Assessment of a Potential Hybrid Offshore Renewable Energy Resources for Power Generation

by

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Dissertation submitted by in partial fulfilment of
the requirements for the
Bachelor of Civil Engineering with Honours

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved by,

____

(Dr. Montasir Osman Ahmed Ali)

UNIVERSITI TEKNOLOGI PETRONAS

SERI ISKANDAR, PERAK

January 2022

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MUHAMMAD IZZAT BIN SUHAIMI

ABSTRACT

Fossil fuels are non-renewable energy that once they have been used up, they can only be replenished on a geological time scale, which would take a long period of time. As the exploration of the power generation and the method of supplying energy to them are further evolving, more and more aspects are needed to be considered. One of the most important factors that is needed to be consider is the sustainability of the power generation as the conventional method could cause concern such as high pollution and high cost of application. Hence, nations around the world are increasingly turning from fossil fuels to renewable energy to power their economies, industries, and lifestyles. However, a single renewable energy is not the best of initiatives as it conjures a lower productivity rate, more intermittency problems, tends to overdesign, has fewer capacity factors, and has a high intra-annual variability of energy production as compared to a hybrid offshore renewable energy resource. The acquired levelized cost is also in the allowable range and the reduction of emission was approximately 281kton/year. The proposed resolution could lead to further develop the energy generation, enabling new ideas and improvements for the hybrid offshore renewable energy resources system to be broadly implemented in the future.

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First and foremost, I would want to deliver my sincerest form of appreciation towards Universiti Teknologi PETRONAS for the continuous cultivation of knowledge during the course of five years of my study.

In addition, I would like to acknowledge my supervisor, Dr, Montasir Osman Ahmed Ali, for the never-ending support and guidance throughout this research study. His outlook on this subject has been an inspiration towards me and constantly piqued my interest in this study. This research has also enhanced my understanding in this subject while given me an unforgettable experience in preparing a research paper.

Lastly, I would like to express my gratitude to my family and friends for their crucial support of me undergoing my Final Year Project II. Their encouragement has motivated me to never give up and to always give my best in every endeavour.

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CHAPTER 1

INTRODUCTION

1.1 Background

To lessen the most awful effects of environmental change, countries all throughout the world are progressively abandoning petroleum products to environmentally friendly power to drive their economies, enterprises, and ways of life. Fossil fuels are non-renewable energy that once they have been used up, they can only be replenished on a geological time scale, which would take a long period of time. According to World Metrological Organization (2019), the globally average centralizations of carbon dioxide arrived at 407.8 parts per million (ppm) in 2018, which is a significant rise from 405.5ppm in 2017. Conference of scientists likewise figures a temperature ascension of 2.5 to 10 degrees Fahrenheit over the course of the following century (NASA, 2019). During the present period, renewable energy is under immense development throughout the world parallel with the advancement of modern technology. Hence, it is inevitable the accumulation of said energy will be done vastly in the future.

Renewable energies, such as, wave, tidal, wind and solar have different concentration depending on various locations on Earth. It has been estimated that the global coastal energy resource to be greater than 2TW. Generally, the locations with a high potential for wave power are the northern part of UK, and along the Pacific coastlines of North and South America, Southern Africa, Australia, and New Zealand. The north and south region are the optimum for capturing wave power with temperate zone. So, it became a responsibility for countries to make use of these already existing renewable energy resources to power their economy and take it for granted. It will produce a lot of benefits in the long run, and it is a sustainable investment for a healthy environment and future for the coming generations. But according to studies, it is not reliable to only depend on single renewable energy resource. Therefore, this paper will delve more into a hybrid of two offshore renewable energies.

1.2 Problem Statement

Conventionally, power generation through a single renewable energy resource could cause high degree of pollutions let alone using the traditional systems, for example, gas turbines to generate power for offshore oil and gas platforms. As time goes by, taxes are incurred to parties that exceed a certain limit of greenhouse gas emission such as CO_2 and NO_X. This gives the countries another reason to switch to renewable energy resources to generate power for their economy and population. But using single renewable energy resources alone are not the best initiatives to combat with these issues, that is the reason why we opt for the integration or a hybrid offshore renewable energy resource, in this case, wave and solar energy hybrid system. The emphasis is on developing a sustainable power generation.

1.3 Objectives

There are three objectives in this study which are:

- To collect relevant data for wave and solar energy for a particular location.
- To determine power generated using independent renewable energy.
- To analyse data when using hybrid offshore renewable energy resources.

1.4 Scope of Study

The scope of study covers all the important aspects that are going to be conducted in this project and focuses on specific locations in the region of Indonesian wave. The aim of this study is to assess whether the location stated earlier have the adequate energy, in this case, wave and solar energy required for power generation. Therefore, a few parameters have been taken into further consideration to execute the necessary calculations. Furthermore, stated are the area that will be covered in this study, assessment of wave and solar information in distinct spot, which is Davao Gulf, Philippines, calculation of power generation per month in a specific period, and the sustainability of hybrid offshore renewable energy resources implementation.

For the calculation of power generation for wave and solar energy, the parameters that are taken into consideration are as following:

i. Significant wave height
ii. Wave speed
iii. Wave peak period
iv. Solar irradiance

CHAPTER 2

LITERATURE REVIEW

Since the commencement of the Industrial Revolution, fossil fuels have been the dominant source of energy for developing nations with increased human health and welfare. According to the World Energy Outlook 2020, fossil fuels will continue to dominate the global energy system in 2019, with oil accounting for 32% of primary energy supply, natural gas at 23%, and coal at 26%. As a result, pollution and climate change have become more prevalent in recent years, with CO2 emissions from fossil fuel burning accounting for the majority of greenhouse gas emissions. On the other hand, energy security has become problematic as a result of a combination of increased political concerns in important energy-producing countries, resource competition, and record oil prices. Figure below shows the data of which source are used the most in the production of electricity.

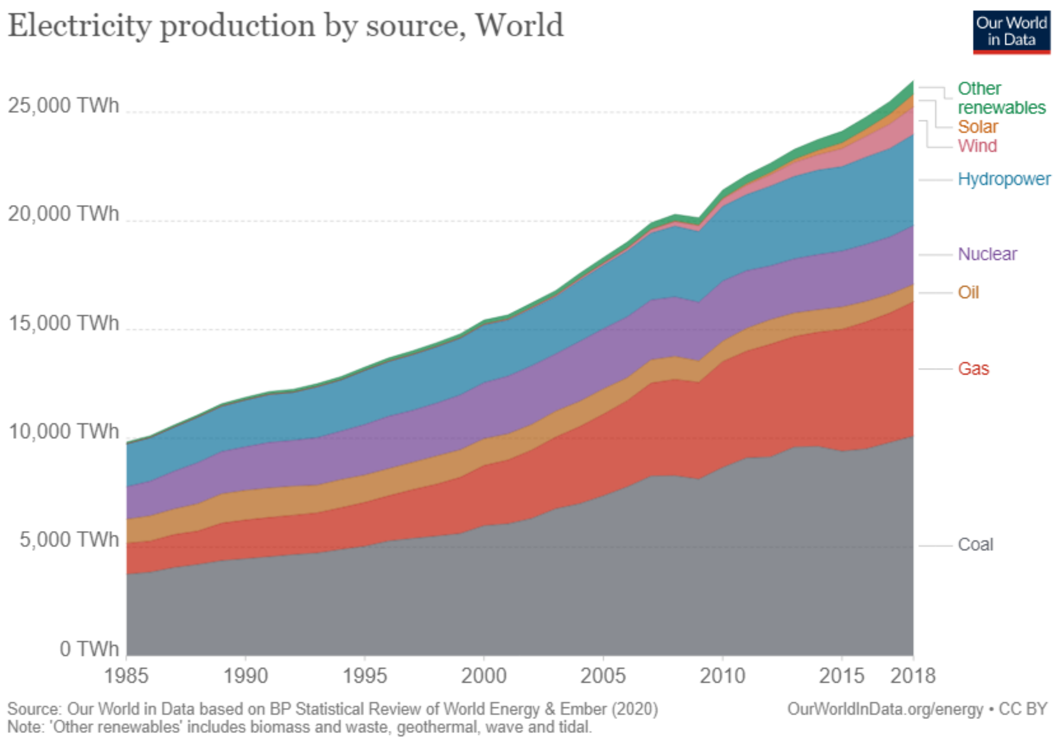

FIGURE 2.1: Fossil fuels with the highest source of power generation.

Renewable energy, in its most basic form, is obtained from natural elements that can be replaced in less than a human lifetime without depleting the planet's resources. Sunlight, wind, rain, tides, waves, biomass, and thermal energy stored in the earth's crust are all resources that are available in some form or another practically everywhere. They're nearly indestructible. They also have a negligible influence on the environment and climate. Furthermore, concentrating on renewable energy sources rather than fossil fuels and coals may aid in the reduction of environmental consequences such as air pollution and greenhouse gas emissions. Regardless, each technique of producing electricity has its own set of consequences.

In addition, renewable energy, particularly coastal energy, provides a number of environmental benefits. It also multiplies the amount of energy produced, is less expensive than electricity, and, with a growing focus on global warming and many governments setting ambitious carbon-reduction goals, one of the unexpected renewable energy perks is that it has instantly become a part of important growth in the economy. To put it another way, renewable energy is our best chance for endless and zero-harm energy sources for generating power. Renewable energy sources such as solar, wind, and wave may be implemented at a lower cost and in less time than traditional fossil fuels. In the long term, renewable sources are unquestionably the best alternative since they provide energy and with much less carbon emissions than fossil fuels. Figure below shows the reduction of renewable energy cost over the years.

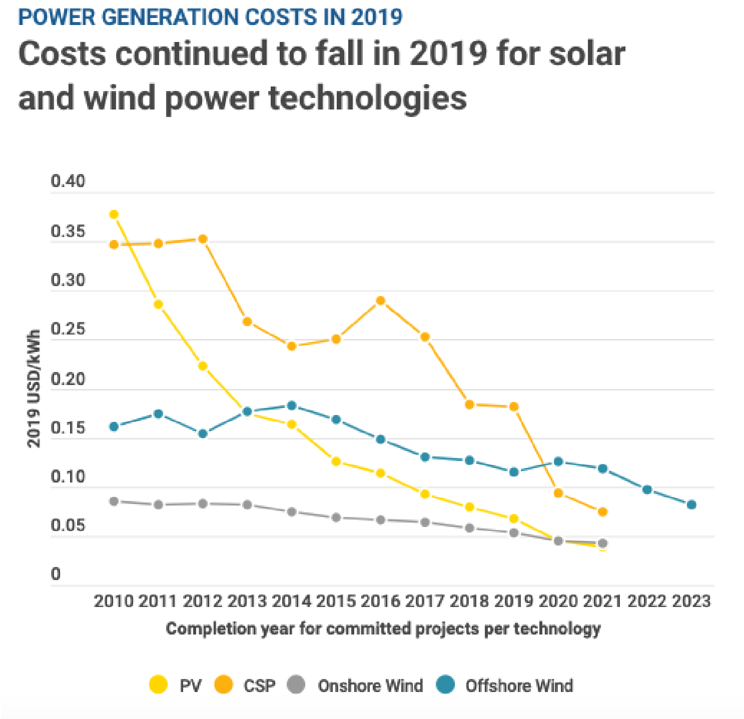

FIGURE 2.2: Falling of cost of renewable energy.

According to He et al. (2013), offshore oil and gas platforms require a lot of energy, ranging from 10MW to a few hundreds of MW, depending on a few parameters such as the platform's dimensions and the field's condition or attributes. Gas turbine engines supply the essential energy for power generation on these typical platforms. As a result, there is a larger usage of fuel and a 30% reduction in efficiency, resulting in a negative impact on carbon footprint (Francisco Haces-Fernandez, 2018). According to several studies, classic gas turbines used in power generation are the primary contributors of CO2 (carbon dioxide) and NOX (nitrogen oxides) (nitrogen oxide). According to Rusu L. (2019), the expansion of the economy in the previous ten years has been the primary contributor to increased greenhouse gas emissions, particularly CO2 from the combustion of fossil fuels. As a result, it's critical to look for alternative solutions to satisfy the needs of offshore activities, where the primary catalysts are the depletion of gas supplies, cost, and the need to reduce greenhouse gas emissions. Furthermore, there are several technological advantages of hybrid renewable energy resources, and future questions will arise as a result of the coastal region's restricted size (C.Pérez-Collazo, 2015). As a result, a complete examination of these resources is urgently required. Figure shown are the estimated carbon footprints caused by various energy, be it renewable or non-renewable energy.

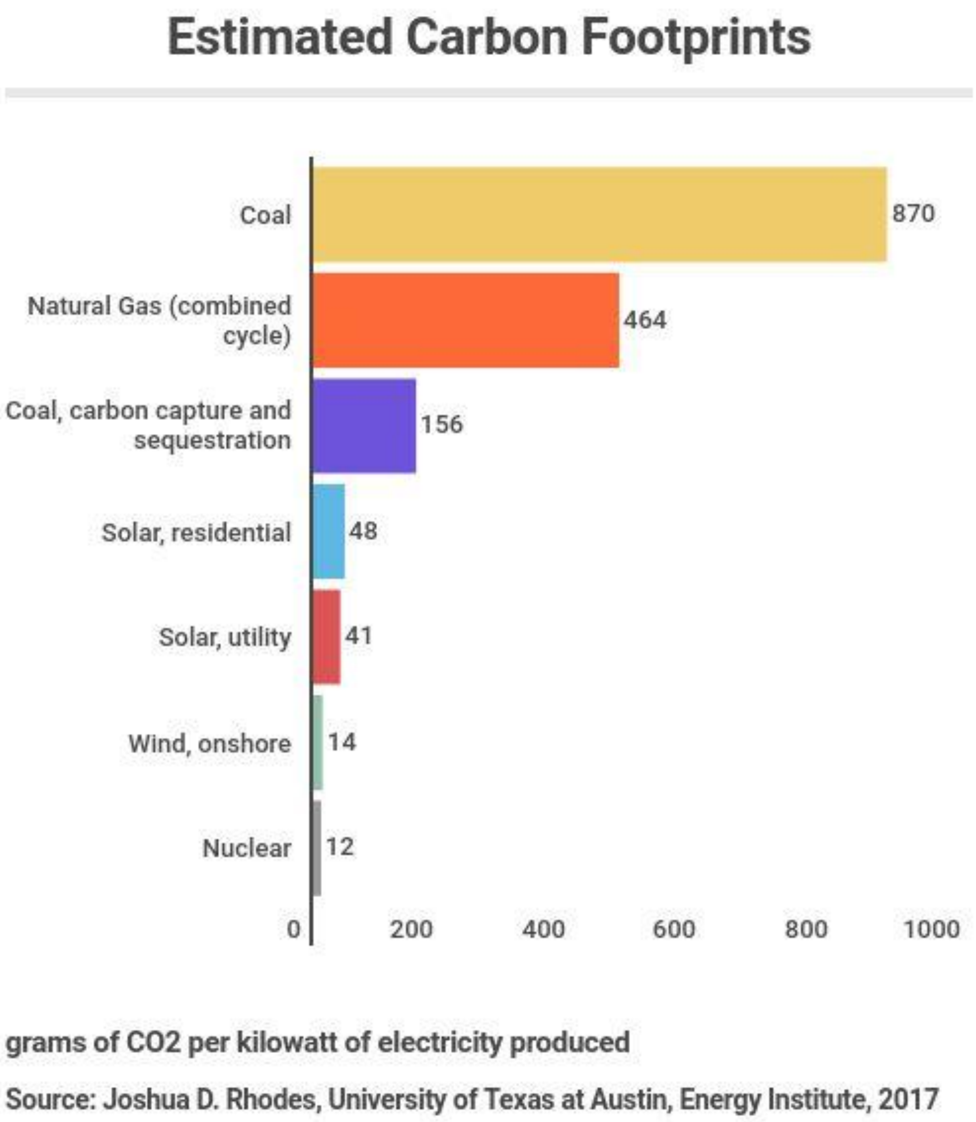

FIGURE 2.3: Estimated carbon footprint of various energy sources.

2.1 Wave Energy

Wave is a popular form of renewable energy which can be harnessed by the movement of the waves. Method of harnessing wave energy includes the placement of wave energy converters, generators, and oscillating water column on the surface of the ocean. Waves are caused by tides which on the other hand are dependent on the lunar cycles of the moon. The closer the moon to the Earth, the higher the pull of gravity of ocean towards the moon which subsequently causes tide. Waves are also a renewable energy source like wind, solar and geothermal energy. As long as the Earth orbits around the Sun and the moon still in orbit around the Earth, wave will remain a feasible option of energy. Unlike traditional fossil fuels such as oil and coal, waves produce way less significant amount of carbon emission, therefore making it an eco-friendly alternative. One concern about wave energy is its fluctuation of magnitude makes it very unpredictable and could causes trouble in utilizing it. Also taken into consideration is the parameters of the said energy, for instance, significant wave height, wave speed, wavelength, and peak wave period. Figure below shows an example of a wave energy converter, which is the Pelamis.

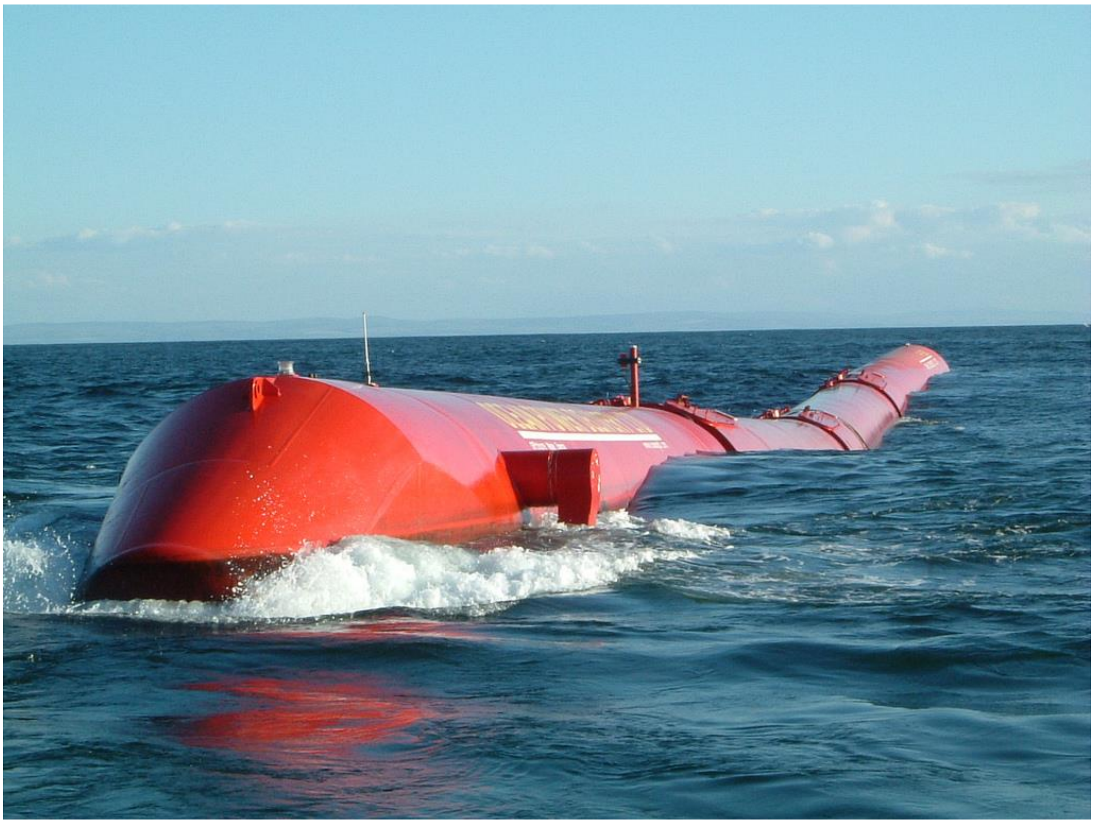

FIGURE 2.4: Pelamis wave energy converter in open sea.

In this ever-changing landscape and rapid development of technology, experts and researchers have been studying other initiatives at harnessing a higher factor of wave energy. Moreover, wave energy has incredible potential in the future, the energy density is between 30kW to 40kW for every square meter of waves along shores. In the U.S itself, there is approximately 2640TWh/y of wave energy along the continental shelf edge according to the Electric Power Research Institute (EPRI). In addition, wave energy arises with vast positive factors for instance: i) water covers around 70% of the Earth, ii) contains sizable amount of potential energy, where the transmission goes on for thousands of miles, iii) wave existed with higher density than wind and solar energy (Offshore Renewable Energy: ocean waves, tides and offshore wind., 2019). Thus, for the reasons stated above, a vigorous effort is executed to assess and develop sustainable system and exploitation of the energy. Figure below shows the global estimation of annual mean wave power.

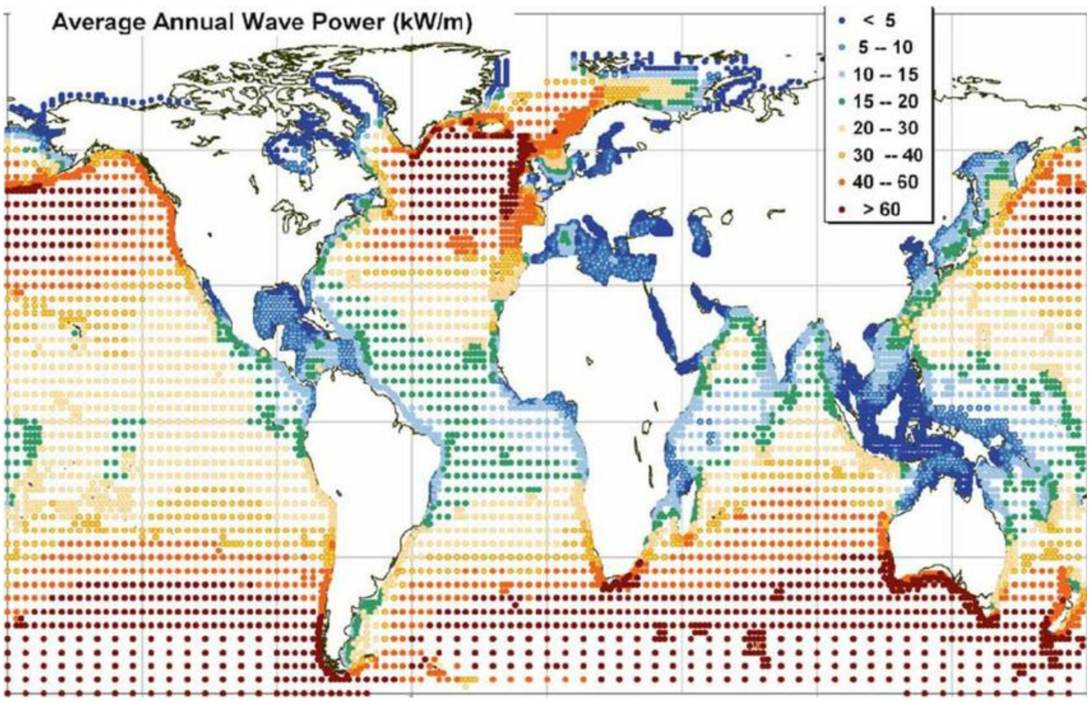

FIGURE 2.5: Estimation of global annual mean wave power.

There are several ways of harnessing wave energy, and some are implemented widely in other countries. Wave energy converters can be classified into two categories, which are fixed device and floating device, and a few of examples are oscillating water column, Salter's nodding duck, overtopping device, wave energy raft, point absorber and wave energy pendulum. The implementation of the machines is affected by a lot of practical factors for instance, transforming the efficacy of energy. Some of the devices had gone through marketable phase and have also been deployed in the open sea. Figure below shows the Salter's Nodding Duck wave converter.

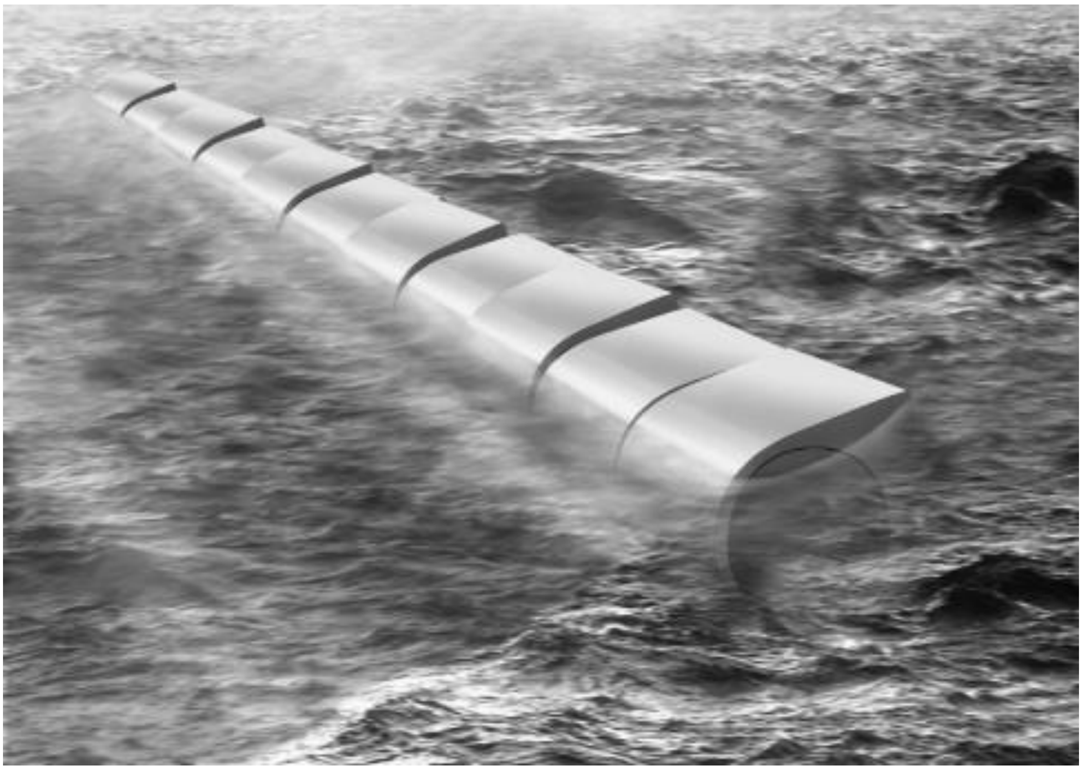

FIGURE 2.6: Salter's Nodding Duck wave energy converter.

2.2 Solar Energy

The world's electricity consumption is continually growing as a result of population growth and technological improvements. As a result, for future energy demands, selecting a safe, cost-effective, and everlasting renewable energy source is critical. Solar energy, like other renewable energy sources, is a feasible and readily accessible energy source for addressing the long-term issues of the energy crisis. Despite the fact that the primary energy source, fossil fuels, and other sources are somewhat expensive, the solar industry is steadily growing throughout the world due to the enormous need for electricity. Due to India's vast population, land is a limited resource. As a result, an offshore solar photovoltaic (PV) installation might be a new option.

The world's energy demand is increasing at a rapid rate. Solar panels, also known as solar photovoltaic systems, are used to produce power from the sun. One or more solar panels, an inverter, and other electrical and mechanical components make up a photovoltaic (PV) system, which uses the Sun's energy to create electricity. The photovoltaic effect occurs when light from the Sun, which is made up of packets of energy called photons, falls on a solar panel and creates an electric current. Each panel produces a little amount of power on its own, but when joined as a solar array, they may produce a lot more (Afework, 2020). The number and type of solar panels we utilised had an impact on the electric energy. Considering distinct types of solar panels have variable yield quality, this is the case. The more effective a photovoltaic solar panel is, the more energy it can produce per unit of light energy it receives, which means it can satisfy your energy needs with less surface area. Figure below shows the implementation of floating solar farm.

FIGURE 2.7: Floating photovoltaic solar panels in Andhra Pradesh, India.

Empire Renewable Energy, LLC claims to have an energy efficiency rating of 11 to 15%. It refers to the percentage of light that is transformed into usable power. As a result, the quantity of solar panels and their yield efficiency have a substantial impact on the amount of energy produced. Further, there are additional benefits to using solar energy overseas. Reflection of light from the water and natural evaporative cooling as a result of the water body can keep PV panels cooler than land-based ones, enhancing their efficacy (Solomin E, 2021). It also contributes to the preservation of land. It's because there won't be any valuable land left for agricultural, mining, tourist, and other property businesses, and untapped and non-revenue-generating water surfaces will be converted into commercial solar power plants.

In reality, several nations have already adopted this innovation for their industries, such as China, which had 208 GW of installed solar capacity by early 2020, accounting for one-third of world total solar capacity. By 2020, at least 37 nations will have a total PV capacity of more than one gigawatt. Furthermore, the International Energy Agency (IEA) predicts that solar will establish new worldwide deployment records every year following 2022, with an average of 125 GW of additional capacity planned internationally between 2021 and 2025. As a result, there is little question that offshore solar power will be one of our world's renewable resources in the future.

2.3 Hybrid Offshore Renewable Energy Resources

The constraint of habitable land, increasing power use, and the impact on the environment of fossil fuels are all propelling the growth of maritime renewable energy projects. Offshore wind, wave, and tidal energy are the main types of marine renewable energy that are the subject of many studies. However, we are investigating the use of wave and solar as a hybrid energy source in this article. Hybrid wave solar systems combine offshore wave energy with solar energy on a same platform. These systems enhance power output at a single place by mixing wave and solar energy. Figure below shows the hybrid system of wave and solar energy converter.

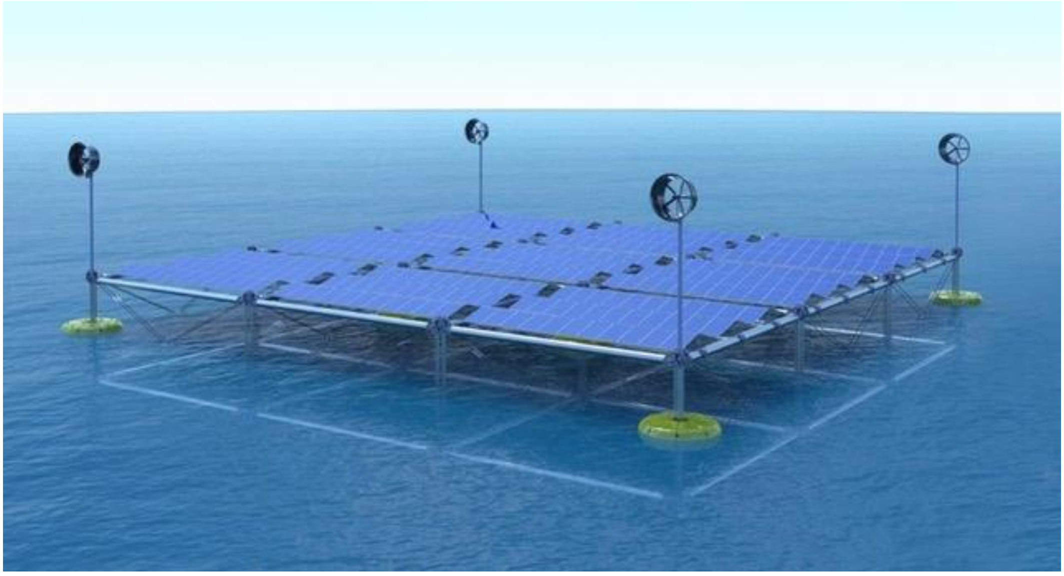

FIGURE 2.8: Example of a hybrid system; wave and solar energy converter.

Countries around the world have adopted several policies to tax the emissions of greenhouse gases, creating an important relation between carbon emission and cost. Thus, inducing a much-needed pressure to lessen the emission of the sectors, inspired by ecological awareness and because of the economical disadvantages associated to the greenhouse gases emissions. Demands of power generations are growing inevitably and showing no signs of stopping in the upcoming years, consequently resulting in a rising amount of greenhouse gases emissions and large financial penalties. Referring to a study by Kolstad et al. (2017), there are various methods in supplying oil and gas platforms in offshore areas instead of using gas turbines that have several drawbacks like stated previously, for example: i) powering offshore platforms using electricity via subsea wires, ii) using a separate offshore renewable energy system and iii) the synergy of renewable energy system and onshore power generation. Figure below shows the taxation of carbon by each countries.

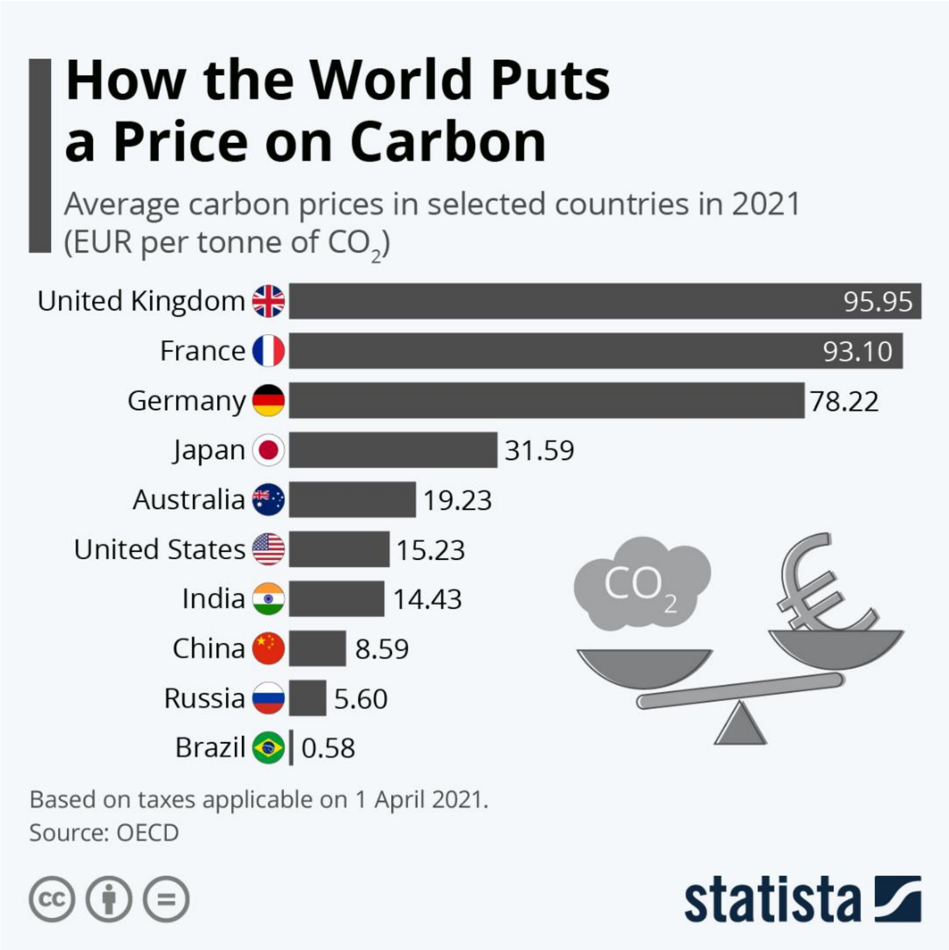

FIGURE 2.9: Carbon taxation implementation by nations.

While energies are often considered solitarily, there are many advantages in terms of economically as well as technically to the co-existent of wave and solar technologies. For instance, to combat structural loads to offshore systems, to make use of spatial usage, and the financial benefits of sharing dual infrastructures. Moreover, there will be future question for restricted marine land, so there is an earnestness to foster expected evaluations of these seaward assets (C.Pérez-Collazo, 2015). Routinely, wave and sun-based energy asset assessment have been led as discrete methodology, with limited scope collaboration between the two networks regarding best practices, illustrations learnt, or possibilities to make appropriate strategies for future activity by the bigger seaward energy area.

According to Oliveira-Pinto S. (2020), results show that for all destinations the mix of wave and solar powered energy asset builds power generation, lessens the intrayearly fluctuation of energy creation and discontinuity issues, expands limit factors up to 24% and therefore preventing overdesign. The acquired levelized cost of energy is in the reach 131–263 €/MWh and the decrease in outflows was assessed at around 281,915 ton/year at each site, which exhibits the practicality and interest of giving power from these consolidated frameworks to offshore platform. Figure below shows the global investment in renewable energy.

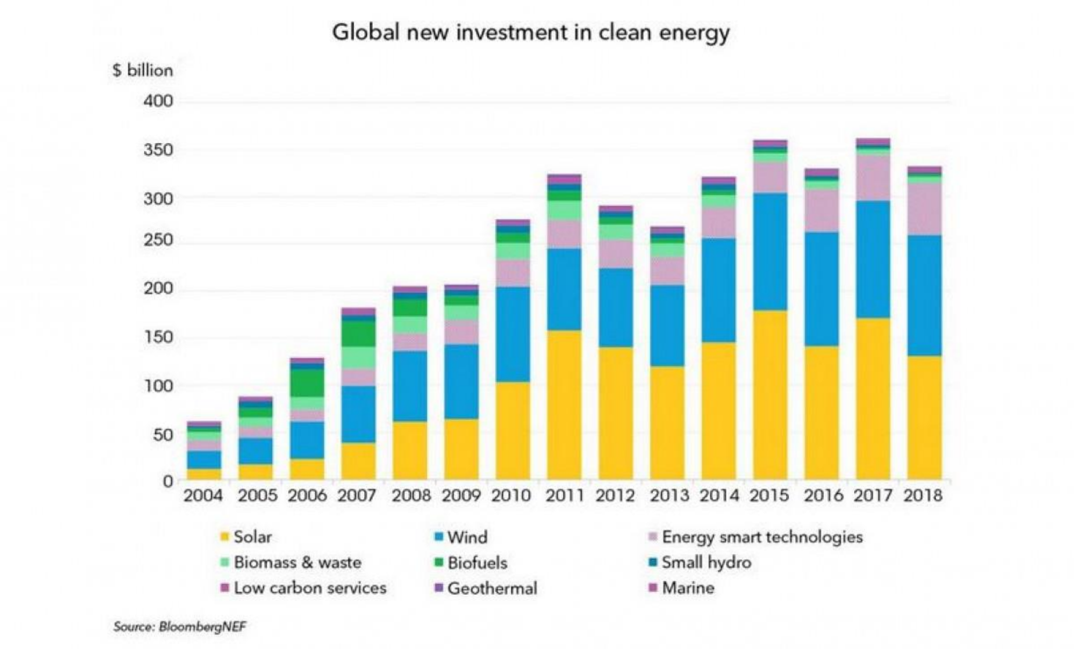

FIGURE 2.10: Global investment in renewable energy.

Furthermore, structures like as those present in lakes and reservoirs can be used to erect Floating Photovoltaic Systems. Most of these systems employ photovoltaic panels that are mounted to pontoons to keep them afloat. These designs would have to be modified for use in a maritime setting, taking into account the structural stresses caused by wave action, which would greatly raise their cost. As a result, adaptable wave energy converter systems have been created. The adaptable designs are meant to reduce stress on the structure and its mooring while yet allowing it to survive extreme sea conditions. Aside from that, uninterrupted power supply, minimal maintenance costs, great efficiency, and efficient load control are just a few of the advantages of hybrid wave-solar energy. This study will focus on the synergies between solar and wave energy, while previous research has focused on themes such as optimal array design and cost savings in operation and maintenance. Wave and solar farm synergies, on the other hand, have yet to be explored, with only their combined usage with aquaculture being proposed. As a consequence, this research will be valuable in establishing the wave and solar energy's potential as a hybrid renewable energy source.

CHAPTER 3

METHODOLOGY

3.1 Study Area

The focus of this study is at one location specifically, Davao City, Philippines which is in the region of Indonesia Wave. The exact coordinate of the location is 6.599900 N, 125.8000 E as shown in the diagram below:

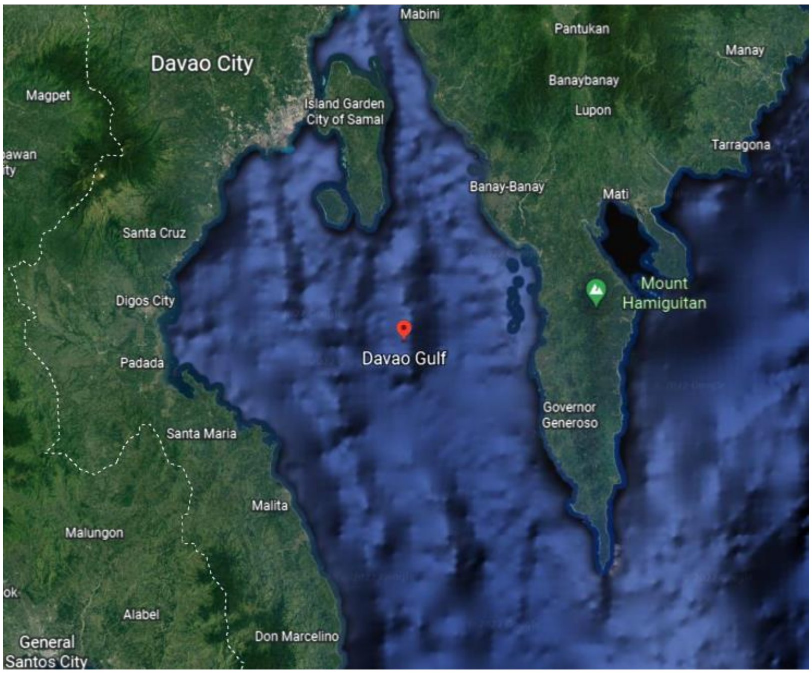

FIGURE 3.1: Location of Davao City, Philippines in Google Earth.

Philippines is an archipelagic country in Southeast Asia, formally known as the Republic of the Philippines. It is in the western Pacific Ocean and is made up of approximately 7,640 islands divided into three primary geographical divisions from north to south: Luzon, Visayas, and Mindanao. Davou Gulf is a gulf in Mindanao, Philippines, located in the southeast corner of the island. It covers 5,200 km^2 (520,000 hectares) of land. Because of its proximity to the equator, the Philippines enjoys a tropical environment with many sunny days. The Philippines has a temperature range of 25.4-26.7°C, with April being the warmest and January being the coldest. Davao City receives heavy rainfall throughout the year.

3.2 Methods and Tools

3.2.1 *MetOceanView Hindcast*[2]

The acquisition of wave data is obtained from a free to access online website provided by MetOceanView. The software is for coastal operations administration which is a high-quality web-based weather forecasting tool. It also offers a thorough medium of delivery that enables the right to use, observe and manipulate climate data required for procedures and developments. It uses the state-of-the-art atmospheric and coastal forecast system that accustomed at the suitable scale of process. A high-definition wave model can be designed and executed for a particular region respective geography and elements as the MetOceanView is developed on a complex oceanographic and meteorogical projection model. The steps to acquire the wave data are simple and concise, which takes merely less than five steps/clicks of a button. Figures below are the steps taken to obtain the said data according to the website:

1. Go to https://app.metoceanview.com/hindcast-squared/#/ via your web browser.

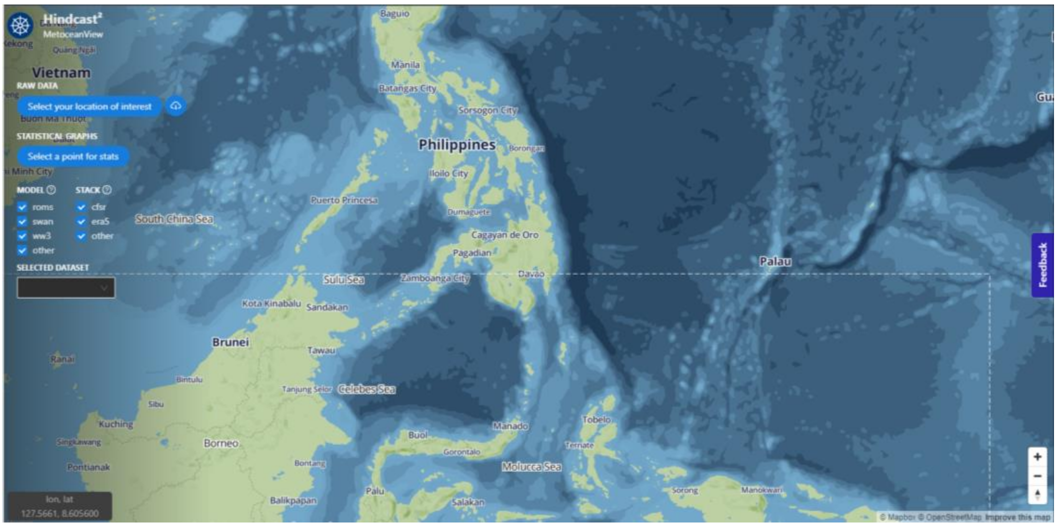

FIGURE 3.2: General interface of MetOceanView website.

2. Click ‘Select a point for stats’ under the STATISTICAL GRAPH, then click at any point on the map according to your preference.

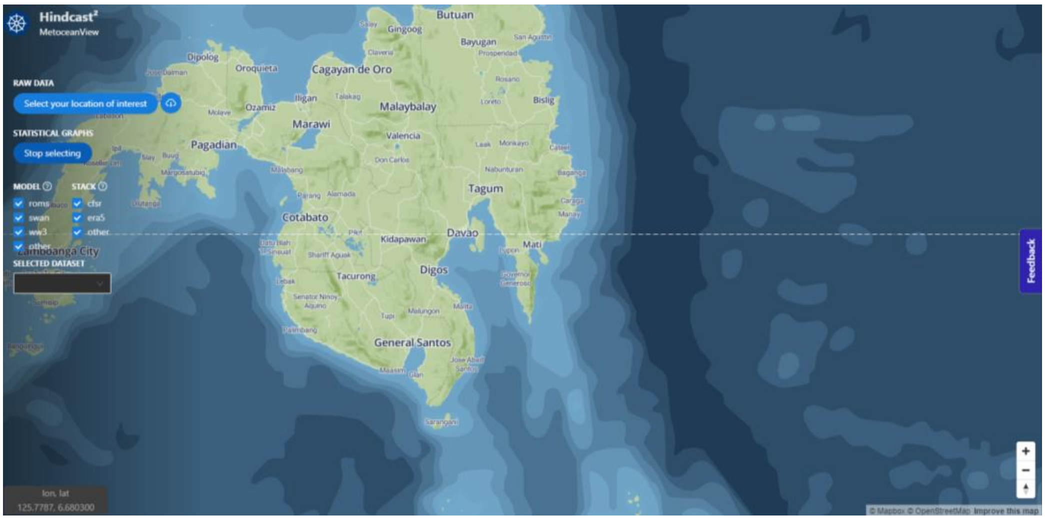

FIGURE 3.3: Selection of preferred point of study.

3. Next, select a dataset from the choices given and press NEXT.

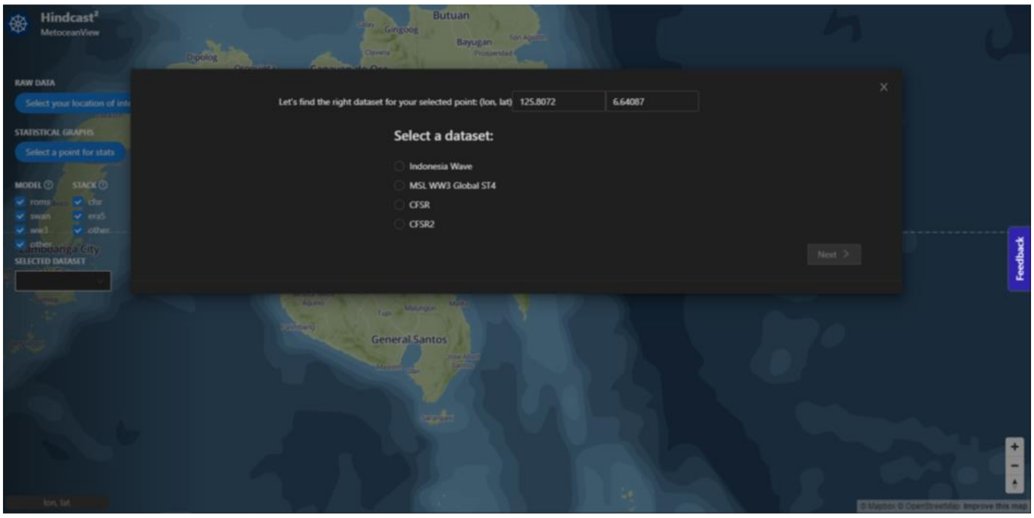

FIGURE 3.4: Selection of dataset.

4. Lastly, choose a specific point of the region that you have selected earlier and confirm your selection by clicking NEXT.

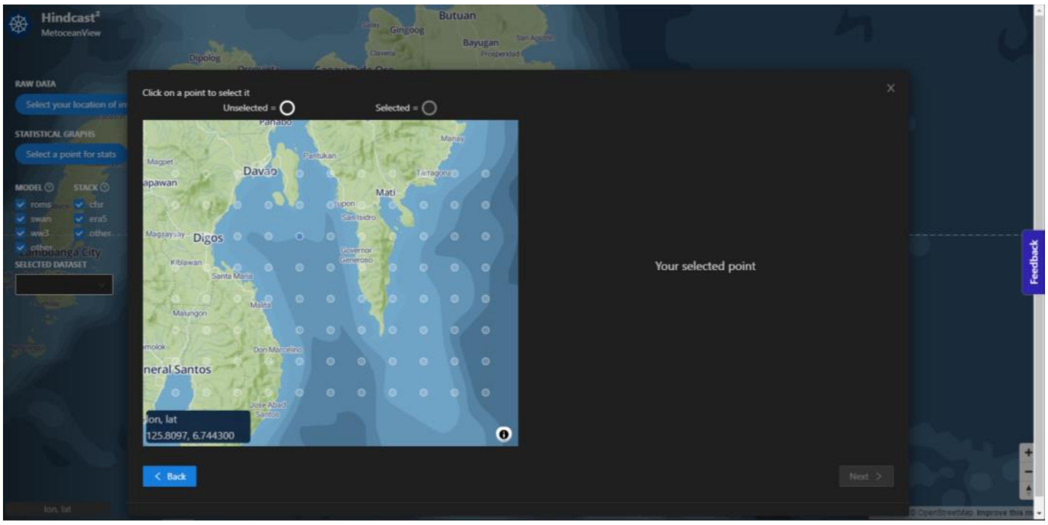

FIGURE 3.5: Selection of specific point in the region.

5. The wave data are shown by a few forms, which are roses, data matrices, line charts and extremes. The CSV file for all the data are also downloadable for an easier viewing.

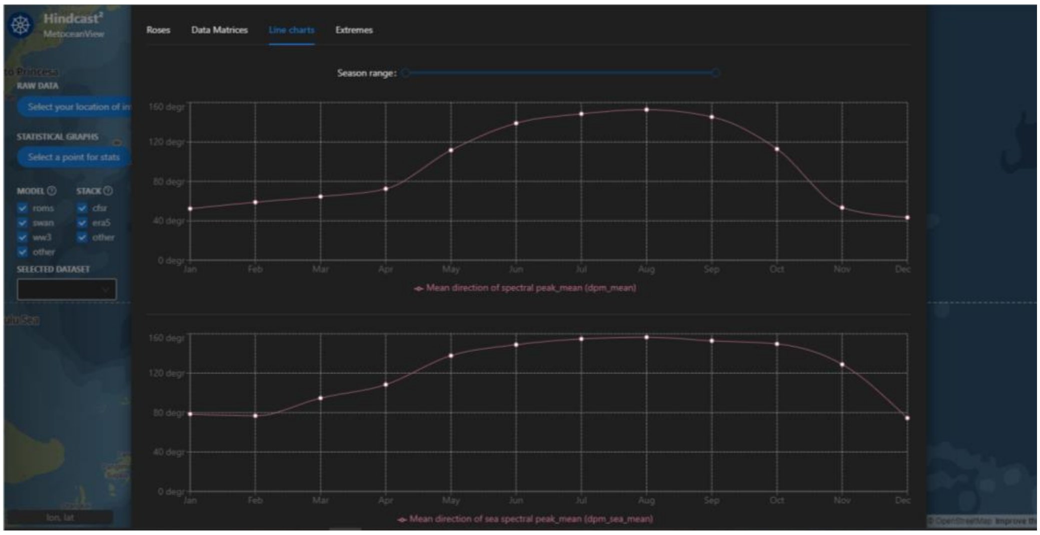

FIGURE 3.6: Views of example data acquired from the specific location.

3.2.2 *POWER Data Access Viewer*

Prediction of Worldwide Energy Resource (POWER) Data Access Viewer is the tools that are used to acquire the solar irradiance data. The dataset is recognised by NASA for uses in studies regarding renewable energy. The datasets included countless years and the most vital thing is the data provided are recorded in real time. POWER provides three meteorological data which consist of environmental buildings, renewable energy, and agroclimatology. Figures included below are the stages to obtain the solar irradiance data:

1. Go to the website https://power.larc.nasa.gov/data-access-viewer/ through your web browser.

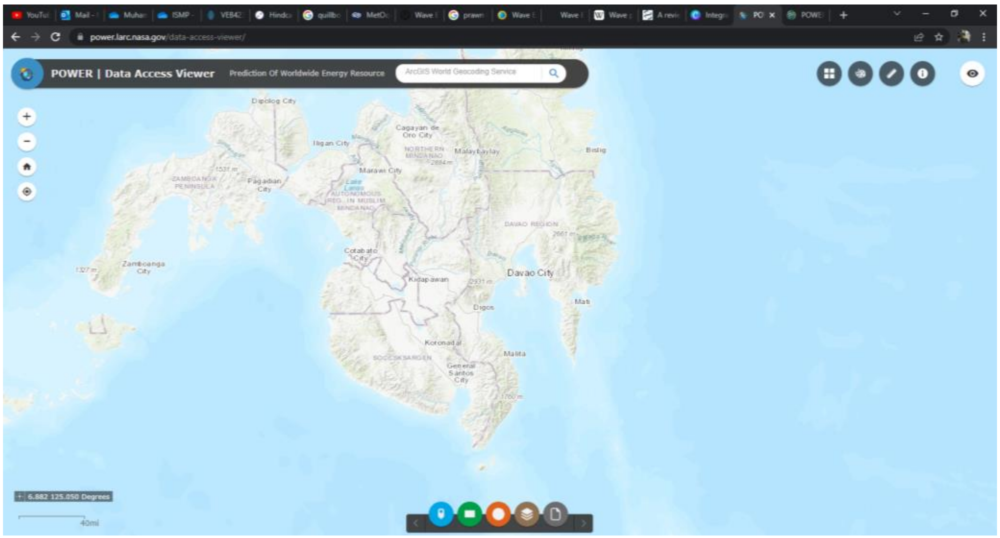

FIGURE 3.7: Web interface of POWER Data Viewer

2. Then, click on the blue button at the bottom of the page.

FIGURE 3.8: Features of POWER Data Viewer.

3. Input the following parameters at the web interface that appeared as shown in the figure below:
   a) Choose a User Community
      - Renewable energy
   b) Choose a Temporal Average
      - Monthly & Annual
   c) Enter a Latitude/Longitude or Add a point to map
      - Latitude/Longitude – 6.5999 N, 125.8000 E
   d) Select Time Extent
      - 2001 – 2007

Figure below shows the interface for parameter input selection in POWER Data Access Viewer.

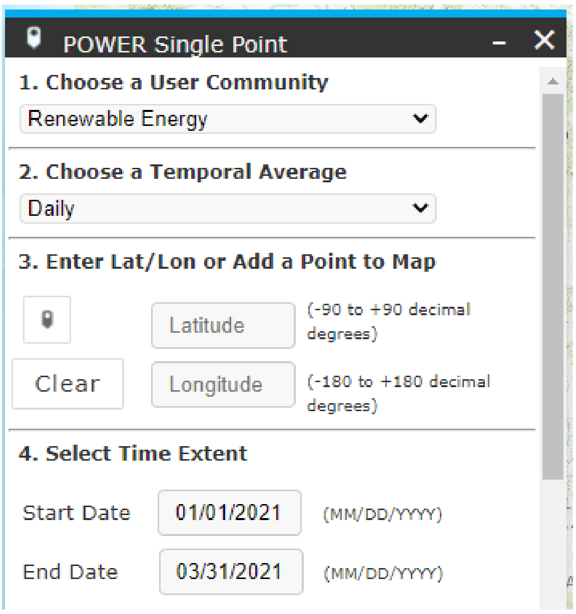

FIGURE 3.9: Parameter input selection.

e) Select Output File Format
   - Comma Separated Value (CSV)
f) Select Parameters
   - Solar Fluxes and Related
g) Submit.

Figure below shows the continuation of the parameter input selection on the website.

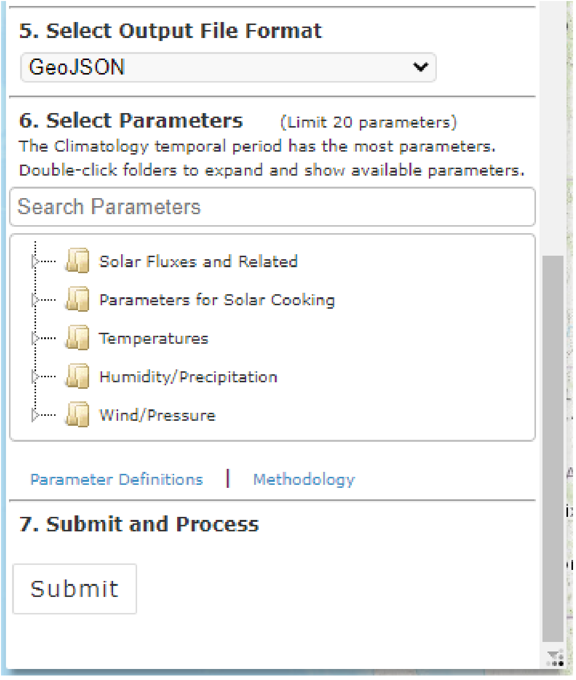

FIGURE 3.10: Parameter input selection.

3.3 Definition of Parameters

3.3.1 Wave Power

Wave powers can be categorised into many parameters, such as significant wave height, wave speed, wave direction, relative peak period, mean direction of spectral peak, wind speed, wind direction, and many more. In this study, we only consider two of those parameters which are, significant wave height (H_s) and wave period (T_e). The equation that had been used are as follows:

$$WPD = \frac{\rho g^2}{64\pi} H_s^2 T_e$$

WPD = Wave Power Density (kW/m)

ρ = density of seawater = 1.025g/cm^3

g = gravitational acceleration = 9.81m/s^2

H_s = significant wave height (m)

T_e = wave period (s)

3.3.2 Solar Power

In the case of solar energy, the following equation is used and shown below are the parameters to get the power output:

$$\boldsymbol{E = A * r * H * PR}$$

E = Energy

A = Total solar panels area (m^2)

r = Solar panel yield of electricity (%)

H = Annual average solar radiation on tilted panels (shadings not included)

PR = Performance Ratio, coefficient for losses (default value = 0.75)

E is a symbol representing energy or solar power production in kWh in this equation. The electricity created by the power generating is theoretically equal to the quantity of power output that this equation produces. Following that, A stands for total solar panel area, and as previously said, the total area for solar panels required in this study is 100m2. This is about 60 SunPower E-20 solar panels. Furthermore, H denotes the annual average solar radiation on slanted panels. This is the parameter that has the most impact on the power output. It's also the data we'll need to look for and download from the POWER datasets. Because efficiency is the key to a better system, it is assigned to r, which stands for solar panel yield or efficiency. According to Empire Renewable Energy, LLC, a subsidiary of EMPIRE SOUTHWEST, LLC, solar panels in 2021 will have an energy efficiency rating of 11 to 15%, which is the proportion of solar energy transformed into usable power. As a result, our SunPower E-20 solar panel, which has a 23 percent efficiency, is an unquestionable option for us to use in this study. Finally, PR stands for loss coefficient or performance ratio. It's the same with wind power, which is measured in terms of power coefficient. However, for the performance ratio, PR, which is equivalent to the coefficient losses, 0.75 is assumed.

CHAPTER 4

RESULT & DISCUSSION

4.1 Results for Wave Power Analysis

In this study, the wave power generation are calculated based on months from January to December, from 1979 to 2017. For every month, it is a mean value of wave power generated throughout the 38 years in Davao City. The respective significant wave height and wave period can be obtained from the MetOceanView Hindcast[2] web as stated previously. Figures below shows the said data.

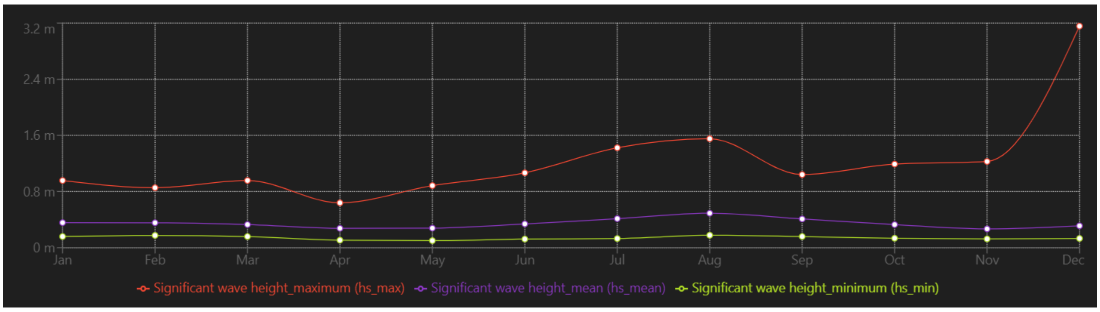

FIGURE 4.1: Significant wave height obtained in MetOceanView.

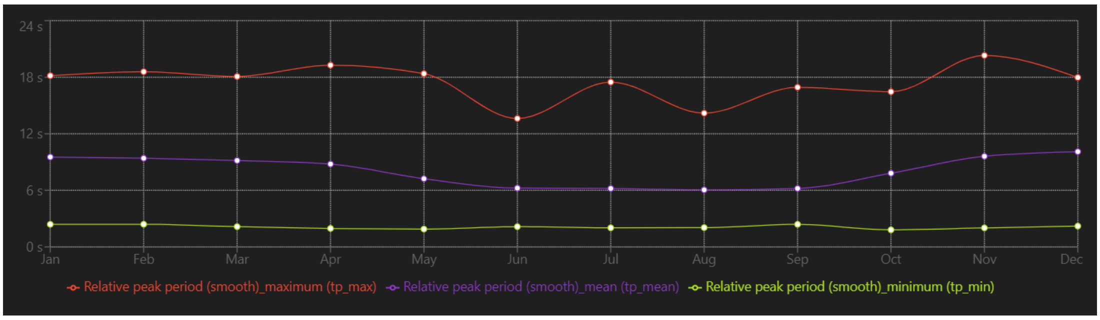

FIGURE 4.2: Wave period obtained in MetOceanView.

Using the following equation including the significant wave height, H_s and wave period, T_e stated, it is possible to calculate the Wave Power Density (WPD):

$$\boldsymbol{WPD = \frac{\rho g^2}{64\pi} H_s^2 T_e}$$

$$January = \frac{(1.025)(9.81)^2}{64\pi}(0.356)^2(9.5) = \mathbf{0.59kW/m}$$

$$February = \frac{(1.025)(9.81)^2}{64\pi}(0.355)^2(9.4) = \mathbf{0.58kW/m}$$

$$March = \frac{(1.025)(9.81)^2}{64\pi}(0.329)^2(9.2) = \mathbf{0.488kW/m}$$

$$April = \frac{(1.025)(9.81)^2}{64\pi}(0.276)^2(8.8) = \mathbf{0.328kW/m}$$

$$May = \frac{(1.025)(9.81)^2}{64\pi}(0.278)^2(7.2) = \mathbf{0.273kW/m}$$

$$June = \frac{(1.025)(9.81)^2}{64\pi}(0.338)^2(6.2) = \mathbf{0.347kW/m}$$

$$July = \frac{(1.025)(9.81)^2}{64\pi}(0.413)^2(6.2) = \mathbf{0.518kW/m}$$

$$August = \frac{(1.025)(9.81)^2}{64\pi}(0.491)^2(6.0) = \mathbf{0.709kW/m}$$

$$September = \frac{(1.025)(9.81)^2}{64\pi}(0.409)^2(6.2) = \mathbf{0.508kW/m}$$

$$October = \frac{(1.025)(9.81)^2}{64\pi}(0.328)^2(7.8) = \mathbf{0.411kW/m}$$

$$November = \frac{(1.025)(9.81)^2}{64\pi}(0.267)^2(9.6) = \mathbf{0.335kW/m}$$

$$December = \frac{(1.025)(9.81)^2}{64\pi}(0.311)^2(10.1) = \mathbf{0.479kW/m}$$

The table below shows the wave power density for every month from 1979 to 2017.

	Month	Significant Wave Height, Hs (m)	Wave Peak Period, Te (s)	Wave Power Density, WPD (kW/m)
1979 - 2017	**Jan**	0.356	9.5	0.590
	Feb	0.355	9.4	0.580
	Mar	0.329	9.2	0.488
	Apr	0.276	8.8	0.328
	May	0.278	7.2	0.273
	Jun	0.338	6.2	0.347
	Jul	0.413	6.2	0.518
	Aug	0.491	6.0	0.709
	Sep	0.409	6.2	0.508
	Oct	0.328	7.8	0.411
	Nov	0.267	9.6	0.335
	Dec	0.311	10.1	0.479

Assuming the area of the study at Davao Gulf is 150.28km^2 or 12258.67m. To find the wave power generated **annually**, it is necessary to multiply the value by 12258.67m, and 12 months.

$$January = 0.590kW/m * 12258.67m * 12months = \mathbf{86791kWh}$$
$$February = 0.580kW/m * 12258.67m * 12months = \mathbf{85320kWh}$$

$$March = 0.488kW/m * 12258.67m * 12months = \mathbf{71786kWh}$$

$$April = 0.328kW/m * 12258.67m * 12months = \mathbf{48250kWh}$$

$$May = 0.273kW/m * 12258.67m * 12months = \mathbf{40159kWh}$$

$$June = 0.347kW/m * 12258.67m * 12months = \mathbf{51045kWh}$$

$$July = 0.518kW/m * 12258.67m * 12months = \mathbf{76200kWh}$$

$$August = 0.709kW/m * 12258.67m * 12months = \mathbf{104296kWh}$$

$$September = 0.508kW/m * 12258.67m * 12months = \mathbf{74728kWh}$$

$October = 0.411kW/m * 12258.67m * 12months = \mathbf{60459kWh}$

$November = 0.335kW/m * 12258.67m * 12months = \mathbf{49279kWh}$

$December = 0.479kW/m * 12258.67m * 12months = \mathbf{70462kWh}$

Table below shows the annual wave power density (WPD).

TABLE 4.1: Annual WPD.

Month	**Annual Wave Power Density, WPD (kWh)**
Jan	86791
Feb	85320
Mar	71786
Apr	48250
May	40159
Jun	51045
Jul	76200
Aug	104296
Sept	74728
Oct	60459
Nov	49279
Dec	70462

Based on the calculations above, the annual mean wave power density is **68231.25kWh**.

4.2 Results for Solar Power Analysis

$$\boldsymbol{E = A * r * H * PR}$$

a) Area (m^2) = $100m^2$ is about 6133 units of SunPower E-20 solar panels.
b) Solar panel yield of electricity (%) = 20.3%

c) Annual mean for all sky surface shortwave irradiance ($kWh/m^2.day$)

The table below shows the annual mean solar irradiance for all sky surfaces.

TABLE 4.2: Annual mean solar irradiance for all sky surfaces.

Parameter	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annually Mean
H, kW.hr/m^2.yr	2001	4.34	4.9	5.16	5.77	5.42	5.19	4.99	4.96	6.27	5.59	4.7	4.35	**5.13**
H, kW.hr/m^2.yr	2002	4.61	5.39	5.67	6.38	5.16	5.06	5.36	4.93	5.39	5.52	5.13	5.14	**5.32**
H, kW.hr/m^2.yr	2003	4.98	5.02	5.46	6.47	5.07	5.32	4.96	5.3	5.42	5.31	5.44	4.23	**5.25**
H, kW.hr/m^2.yr	2004	5.05	5.06	5.83	6.12	5.46	5.17	5.18	5.25	5.79	5.48	5.69	4.85	**5.41**
H, kW.hr/m^2.yr	2005	4.5	5.51	5.9	5.73	5.01	4.88	4.77	5.1	5.49	5.77	4.8	4.42	**5.15**
H, kW.hr/m^2.yr	2006	4.58	4.74	5.25	5.81	5.6	4.99	5.31	5.02	5.46	4.83	5.45	4.96	**5.17**
H, kW.hr/m^2.yr	2007	3.91	5.13	5.75	6.22	5.79	5.1	4.73	5.05	5.29	5.49	4.83	4.43	**5.14**

d) Energy in kWh/day

Year 2001 $= (100m^2)\ (0.203)\ (5.13kW.hr/m^2.yr)\ (0.75)$
$= 78.1kWh/day$
Year 2002 $= (100m^2)\ (0.203)\ (5.32kW.hr/m^2.yr)\ (0.75)$
$= 81kWh/day$
Year 2003 $= (100m^2)\ (0.203)\ (5.25kW.hr/m^2.yr)\ (0.75)$
$= 79.93kWh/day$
Year 2004 $= (100m^2)\ (0.203)\ (5.41kW.hr/m^2.yr)\ (0.75)$
$= 82.37kWh/day$
Year 2005 $= (100m^2)\ (0.203)\ (5.15kW.hr/m^2.yr)\ (0.75)$
$= 78.41kWh/day$
Year 2006 $= (100m^2)\ (0.203)\ (5.17kW.hr/m^2.yr)\ (0.75)$
$= 78.71kWh/day$
Year 2007 $= (100m^2)\ (0.203)\ (5.14kW.hr/m^2.yr)\ (0.75)$
$= 78.41kWh/day$

To convert the kWh/day to kWh, it is required to multiply the values by 365 as there are 365 days in a year. Hence, the power generated by solar power annually at Davao City can be obtained as stated below:

Year 2001 = 78.1kWh/day x 365 days
= 28506.5 kWh
Year 2002 = 81.00kWh/day x 365days
= 29565 kWh
Year 2003 = 79.93kWh/day x 365days
= 29174.45 kWh
Year 2004 = 82.37 kWh/day x 365days
= 30065.05 kWh
Year 2005 = 78.41kWh/day x 365days
= 28619.65 kWh
Year 2006 = 78.71kWh/day x 365days
= 28729.15 kWh
Year 2007 = 78.41kWh/day x 365days

= 28619.65 kWh

4.3 Analysis of LCOE

Levelized Cost of Energy (LCOE) is a simple approach of comprehending the Net Cost to install a wave-solar power system by its estimated life cycle power productivity. Generally, it consists of Capital Expenditure (CAPEX), and Operational Expenditure (OPEX).

4.3.1 Calculation

Wave Energy Converter Cost Calculation:

In this study, the Pelamis wave converter is the type of converter that are opted for. Tables below shows the capital, operation, and maintenance cost of Pelamis wave energy converter.

TABLE 4.3: Capital cost of wave energy converter.

Type	Cost Range
Device	USD3.50million
Moorings	USD0.35million
Installation	USD1.24million
Shipping	USD0.21million
Total	**USD5.30million**

TABLE 4.4: Operation and maintenance cost of wave energy converter.

Type	Cost Range
Annual operation & maintenance	USD0.16million
Mid-life refit	USD0.59million
Decommissioning	USD0.50million
Total for device lifetime (25 years)	**USD1.25million**

Therefore, by adding the capital cost and the operation and maintenance cost of the wave energy converter, the total life cycle cost is approximately around

USD6,550,000. The cost of wave energy converter annually is USD6.55million/25 = **USD262,000.00**.

Solar Panel Cost Calculation:

Price of one panel = USD110.00

Number of solar panels utilized = 6000units

Total expenditure = USD660,000.00

Life cycle of one solar panel = 25 years

Therefore, cost per annum = USD660,000.00/25 = **USD26,400.00**.

Battery Cost Calculation:

The cost of battery is assumed to be USD6,000.00 per 10 years. Thus, annually, the cost of battery will be USD600.00.

Capital Cost Calculation:

Cost of wave energy converter annually = USD262,000.00

Cost of solar panel = USD26,400.00

Cost of battery = USD600.00

Total annual capital cost = **USD289,000.00**

Operation and maintenance (O&M) cost:

The cost of annually for wave energy is USD50,000.00.

Assume the cost for solar energy is USD28,018.00

Total O&M cost = **USD78.018.00**

Energy Consumption:

Based on results calculate earlier, the total annual mean energy can be obtained.

Mean energy for wave energy = 68,231.25kWh

Mean energy for solar energy = 29,039.92kWh

Total annual mean energy = **97271.17kWh**

Cost of Electricity:

Based on all the calculations earlier, the Cost of Energy (LCOE) can be obtained:

LCOE = (USD289,000 + USD78,018) / 97271.17kWh = **USD3.77/kWh**

4.4 Sustainability

The capacity to live in a somewhat constant manner throughout a range of life domains is characterised as sustainability. "Meeting the demands of the present generation without jeopardising future generations' ability to satisfy their needs" is another definition of sustainability. The phrase "sustainability" refers to a wide range of programmes, projects, and efforts aiming at resource conservation. Personal, social, economic, and environmental sustainability are the four essential dimensions of sustainability, sometimes known as the four pillars of sustainability. However, in this study, we will just look at three of them, which are listed below:

4.4.1 Environmental

As a result of this study, we can confidently state that this mix of renewable energy benefits the environment by providing clearer air and water. Because using fossil fuels to create electricity pollutes the air we breathe and the water we drink while also changing the planet, it is a no-brainer. Furthermore, coal-fired power facilities generate significant volumes of carbon dioxide (CO_2) and nitrous oxide (NOx) (N_2o). These are two of the most powerful greenhouse gases that enter the atmosphere directly. Mercury, lead, sulphur dioxide, particulates, and toxic metals are also released, which can cause a number of health concerns ranging from respiratory difficulties to early death. Fossil fuel energy may pollute waterways, both through air pollution that falls to the ground during rain and from waste materials created during the production process. As a result, developing hybrid offshore renewable energy resources as a source of power is a rational decision to decarbonize our environment and integrate energy sources that do not contribute to global warming. Renewables are assisting us in providing emission-free electricity, heat, automobiles, and even air travel.

4.4.2 Economy

Because of the rapid increase of renewable energy over the last 10 years, solar and wave power are now the cheapest sources of electricity in many parts of the world. The world's lowest solar energy price of 1.35c per kilowatt-hour was recently achieved by a new sun farm in the United Arab Emirates, which is known for its huge acreage and sunny weather. The huge reduction in the cost of solar and wave energy has pushed some fossil fuel corporations, notably the six major oil companies, to move their assets to renewable energy. Green energy, which was formerly seen to be a "clean but expensive" alternative, is now helping consumers all over the world save money on their energy bills.

4.4.3 Social

Furthermore, with an increasing focus on global warming and many governments establishing strong carbon-reduction goals, one of the unexpected benefits of renewable energy has been its rapid growth as a key source of new job creation.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

In summary, this study acts as a platform to take further research and analytical approach into the potential of the synergy of two resources of renewable energy for power generation. According to the results that are calculated in the study, it is obvious that the highest amount of energy is 104296kwh and 30065.05 kWh for wave and solar energy respectively. While on the other hand, the annual mean for wave is 68231.25kWh and 29039.92 kWh for solar energy. Hypothetically, the levelized cost of electricity (LCOE) is around USD3.77/kWh for both energies.

For the LCOE of this project, the capital cost of the hybrid renewable energy system is calculated to be USD289,000.00 while the operating and maintenance cost is USD78.018.00 that can be found in the calculation of this study. There is no denying that the LCOE for this research costs a fortune. However, we must look at the bigger picture and observe the amount of energy produced by the wave energy converter and solar panels as stated previously as they produced a large amount of energy. Furthermore, this study only covers 150.28km^2 area, meaning it is only a small portion of area of Davao Gulf. Therefore, the location which is Davao City has a decent potential energy produced annually. Also, to take into considerations, the magnitude of wave energy varies from time to time. For instance, wave height is higher during a full moon than a regular occasion so, the system may not reach its full potential in low tide. Meanwhile for power generation by solar, it is dependent on the effectiveness of solar panels.

Referring to the objectives, safe to say that this study has reached the objectives of this study. Firstly, the data for both wave and solar energy had been collected via software on the internet. Secondly, calculations for power generation via independent renewable energy had also been done as per the result section of the study and finally, the data for potential hybrid renewable energy resources for power generation had been analysed which is the LCOE of this project.

5.2 Recommendation

After executing this research, a few flaws have been identified and recommendations to further improved this study has been taken into account as follows:

- Conduct the research over a larger area of study.
- Widen the scope of study by implementing various energy such as wind and tidal.

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