cebu is not high and can be accommodated by using an existing power plant at Toledo city, without the need to displace any persons.

13.0 Biomass

Biomass power plants are very similar to fossil fuel power plants with the exception of the fuel source. In biomass power plants the fuel source can vary from agricultural waste, municipal waste to wood chips. Cebu has a large amount of biomass mass potential with the feed source being rice husk or bagasse. Additionally, like fossil fuel plants, biomass plants can be used to supply peak power. For this analysis rice husk will be used as the feed source.

13.1 Location

As the power plants would be similar to fossil fuel power plants it is proposed that Toledo city and Cebu city be used as sites for the power plants. The site locations are illustrated in Figure 16.

13.2 Analysis

The assumptions used to analyze the biomass plant are summarized in Table 24. The overall cost breakdown is summarized in

Table 25. The overall environmental impact of biomass electricity production is summarized in

Table 24 Assumptions used for biomass analysis

Assumptions Biomass	Rice Hull Value
Price$ / GJ	3.6
Source MJ/kg	15.5
Capital Cost $/ kW	3000
OM cost /MWh	50
CO_2 kg/MWh	75
Efficiency	0.3
Fatalities/GWeYR	0.569

Table 25 Cost analysis for biomass power production

30 Year Biomass Cost Summary	Costs (MM)
Total Cost	328643
Capital Cost	2241
Fuel Cost	320650
O&M	5752

Table 26 Lifetime environmental impact

30 Year Environmental Impact	Value
CO_2 Thousand Metric Tonne	8629
Fatalities	0.20

13.3 Transmission

As the locations of the power plants are the same as those in the fossil fuel section the costs and transmission lines will also be the same. See section 10.3 for analysis and summary.

13.4 Evaluation

It is noted that while a price of $3.6/GJ for rice husk is used to evaluate the cost of the power plant, rice is husk is a waste product. Therefore it is likely that the only costs associated with rice husk will be to transport it from a waste facility to the power plant. Additionally, in many jurisdictions a tipping fee is paid to any individual/ organization that is willing to take waste away from a landfill. Many biomass plants utilize this to help subsidize cost of operations. The quantity of biomass needed to generate electricity is considered to be extremely high for Cebu

14.0 Solar Thermal

Solar thermal power plants work by directly heating the working fluid by running it through solar panels. As the liquid heats up it is collected and sent through a turbine where, similar to a thermal plant, the working fluid spins the turbine and generates electricity.

Cebu does not currently have many sources of solar thermal electricity. The existing power plant locations at Toledo city are analyzed for solar thermal plant viability. Cebu city could also be a consideration, however the high population density in Cebu would make the land needed for solar thermal panels difficult to acquire. A simplified schematic of how solar thermal facilities would work is illustrated in Figure 25.

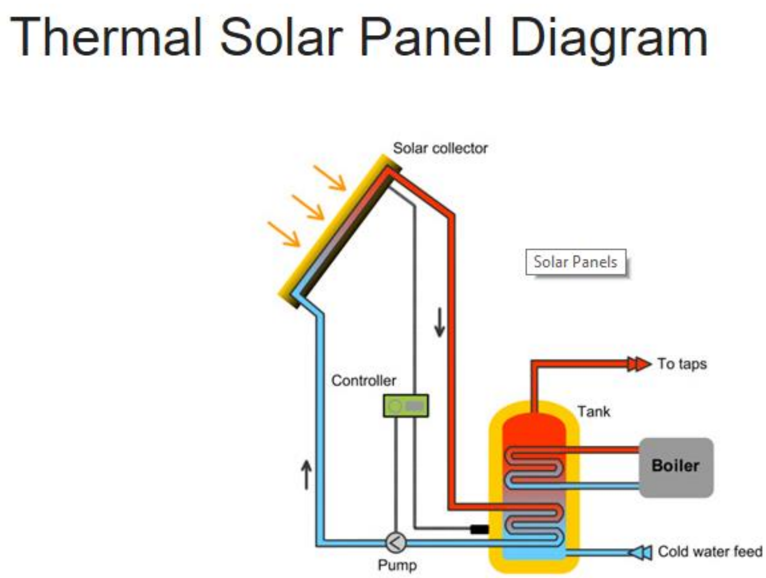


Figure 25 Simplified schematic of solar thermal installation [24]

14.1 Location

The same location as the geothermal power plant will be considered for this analysis, please see section 12.1.

14.2 Analysis

The assumptions used to analyze the solar thermal installation are highlighted in Table 27. The total cost analysis is outlined in Table 28. The overall environmental impact of solar thermal power is summarized in Table 29.

Table 27 Solar thermal assumption summary

Assumptions Solar	Value
Energy needed MW	2189
LEC cost $/kWh	0.07
Power per unit collector area W/m2	508
CO_2 kg/kWh	0.2
Solar Thermal Land m2/GWhr	3561
Water l/MWh/Year	108000

Efficiency	20%

Table 28 Cost summary for Solar Thermal

30 Year Solar Thermal Cost Summary	Costs (MM)
Total Cost (MM)	$ 8,053
LEC (MM)	$ 8,053.36

Table 29 Lifetime environmental impact

30 Year Environmental Impact	Value
CO_2 Thousand Metric Tonne	2
Water L	236399897
Land (km^2)	34
Displaced People (507/km2)	17309
fatalities	0.00

14.3 Transmission

The same transmission analysis as conducted for geothermal would be used for solar thermal. Please see analysis in section 12.2.

14.4 Evaluation

The total amount of land required for a solar thermal plant would be 34 km^2. The total amount of land mass for Cebu is 534200 hectares [18], which is estimated at 5,342 km^2. The amount of land needed to provide Cebu with thermal power translates to .6% of its total land mass and would result in the displacement of 17309 people. Additionally, solar panels require a location where the elevation grade does not exceeded 5 degrees [17]. Cebu has a fairly uneven topography that would make solar panel installation difficult.

15.0 Solar Photovoltaic (PV)

Unlike the power plants discussed in sections 7.0 to 14.0, where a turbine is needed to generate electricity by generating heat or through direct mechanical power, PV cells directly convert the suns energy into electricity. As light photons are absorbed by photoelectric material they release electrons and produce electricity [23]. A general schematic of how PV cells work is shown in Figure 26.

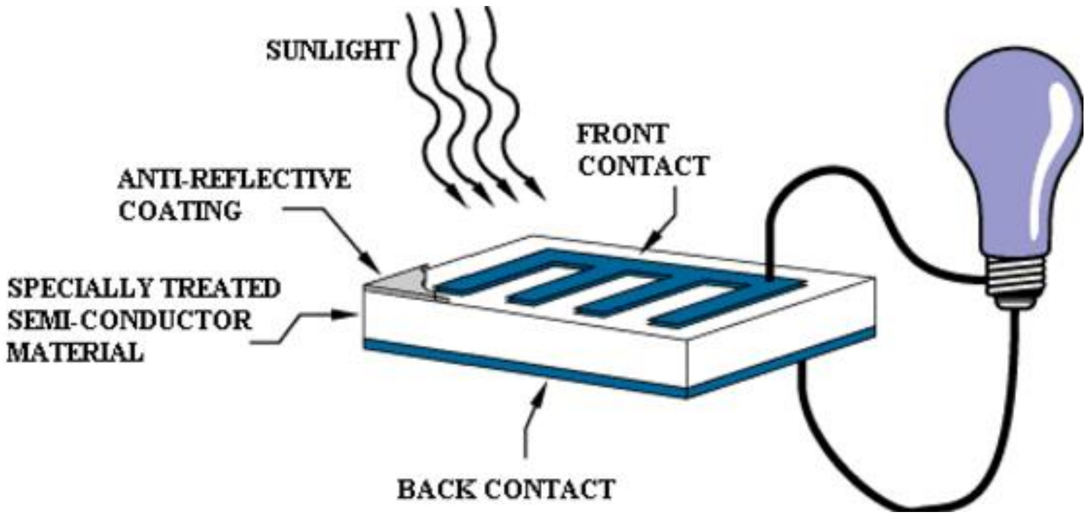


Figure 26 Schematic of how PV cells work

15.1 Plant location

PV panels have the advantage of being easy to install on rooftops, therefore they have the potential to be easily integrated into city infrastructure without causing much disruption. PV panels would need strong rooftops and would likely not be installed easily in rural areas. With the very high population density of Cebu city along with its reputation for being a metropolitan urbanized area, it is expected that Cebu city will have a large amount of viable rooftop locations to be used for generating electricity through solar panels. Thus Cebu city will be analyzed for its potential as a PV generation site. Please see Figure 16 for location of Cebu city.

15.2 Analysis

The assumptions used to analyze the feasibility of Solar PV are highlighted in Table 30. The overall cost breakdown is summarized in Table 31. The 30 year environmental impact of Solar PV is summarized in

Table 30 Assumptions for Solar PV

Assumptions Solar PV	Value
Yearly Insolation kWH/m^3/day	5
Capital Cost/ kW	7500
P_{panel} W/m2	127
Panel efficiency, η	0.3
Demand	970
LEC $/kWh	0.2
CO2 kg/kWh	0.2
Capacity Factor	0.2
Land m2/GWh	3237

Table 31 Total cost for Solar PV

30 Year PV Cost Summary	Costs (MM)
Total Cost	$ 850
LEC	$ 850

Table 32 Lifetime environmental impact

30 Year Environmental Impact	Value
CO_2 Thousand Metric Tonne	5821
Land (km^2)	14
Displaced People (507/km2)	6974
fatalities	0.00

15.3 Transmission

The overall cost of the transmission would be calculated using the assumptions in Table 6. The cost of the transmission network is estimated in Table 33.

Table 33 Transmission network cost estimate

Transmission Cost	Value
Net km	231

Net Substation	17
Transmission AC line MM	54
Substation MM	119
30 Year O&M MM	24
30 Year Cost MM	198

15.4 Evaluation

Solar PV would need 14km^2 of land or rooftop space for installation. Solar PV like Solar Thermal panels would need a flat grade of land for installation. While Solar PV does present an attractive option of electricity supply it would be recommended that the panels be placed on rooftops to avoid the displacement of almost 7 thousand people. Additionally Solar PV is an intermittent source and would need a complimenting technology to ensure electricity stability to the grid.

16.0 Energy Storage

Energy storage technologies can temporarily store energy for a period of time and then release that energy back into the grid when it is desired (Policy Department A, 2015). These technologies can be used to store electricity for a few seconds, a day or even a few months. The type of storage technology used will be dependent on the need for storage within the system. Utility scale storage projects would be large and comprise of technologies such as pumped hydro while distributed generation technologies may benefit more from small scale thermal storage or battery banks.

While there are several types of technologies available for storage the following analysis will concentrate on battery technology. For this analysis wind, solar PV and solar thermal technologies will be analyzed for use with battery technologies. These fuel sources are intermittent and would need to be supplemented to ensure electricity reliability and power supply.

16.1 Location

The location of the energy storage technology will be assumed to be near the location of the power plants being analyzed.

16.2 Analysis

The assumptions used to carry out the analysis for energy storage are highlighted in Table 34. The total cost analysis for storage is summarized in Table 35. The 30 year environmental impact of using batteries is summarized in Table 37. The total discharge rate for each installation is highlighted in Table 36.

Table 34 Assumptions used to calculate energy storage potential

Assumptions Storage Ni-Cd	Solar PV	Wind	Solar thermal
Capacity Factor	19%	32%	77%
Battery storage years	30	30	30
NI-Cd efficiency	0.65	0.65	0.65
Capital cost $ /kW	1000	1000	1000
Ni-Cd kWh/ton	30	30	30
VOC (g/kg)	2	2	2
CO (g/kg)	4	3.5	4
NOx (g/kg)	17	17	17
PM (g/kg)	12	12.1	12
SOx (g/kg)	79	79	79
CH_4 (h/kg)	9	8.8	9
N_2O (g/kg)	0	0.1	0
CO_2 (kg/kg)	13	12.5	13

Table 35 Cost summary for storage

30 Year Storage Cost Summary Ni-Cd	Costs (MM)
Total Cost (MM)	$ 747

Table 36 Discharge rate for each production source

	Solar PV	Wind	Solar thermal
Discharge in Days	5	3	1

Table 37 Lifetime environmental impact

30 Year Environmental Impact	Storage Emissions Solar PV

CO_2 Ton	2208.51
SO_2 Ton	13.96
NO_2 Ton	0.02
VOC Ton	0.35
CO Ton	0.62
PM Ton	2.14
CH_4 Ton	1.55
N_2O Ton	0.02

16.3 Transmission

No additional transmission infrastructure would be added as the storage facilities will be built next to the energy production facilities.

16.4 Evaluation

Given the capacity of 747 MW of peak demand required by the island and the discharge days as calculated in Table 36 energy storage does not seem to be a feasible option using battery technology. According to Table 36 (also slide 40 in [25]) the discharge rate for all PV applications is 5 days. Irrespective of the rated power chosen for the storage device, according to Figure 27, no battery option will allow for a discharge rate of 5 days. Solar thermal seems to be the only option that could be able to technically allow for battery storage technology as a compliment. Given that no hydro option is present at Cebu the energy storage alternative does not seem to be practical.

It is noted that there is an assumed inconsistency in the analysis. The discharge rate is assumed to be anomalous for Solar PV calculations. It will be assumed that Solar PV applications are feasible with energy storage compliments. This assumptions will be made based on the proliferation of Solar PV and battery installations and also the development of solar farms for PV storage [26].

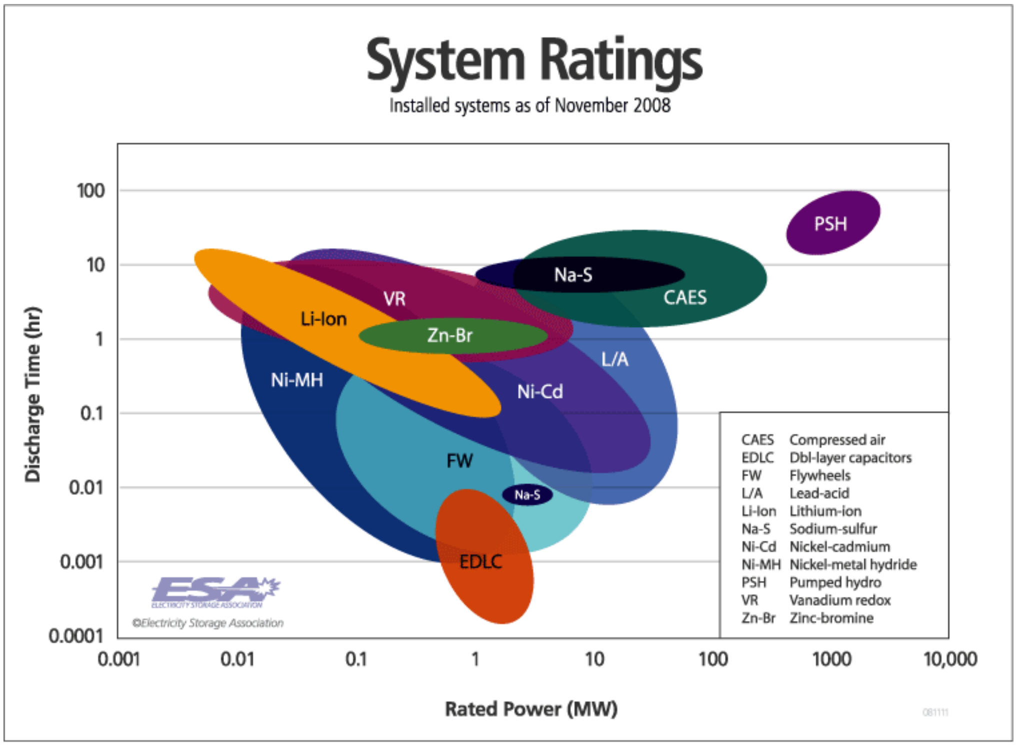


Figure 27 Feasibility for battery storage [29]

17.0 Overall analysis

The following analysis will compare each source of production and evaluate them on 4 measures cost competitiveness, environmental impact, safety and overall desirability.

17.1 Cost competitiveness

The overall cost analysis is shown in Figure 28 however this cost shows that the biomass production would be the costliest means for electricity production. This cost is very high due to the estimated fuel cost. As agricultural waste would be used for this production the true cost of biomass production is accurately reflected in Figure 29. Figure 30 shows a blended cost of production. According to this analysis wind and solar PV are the most economical means of electricity production.

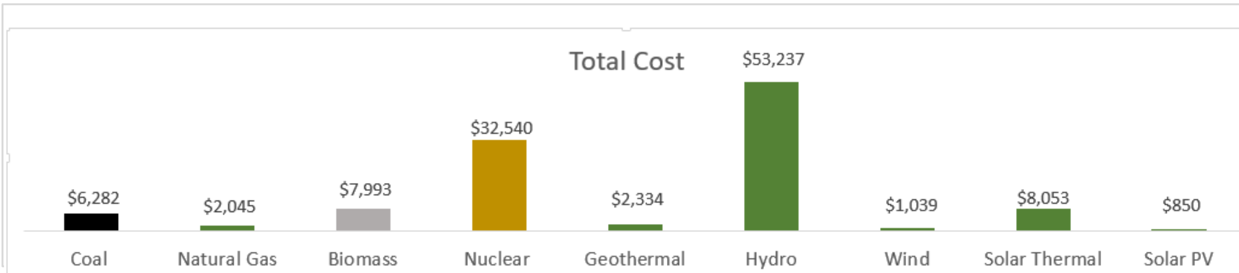


Figure 28 Overall cost comparison

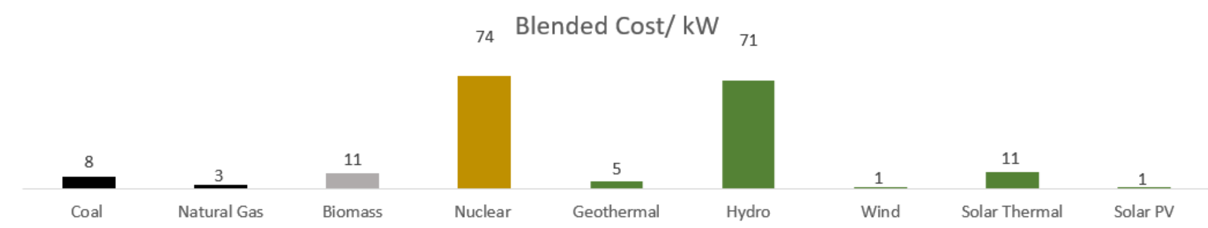


Figure 30 Blended fuel cost without biomass fuel cost

17.2 Environmental Impact

An environmental impact assessment as show in Table 38 shoes that coal has the highest greenhouse gas emissions while solar thermal uses the most amount of water. Additionally the largest land footprint is attributed to wind. It is noted that while solar PV does show to use land this will be in the of rooftop space, additionally while geothermal is calculated to need yearly expansion for continued operation the resource in Cebu is very rich and no new geothermal wells are expected to be needed for 30 years. The largest number of people displaced will be sue to wind installations

Table 38 Environmental impact assessment

30 Year GHG	Coal	Natural Gas	Biomass	Geothermal	Solar Thermal	Wind	Solar PV
CO_2 Thousand Metric Tonne	117349	59250	8629	3141	2	0	5821
SO_2 Thousand Metric Tonne	690	6	0	18	0	0	0
NO_2 Thousand Metric Tonne	311	89	0	0	0	0	0
Water L	2024844	0	0	345144	236399897	0	0
Land (km^2)	0	0	0	0	34	48	14
Displaced People (507/km2)				174987932	17309	24292	6974

17.3 Safety

The overall fatalities are summarized in Table 39. The safest electricity production resources are solar thermal and hydro while the most dangerous is coal.

Table 39 Fatalities expected during operational life

	Coal	Natural Gas	Biomass	Nuclear	Geothermal	Hydro	Wind	Solar Thermal	Solar PV
Fatalities	7.473	1.510	0.196	0.095	0.023	0.000	0.025	0.000	0.003

17.4 Overall desirability

Overall desirability is measured by a combination of a feasibility score and a renewable score. A feasibility score is given if the proposed method of production can be implemented without causing significant disruption or encountering a significant technical challenge. A renewability score is allocated if the proposed means of electricity production does not release significant emissions.

From the analysis shown in Figure 31 and Figure 32 it is noted that coal, natural gas, biomass, nuclear, geothermal and solar PV are all feasible options for producing electricity on the island. The island currently generates electricity though coal and natural gas. Biomass would be similar production method. Nuclear is a possible means of production though it has a high cost. Geothermal resources are very rich on the island and in the neighbouring provinces and are expected to be one of the best resources for Cebu. Additionally solar PV is also an economical and potential option given the urban nature of Cebu. Wind would require the displacement of significant people and the topography of the island would also be a challenge for wind installations. Therefore wind is not considered to be a feasible resource for electricity production on the island. Hydro resources are either limited or production through hydro facilities would interfere with existing economic activity, and this considered not feasible. Solar thermal would require significant amounts of land which would result in the displacement of large number of people. Additionally the grade of land needed to install the solar thermal panels is a challenge for Cebu's uneven topography. Thus solar thermal is not considered to be a technically feasible option.

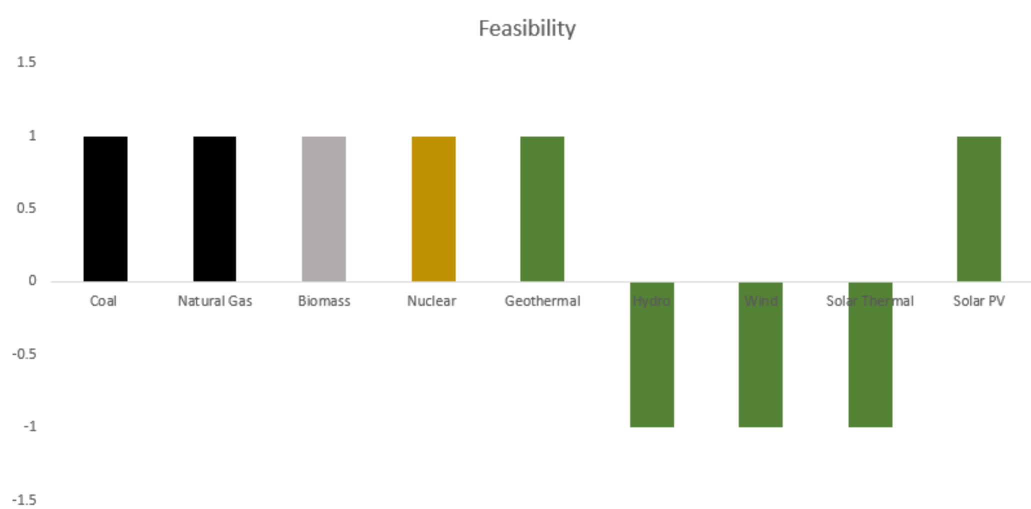


Figure 31 Feasibility ranking

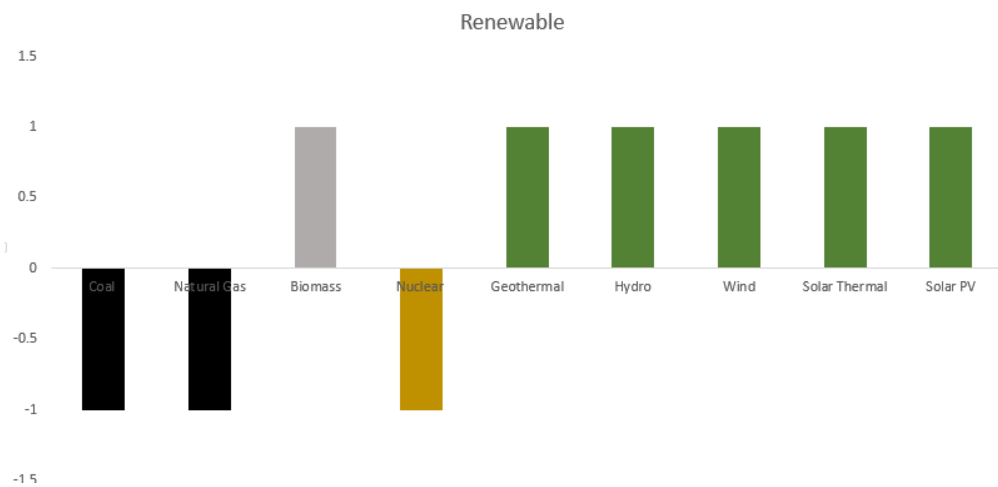


Figure 32 Renewable ranking

Cebu Island is looking to integrate more renewable resources within its energy mix. Thus it is noted that the non-renewable energy alternatives will not be considered viable options for Cebu. From the renewable alternatives only geothermal and solar PV are feasible. A combination of these two sources will be recommended for the Cebu overall electricity production grid.

18.0 Recommendation

It is recommended that a combination of geothermal with solar PV be used to supply the island with electricity. Geothermal would provide baseload power while solar PV paired with energy storage would provide peak power supply.

18.1 Location

The geothermal plant analyzed at Toledo city is recommended for the final location. The final location for the solar PV plant is recommended to be Cebu city.

Figure 33 Location for final power plants

18.2 Analysis

The overall cost analysis for geothermal and solar PV with storage are analyzed to be highlighted in Table 40. The overall capacity for which each option is selected is summarized in Table 41. Table 42 summarizes the total net environmental impact of the proposed option. The proposed option has no recorded fatalities over the 30 year expected life.

Table 40 Overall cost analysis for final recommended option

Summary	Geothermal	Solar PV	Storage	Total
Total Cost (MM)	$ 2,334	$ 352	$ 309	$ 2,995
Capital Cost (MM)	$ 1,554	$ -	$ 309	$ 1,863
O&M	$ 780	$ -	$ -	$ 780
Other	$ -	$ 352	$ -	$ 352

Table 41 Load type and capacity

	Geothermal	Solar PV Final
Load (MW)	438	309
Load Type	Base	Peak

Table 42 Net lifetime environmental impact

30 Year GHG	Geothermal	Solar PV	Storage Ni-Cd	Net
CO_2 Ton	3140.8	2409.5	0.9	5551.2
SO_2 Ton	18.4	0.0	5.8	24.2
NO_2 Ton	0.0	0.0	1.2	1.2
Water L	345.1	0.0	0.0	345.1
Land (km2)	0.0	0.0	0.0	0.0
VOC Ton	0.0	0.0	0.1	0.1
CO Ton	0.0	0.0	0.3	0.3
PM Ton	0.0	0.0	0.9	0.9
CH_4 Ton	0.0	0.0	0.6	0.6
N_2O Ton	0.0	0.0	0.0	0.0

18.3 Transmission

The net transmission cost is estimated to be a blend of the cost for geothermal and solar PV. Storage will not reflect a significant portion of the cost as storage sites will be built near production facilities. The overall transmission cost is summarized in Table 43.

Table 43 Overall transmission cost

Transmission Cost	Value
Net km	231
Net Substation	18
Transmission AC MM	54
Substation MM	126
30 Year O&M MM	24
30 Year Cost MM	205

18.4 Evaluation

The recommended option is evaluated and compared to the existing coal plants in this section. Figure 34 breaks down the cost components for coal and the recommended alternative. Coal has an additional cost of fuel that is reflected in the ‘other’ cost. A comparison of the estimated overall environmental cost of coal relative to the recommendation in Figure 35 also shows that the recommendation has far less of an impact on the environment. The comparison leaves out the toxins from battery development as the magnitude of these emissions is very low and considered to be negligible.

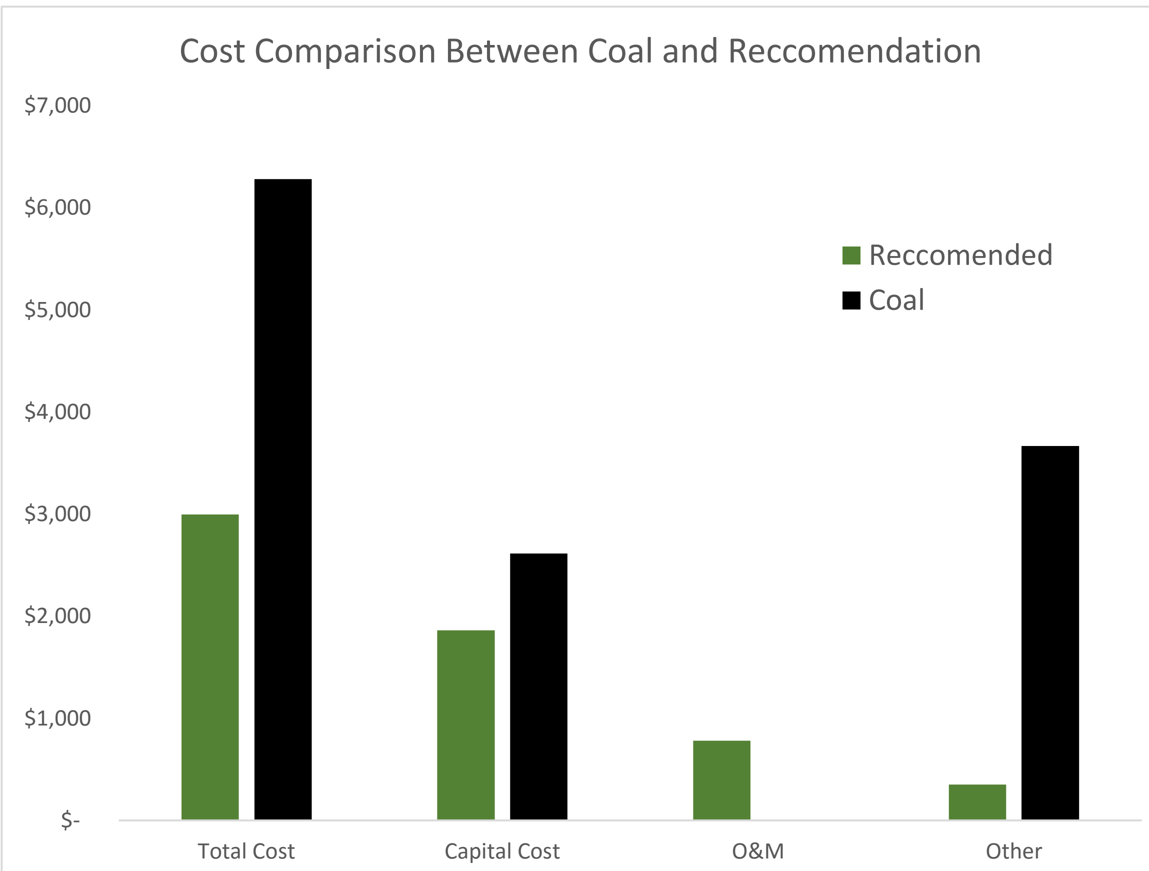


Figure 34 Cost Comparison between coal and recommendation

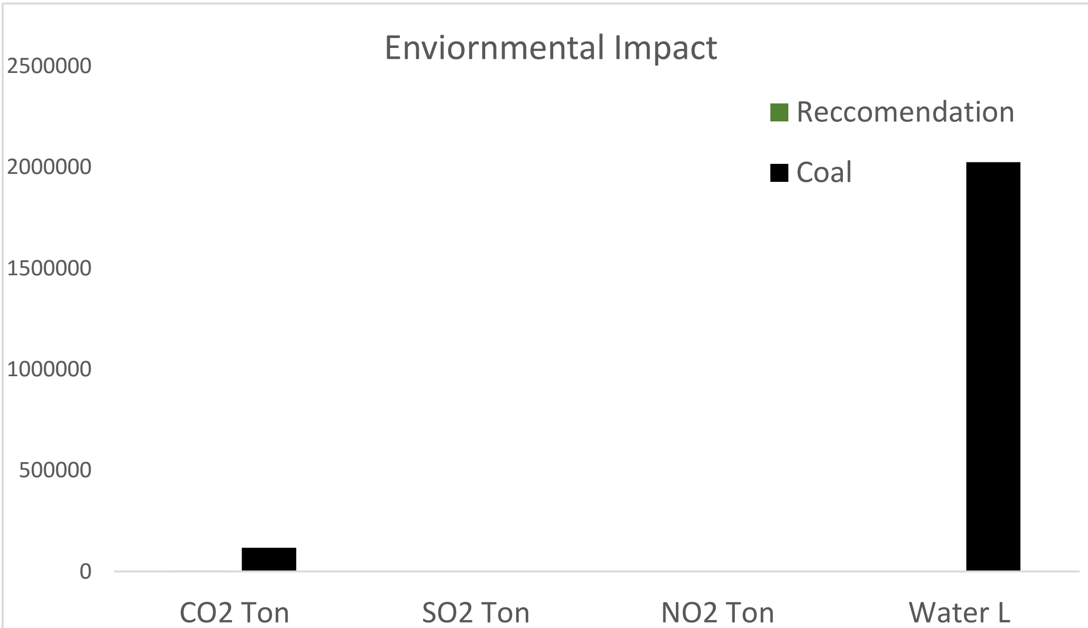


Figure 35 Comparison of the lifetime environmental impact

19.0 Conservation

In addition to the recommendations for electricity production the following recommendations are made for energy conservation by sector:

19.1 Residential

Residential consumers may consider turning off appliances during the day. Energy efficient appliances like efficient air conditioners and washers should be used. Given the climate of Cebu consumers may want to limit the use of dryers. Better insulation on windows and in homes can also reduce the amount of energy wasted as cool air leaks. Better use of blinds and shades can also have reduce how much homes will heat up.

19.2 Commercial

Commercial consumers may want to change all light fixtures in offices to high efficiency LCD bulbs. Additionally they may consider limiting the use of air conditioners during the summer. Better more energy efficient computers and technical equipment will reduce the amount of energy wasted heat.

19.3 Industry

Industry players may want to make use of energy efficient appliances and machinery. Better more efficient machinery can also help reduce the amount of energy consumed.

20.0 Conclusion

This report summarizes the potential options for Cebu Island for energy production. Cebu has expressed a desire to integrate renewables and conserve its natural environment this renewable resources like geothermal and solar PV were considered to be more favorable. Cebu has the potential to maintain its existing urban culture and continue its economic growth by shifting to geothermal and solar PV.

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