

TECHNO-ECONOMIC ASSESSMENT OF PHOTOVOLTAIC AND WIND ENERGY APPLICATIONS AT MONKEY BAY PORT

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A dissertation submitted to the World Maritime University in partial fulfilment
of the requirements for the award of the degree of Master of Science
in Maritime Affairs

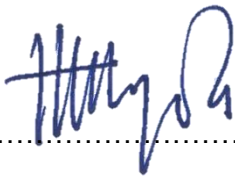
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Declaration

I certify that all materials in this dissertation that are not my work have been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my personal views and are not necessarily endorsed by the university.

Signature:



.....

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NB The supervisor's signature is not required.

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Abstract

Title of the dissertation: **Techno-economic assessment of photovoltaic and wind energy applications at Monkey Bay port.**

Degree: **Master of Science**

This study conducted a techno-economic assessment of implementing a hybrid system (PV and Wind) that can generate electricity to meet the demand of the port aimed at improving energy efficiency of the port and reduce greenhouse gas emissions from diesel generators due to insecure energy supply from the grid.

The study assessed the technical and economic viability of deploying PV and wind generated electricity with a battery storage to cater for intermittent availability of the solar and wind resources. Solar, wind and economic data were used to come up with the best energy system model that will meet the demand of the port using Hybrid Optimization Model for Electric Renewables (HOMER).

The optimization process simulated a number of system configurations under different specified conditions including the grid and diesel generator as a baseline system. The results from the optimization showed that PV and wind with a storage system are technically and economically best option for port use, indicating a decrease in lifecycle cost as compared to baseline system.

The study found out that using Photovoltaic and wind energy with a storage system has lowest LCOE and NPV of \$0.166 and \$3.15 million respectively, and a 90% reduction in GHG emissions as compared to the use of grid and diesel generator.

Keywords: LCOE, NPV, PV, wind, grid, Monkey Bay, Malawi, GHG and renewable energy

Table of Contents

Table of Contents

DECLARATION	II
ACKNOWLEDGEMENTS	III
ABSTRACT	IV
TABLE OF CONTENTS.....	V
LIST OF FIGURES	IX
LIST OF TABLES	X
ABBREVIATIONS.....	XI
SYMBOLS	XII
CHAPTER 1. INTRODUCTION.....	1
1.0. INTRODUCTION.....	1
1.1. BACKGROUND.....	1
1.2. PROBLEM STATEMENT	3
1.3. NATIONAL INLAND SHIPPING ACT	4
1.4. OBJECTIVES OF THE RESEARCH	5
1.4. RESEARCH QUESTIONS.....	5
CHAPTER 2. LITERATURE REVIEW	6
2.1. LITERATURE REVIEW	6

2.2. PHOTOVOLTAIC SYSTEMS.....	6
2.3. WIND ENERGY POTENTIAL.....	8
2.4. RENEWABLE ENERGY BY REGION.....	9
2.5. PORTS UTILISING SOLAR AND WIND TECHNOLOGIES	10
2.5.1. PORT OF ANTEWERP, BELGIUM.....	10
2.5.2. PORT OF ROTTERDAM, NETHERLANDS.....	11
2.6. ECONOMIC AND ENVIRONMENTAL IMPACTS	12
2.7. NATIONAL ENERGY POLICY	12
CHAPTER 3. RESEARCH METHODOLOGY	14
3.0. RESEARCH METHODOLOGY.....	14
3.1. RESEARCH DESIGN.....	14
3.3. RESEARCH PHASES.....	19
3.4. DATA COLLECTIONTECHNIQUE	20
CHAPTER 4. SOLAR AND WIND-GENERATED ELECTRICITY CAPACITY AND FUTURE ENERGY PREDICTION	21
4.1. THE FEASIBILITY OF PV AND WIND-GENERATED ELECTRICITY AT MONKEY BAY PORT	21
4.2. PORT LOADS PROFILE (ENERGY DEMAND).....	21
4.3. MONKEY BAY PORT POWER DEMAND	22
4.4. SUMMARY OF THE SYSTEM COMPONENTS COST.....	24
4.5. RENEWABLE RESOURCE DATA.....	25

4.5.1 SOLAR ENERGY POTENTIAL.....	25
4.5.3. WIND ENERGY POTENTIAL	27
4.6. BATTERY STORAGE SIZING.....	28
4.7. CONVERTER.....	28
4.8. THE GRID.....	28
4.9. DIESEL GENERATOR COMPONENT	29
4.10. PORT ENERGY CONSUMPTION FORECASTING MODEL.....	29
4.10.1 SUMMARY OF THE PORT ENERGY DEMAND AND SYSTEM MODELLING.....	30
4.10.2 PHOTOVOLTAIC AND WIND MODEL CAPACITY.....	31
4.11. INTEGRATING LIFE CYCLE ASSESSMENT (LCA) AND TECHNOECONOMIC ASSESSMENT (TEA) IN A FEASIBILITY STUDY	32
4.12. ECONOMIC DATA.....	32
CHAPTER 5. RESEULTS AND DISCUSSION.....	33
5.1 OPTIMIZATION MODEL.....	33
5.2. TECHNIQUE FOR ORDER OF PREFERENCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS).....	33
5.3. THE OPTIMIZATION PROCESS.....	34
5.4. OPTIMIZATION ALGORITHM.....	35
5.5. LEVELIZED COST OF ENERGY (LCOE) AND NET PRESENT VALUE (NPV) FOR SYSTEM CONFIGURATION.....	35
5.6. OPTIMISATION RESULTS FOR THE TECHNO-ECONOMIC ASSESSMENT OF PHOTOVOLTAIC AND WIND ENERGY MODEL FOR MONKEY BAY PORT	36

5.7. OPTIMAL SYSTEM CONFIGURATION FOR MONKEY BAY PORT	37
5.8. PHOTOVOLTAIC POWER OUTPUT AND BATTERY STORAGE STATE OF CHARGE	38
5.9. WIND SPEED AND TURBINE POWER OUTPUT	40
5.10. EMISSION FROM THE BASELINE SYSTEM AND HYBRID SYSTEM CONFIGURATIONS.....	41
5.11. COMPARATIVE ANALYSIS OF THE BASELINE SYSTEM CONFIGURATION AND HYBRID SYSTEM CONFIGURATION	42
5.12. SENSITIVITY ANALYSIS IN HOMER.....	43
CHAPTER 6. CONCLUSION AND RECOMMENDATIONS	44
6.1. CONCLUSION	44
6.1.1. KEY FINDINGS	44
6.1.1.1. <i>PORT ENERGY DEMAND</i>	44
6.1.1.2. <i>ENERGY RESOURCES</i>	44
6.1.1.3. <i>PERFORMANCE OF PV AND WIND INTERGRATION</i>	44
6.2. RESEARCH RECOMMENDATIONS	45
REFERENCES.....	46
APPENDICES	52
APPENDIX 1: ENERGY FORECASTING CODE	52
APPENDIX 2: ESCOM TARIFFS	54
APPENDIX 3: PROJECT CASHFLOWS	58

List of figures

Figure 1: Renewable electricity generation by source	7
Figure 2: Renewable capacity in Malawi	8
Figure 3: World Electricity generation by region	10
Figure 4: Port of Antwerp	11
Figure 5: Per capita renewable capacity in Malawi	12
Figure 6: Policy and Regulations	15
Figure 7: Environmental data	16
Figure 8: Project cost data	17
Figure 9: Resource data and tools	17
Figure 10: Research phases	19
Figure 11: Data collection tools	20
Figure 12: Port energy loads	23
Figure 13: Daily average power demand	25
Figure 14: Daily solar radiation and clearness index	27
Figure 15: Solar irradiation	27
Figure 16: Monthly average wind speed	29
Figure 17: Forecasted energy demand with annual daily average	32
Figure 18: Inputs and outputs of the model	32
Figure 19: Optimization results of the system configuration	35
Figure 20: Hybrid system configuration architecture	36

Figure 21: PV power output	41
Figure 22: PV power output and battery state of charge	41
Figure 23: Wind turbine power output	42
Figure 24: Wind speed and power output	43
Figure 25: Monthly electricity production	45

List of tables

Table 1: Electricity generation in Malawi	9
Table 2: Annual port energy demand	24
Table 3: Cost of system components	25
Table 4: Diesel generator specifications	31
Table 5: Forecasted energy demand	33
Table 6: MCDM model and Algorithm	36
Table 7: Emission comparison between baseline and hybrid	44

Abbreviations

AC	Alternating current
DC	Direct current
CAPEX	Capital Expenditure
CO ₂	Carbon Dioxide
ESCOM	Electricity Supply Corporation of Malawi
HOMER	Hybrid Optimization Model for Electric Renewables
HRESs	Hybrid Renewable Energy Systems
IMO	International Maritime Organization
IRENA	International Renewable Energy Agency
GHG	Greenhouse Gas
kW	kilowatt
kWh	kilowatt-hour
kVA	Kilovolts-Ampere
LCA	Life Cycle Assessment
LCOE	Levelized Cost of Energy
MCDM	Multi Criteria Decision Making
MEM	Maritime Energy Management
MGDS	Malawi Growth and Development Strategy

MAREP	Malawi Rural Electrification Project
MW	Megawatt
MWh	Megawatt-hour
NASA	National Aeronautics and Space Administration of the United States of America
NPV	Net Present Value
OPEX	Operating Expenditure
PV	Photovoltaic
SCADA	Supervisory Control and Data Acquisition

Symbols

\$	United States of America dollar
Kg	kilogram
Hrs	hours
%	Percent
°C	Degrees Celsius
m ²	square metre
m/s	metre per second

CHAPTER 1. INTRODUCTION

1.0. INTRODUCTION

1.1. BACKGROUND

Malawi, a country in the South-eastern part of Africa, with Tanzania, Mozambique, and Zambia as neighbouring countries. The population of about 20 million people is projected to double to 38 million by 2050 (United Nations, 2024). Malawi has also shipping activities that are carried out on its lakes, and one of the lakes that is heavily in the shipping business is Lake Malawi. Lake Malawi is one of the largest and deepest lakes in the world. The lake is 361 miles long, 47 miles at its widest point and 440 miles deep. The lake covers the southeast, central east and the northern part of the country.

The lake is shared amongst three countries, namely Malawi, Tanzania and Mozambique, with most of the lake being in Malawi. Apart from Lake Malawi, Malawi also has some lakes where maritime activities take place, mainly fishing; these lakes are Chiuta, Malombe and Chirwa. Lake Malawi has several ports, namely: Karonga, Chilumba, Likoma Island, Nkhata-Bay, Chipoka, Nkhotakota, Senga-Bay, Makanjira, and Monkey-Bay. Among these, Monkey-Bay, Chilumba, Likoma Island, and Nkhata-Bay are the major ports.

In Malawi, as a developing country, electricity is generated mainly from hydro power plants (95%) and the rest from other renewable sources and diesel generators (*International Journal of Renewable Energy Technology Research*, 2025). A state-owned company, Electricity Generation Company (EGENCO), is the sole company that generates electricity, which is sold to Electricity Supply Corporation of Malawi (ESCOM), which distributes and sells the electricity to the consumers. According to Evance Chaima et al., (2023), there is an increase in energy consumption across the country due to population growth and industrialisation, in their study they found out that there is an electricity consumption growth of about 165%, and projected an increase in electricity consumption of 218% by 2030, this was in agreement to what Chirwa (2016) found out that the electricity per capita consumption was at 94kWh per

capita in 2014, and 156.84 kWh per capita in 2020. Furthermore, IRENA (2025) indicated that the power consumption per capita in Malawi has increased from 23 W per person in 2016 to 27 W per person in 2022. Harawa (2022) indicated that Malawi's available capacity is 263 MW which falls short of the demand of about 700 MW. The generated electricity is not enough to meet the demand, therefore, ESCOM frequently implement temporary interruptions scheduled load shedding program that allocates areas in groups to manage the electricity supply, this impacts large sections of the country and ports are not spared. These scheduled load shedding programs compelled the community and other stakeholders to use diesel electric generators, this increases the greenhouse gas emissions. The study done by Rahman et al., (2024) in Malawi specifically in Dowa district revealed that most of the people does not have access to clean energy, they heavily rely on use portable generators which are the emitters of GHG. The study also found out that the use of renewable energy of about 5 MW system offers a better system with least cost of energy and avoid 13,877 tons of CO₂ emission annually.

Malawi has an installed electricity generation capacity of about 554 MW (Kampanje, 2025); however, on average, Malawi receives solar irradiation on a horizontal surface of 4-6 kWh/m² per day (Mhango, 2024) which is a huge potential for solar energy utilisation, and average wind speed of 5m/s at a hub height of 50m (NASA, 2024), this speed is significant enough to generate electricity. Clean and affordable energy is vital for the development of any nation and wellbeing of all humans as well as conserving the environment (Küfeoğlu, 2022). Malawi's total available capacity is 263MW, and the current national connected demand is around 700MW (Harawa, 2022).

The gap in installed and available capacity is due to the ageing of the transmission infrastructure and power loss at one of the generation plants that was damaged by a cyclone. The energy gap in Malawi and most developing countries has discouraged social and economic growth of the nations (Evince Chaima et al., 2023). As pointed out by Dalla Longa & Zwaan (2021) that using renewable energy could provide an opportunity to increase the generated capacity and increase the supply in the Sub Sahara region, which will significantly reduce the frequency of load shedding.

Ports in Lake Malawi rely heavily on electricity for their everyday operation; however, with limited and intermittent power supply from the grid, the ports face significant challenges, and mostly they resort to using diesel generators to power their equipment and port operations. Diesel being one of the fossil fuels, heavily reliant on diesel generators, means that a considerable amount of GHG emissions is released into the atmosphere and pollutants around the ports and nearby communities during these power rationing. With this background, most ports in Malawi will continue to face intermittent electricity access, and this will drive the ports into using fossil fuels for their services. Increasing the sustainability and resilience of the ports must be made through diversifying the energy supply options.

1.2. PROBLEM STATEMENT

Sea transport is responsible for over 80 % of all world trade (UNCTAD, 2021), which includes people, crude oil, vehicles and raw goods. The maritime sector contributes 3% of the total greenhouse gas (GHG) emissions, while nitrogen oxides (NO_x) and sulphur oxides (SO_x) contribute 13% and 12% respectively (Mueller et al., 2023). The International Maritime Organisation (IMO), the only competent authority responsible for regulating sea transport and maritime activities with a focus on protecting the people through its Convention of Safety of Life at Sea (SOLAS) and the environment through its Convention of Marine Pollution (MARPOL).

Through MARPOL, the IMO implements regulations on how best the emissions from the maritime sector can be reduced. According to (Toscano et al., 2021), ships anchored in ports contribute between 13-27% of nitrogen oxides (NO₂) and 24-37% of sulphur dioxide (SO₂) to the concentration of polluting emissions. To address these challenges, ports need to switch to clean technologies (Buonomano et al., 2023), and integrating renewable energy and port energy management systems is a promising option for environmental and economic sustainability (Lim et al., 2019).

Monkey Bay Port, which is located on the southern tip of Lake Malawi, is one of the ports along Lake Malawi, and it's the most important facility along the lake as it serves as the connecting node between the various coastal communities along the lake and the only port that has modernised port equipment. As the only hub, Monkey Bay port

faces significant challenges in its port operations because of frequent power interruptions due to scheduled load shedding; this, therefore, drives the port to frequently rely on diesel-driven generators to keep up with power demand from its equipment and other operations that demand energy. Overreliance on diesel generators to produce energy for port operations contributes to the rising emissions of greenhouse gases to the atmosphere, which negatively impacts climate change and air pollution, which have health impacts on the communities around the port.

The use of diesel generators also has economic constraints, Malawi as a landlocked country, relies on imported petroleum products from countries that have oil plants, these products are expensive due to import taxes, therefore exploring alternative energy sources, like photovoltaic and wind-generated electricity, becomes imperative, thus this study aims to assess the techno-economic viability of using photovoltaic and wind as a source of energy to generate electricity at Monkey Bay Port.

1.3. NATIONAL INLAND SHIPPING ACT

Inland shipping act was established to regulate and guide the shipping activities on its lake. The act emphasized on the crew safety, standards of training for seafarers, security and maritime activities within the jurisdiction. Malawi being a member of UN and IMO is bound to all regulations it has signed, one being the Paris Agreement. For it to abide by these international agreements on climate change, Malawi has developed initiatives on dealing with issues relating to climate change one of these initiatives is carbon credits trading (Mpaka, C, 2024), which aims at reducing emissions from the country. Inland shipping is one of the greatest polluters (Mallouppas & Yfantis, 2021), hence a need for improving the technology and alternative solutions that are efficient.

1.4. OBJECTIVES OF THE RESEARCH

The overall objective of this study was to assess the techno-economic of implementing photovoltaic and wind energy to meet the electricity demands at Monkey Bay Port, Malawi, and below are the specific objectives:

- i. To assess the energy demand of the port.
- ii. To evaluate the technical, economic and environmental impacts of using renewable energy sources.
- iii. To identify an energy system model that can meet the demand of the port.

1.4. RESEARCH QUESTIONS

To study used the following questions to achieve the research objectives:

- i. What is the current energy demands at the Port, and how do they vary seasonally?
- ii. What are the economic costs of adopting solar and wind energy solutions compared to existing energy sources?
- iii. What is the best system configuration that is effective for the port?
- iv. What are the technical challenges of the best system configuration and how to overcome them?
- v. How do national policy and regulations challenge the implementation of renewable energy at the port?

CHAPTER 2. LITERATURE REVIEW

2.1. LITERATURE REVIEW

Ports as transit points and hubs for international trade position them in highly energy-demanding and supply activities (Misra et al., 2017). As the global economy continues to grow, developing energy system models that are capable of supplying energy as demanded by the ports and achieving the global effort in decarbonising the maritime sector is important. Studies have been carried out on how we can decrease emissions from vessels (International Energy Agency, 2023); however, less effort has been placed on how we can reduce emissions from ports.

It has been forecasted that shipping industry will continue to grow in the coming years, which is attributed to the population growth and an expansion in global trade (Hercules Haralambides & Merk, 2020); furthermore, there have been a lot of concerns from local communities about health-related respiratory problems and lung cancer (Lam & Notteboom, 2014; Frederickson et al., 2021). This has driven the competent authority to put much emphasis on climate change, air quality and energy efficiency as a means of combating emissions from the port.

Technology advancements in renewable energy have led to a downturn in costs, making photovoltaic (PV) and wind energy increasingly viable options for regions reliant on traditional energy sources. Studies indicate that solar energy can significantly contribute to energy supply in regions with high solar irradiance, while wind energy can offer additional capacity during non-sunny periods (IRENA, 2020).

2.2. PHOTOVOLTAIC SYSTEMS

The effective harnessing of solar energy through photovoltaic panels has gained traction in many developing regions, including Africa. Research (Fatoki, 2022) highlights that the upfront costs of solar installations are decreasing, while efficiency rates are improving. The integration of PV systems in localised energy grids has proven beneficial in rural electrification projects. However, using solar energy will likely need a storage system since solar radiation is not available every time we need it. Renewable energy sources accounted for about 30% of generated electricity

globally, totalling around 9000TWh in 2023 (IRENA, 2025). Solar energy, the fastest-growing energy source, has increased generation by 25.2% annually since 2018, as shown in Figure 1 (IRENA, 2025). In Malawi, there is also an increase in the solar energy technologies uptake out of the total generated capacity; solar energy contributes 21%, as shown in Figure 2.

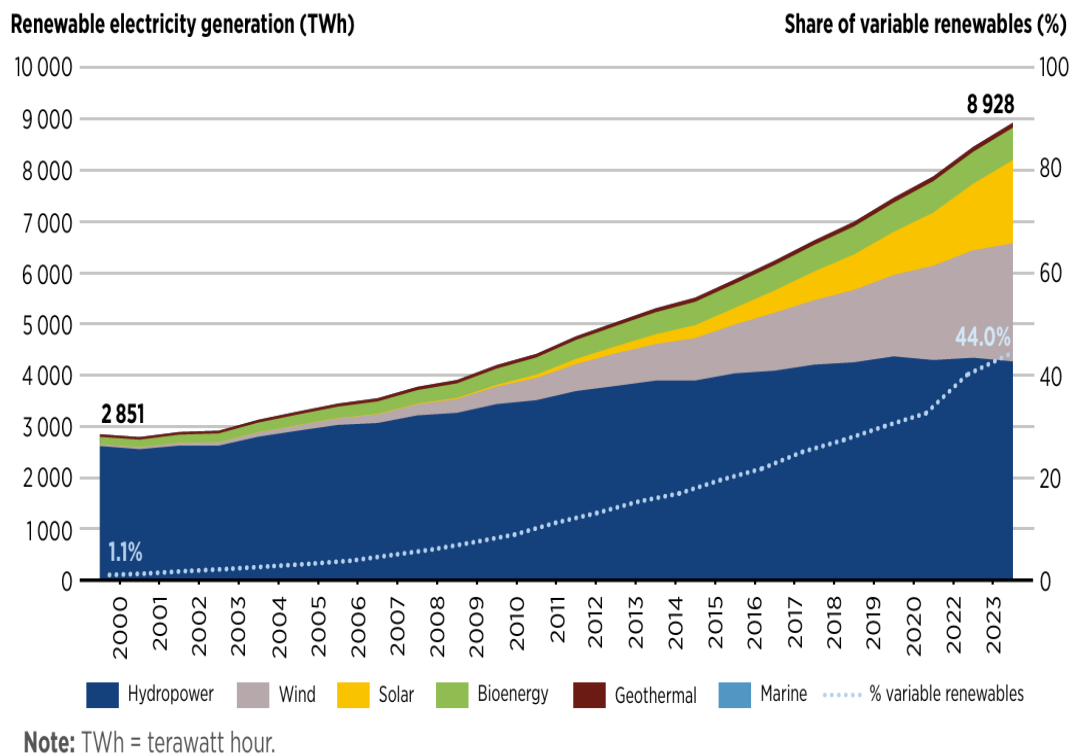


Figure 1: Renewable electricity generation range (IRENA, 2025)

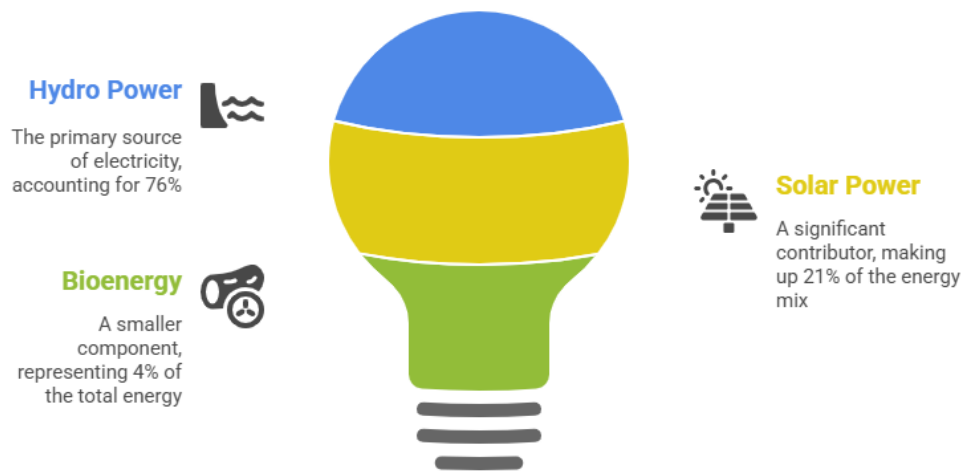


Figure 2: Malawi's Renewable Energy Mix- (IRENA, 2025)

2.3. WIND ENERGY POTENTIAL

Though less explored in Malawi, wind energy possesses considerable potential, especially in specific regions along the lake. According to Evance Chaima et al. (2023), the wind regime in certain locales can support economic generation. However, wind energy is associated with ecological impacts, with birds being one of the living creatures at risk of being killed by the wind turbine's rotating blades (Abbasi & Abbasi, 2000). Wind energy has made significant growth of around 14% and 10% globally in 2022 and 2023, respectively (IRENA, 2025). Malawi, as a country, has not invested much in wind energy, as shown in table 1. According to the IRENA 2025 report, as of 2022, there was no wind-generated electricity in Malawi; this could be attributed to the high capital cost of wind turbine installations.

Table 1: Electricity generation in Malawi-2022

Generation in2022	GWh	%
Non-renewable	466	21
Renewable	1757	79
Hydro and marine	1694	76
Solar	12	1
Wind	0	0
Bioenergy	51	2
Geothermal	0	0
Total	2223	100

Source: -IRENA, 2025.

2.4. RENEWABLE ENERGY BY REGION

As indicated Asia is the leading continent in renewable energy generation in 2023, producing around 4000TWh, representing a 6.9% increase in all technologies except hydropower, which shows a decrease in generation, whilst solar and wind energy show a strong growth (IRENA,2025). Europe has produced 1626 TWh, an increase of 11% whilst North America has generated 1452 WTh, representing a decrease of 2.9% from 2022(IRENA,2025). South America generated around 1000TWh, showing an increase of 6% from 2022, while Africa and Eurasia generated 216 TWh and 370WTh respectively in 2023, representing an increase of 5% and 1.8% respectively (IRENA,2025).

Oceania generated 134TWh, an increase of 18.8%, while the Middle East generated 62TWh, representing 35% growth. Central America and the Caribbean generated 52WTh, showing a decrease of 8% as shown in Figure 3.

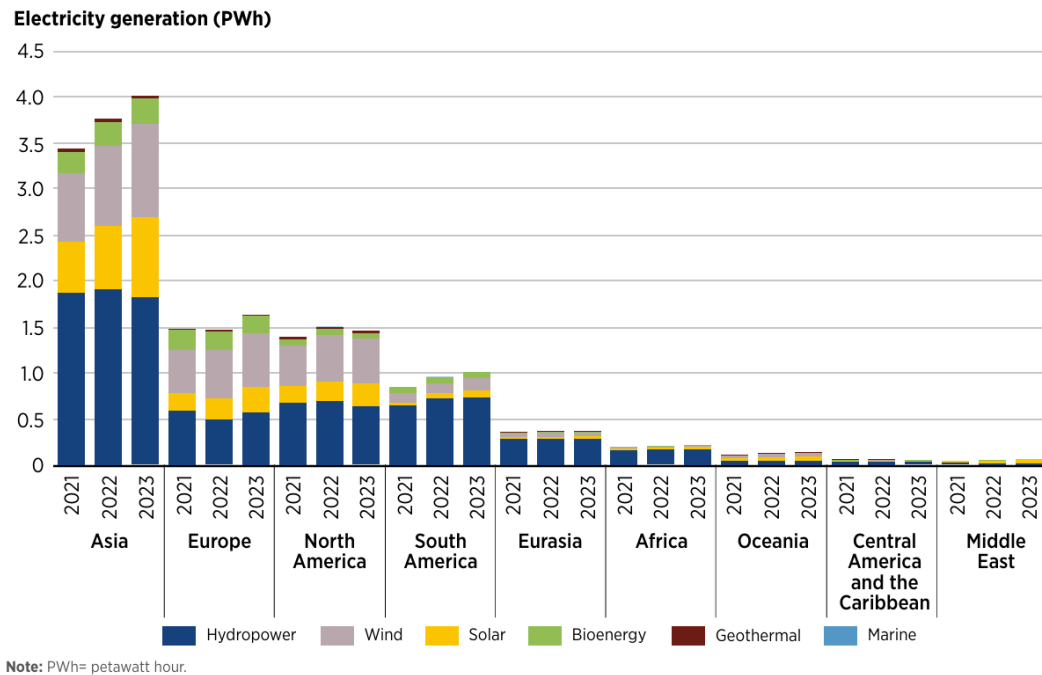


Figure 3: World Electricity generation by region - (IRENA, 2025).

2.5. PORTS UTILISING SOLAR AND WIND TECHNOLOGIES

Ports all over the world are utilising solar and wind energy technologies to produce electricity that is aimed at reducing emissions from the ports. These initiatives help to improve energy efficiency of the port operations thereby reducing emissions, and comply with the regulations on decarbonising the shipping industry. Below are some ports that are utilising solar and wind technologies.

2.5.1. PORT OF ANTEWERP, BELGIUM

As the energy hub, the port of Antwerp is investing heavily in energy transition, and the port is producing renewable energy by utilising solar and wind technologies. The wind turbines located in the port generate electricity that powers the terminals, the berthed ships and the residents around the port. The port has 80 wind turbines, which

have a 200MW capacity in total. This power is used to power the terminals and feed 140,000 families around the port (*Port of Antwerp-Bruges*, 2022).



Figure 4: Port of Antwerp – (Port of Antwerp, 2022)

2.5.2. PORT OF ROTTERDAM, NETHERLANDS

Port of Rotterdam is one of the busiest ports in Europe, approximately 30 thousand ships call at the port annually (Fransen and Davydenko, 2021). The port of Rotterdam is generating wind energy in the North Sea, which is used to produce green hydrogen. The port has also been successful in energy production from solar energy (Port of Rotterdam, 2022). The major focus of the port is to be an energy hub, where it produces alternative fuels to bunker the ships that will be calling at the port.

From the two case studies, it is noted that renewable energy plays a crucial part in global decarbonization, which is one of the key issues affecting the global community.

2.6. ECONOMIC AND ENVIRONMENTAL IMPACTS

Several economic assessments illustrate the financial viability of renewable energy projects, stating the potential for job creation and infrastructure development (Baker, 2021). The adoption of renewables can help stabilise energy prices, boosting local economies and improving the region's overall energy resilience. However, renewable energy projects have some economic and environmental constraints if not properly assessed before implementation, including a lack of proper disposal mechanisms for used batteries and solar panels, and wind turbines pose a threat to living creatures, e.g., birds, which get killed by the rotors. Despite the economic constraints and environmental threats, renewable energy adoption in Malawi is growing, as shown in Figure 5.

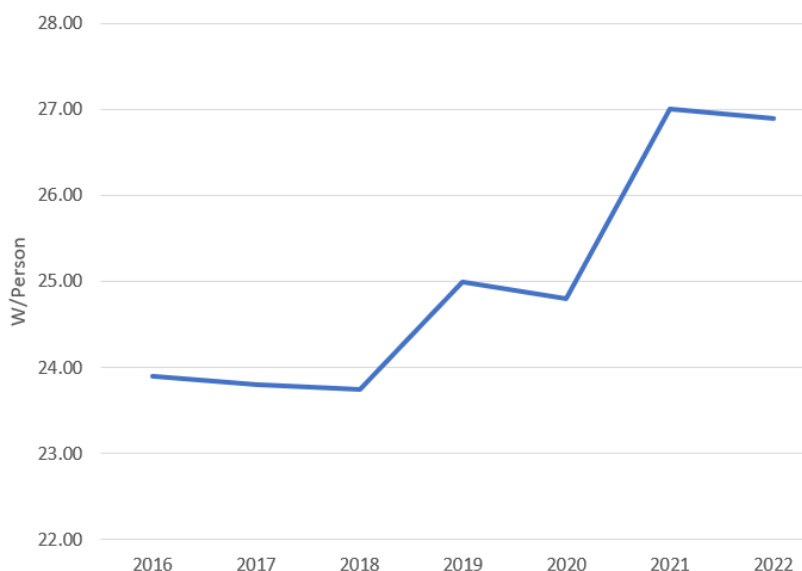


Figure 5: Per capita renewable capacity in Malawi - (IRENA, 2025).

2.7. NATIONAL ENERGY POLICY

Malawi Government through Malawi Growth and Development Strategy (MGDS) III recognizes that energy is one of the crucial elements for economic development of the nation. The policy targets is to increase the access to electricity to 80% by 2035,

through renewable energy generation (GoM, 2018; Zalengera et al., 2020). To achieve its targets the government, has identified electricity as one of the key priority areas, this includes electricity generation from renewable sources and extend electricity access to rural area through Malawi Rural Electrification Project (MAREP) (GoM, 2020).

CHAPTER 3. RESEARCH METHODOLOGY

3.0. RESEARCH METHODOLOGY

For balanced analysis, the study combined qualitative and quantitative (mixed methods), where existing literature, journals, books, articles and reports were systematically reviewed and analysed to develop a comprehensive report, and energy demand data and cost were analysed. Below is the methodology involved:

- i. The use of computer modelling software called Hybrid Optimization Model for Electric Renewables (HOMER) to assess the techno-economic feasibility of Hybrid Renewable Energy Systems (HRESs) for the port.
- ii. Conducting life cycle assessments (LCA) of the systems to ascertain environmental impacts over time.

3.1. RESEARCH DESIGN

The study mixed-method approach, combining qualitative analysis and quantitative analysis.

The qualitative data included:

- i. Policy and Regulations
Detailed national policy and international government policies will be reviewed, IMO policies on decarbonizing the shipping industries were analysed and a thorough examination of policy documents were made. The study will review the national policy and regulations on independent power producers (IPP) and policies will help in decisions making. The study will also look into the port energy frameworks if any.

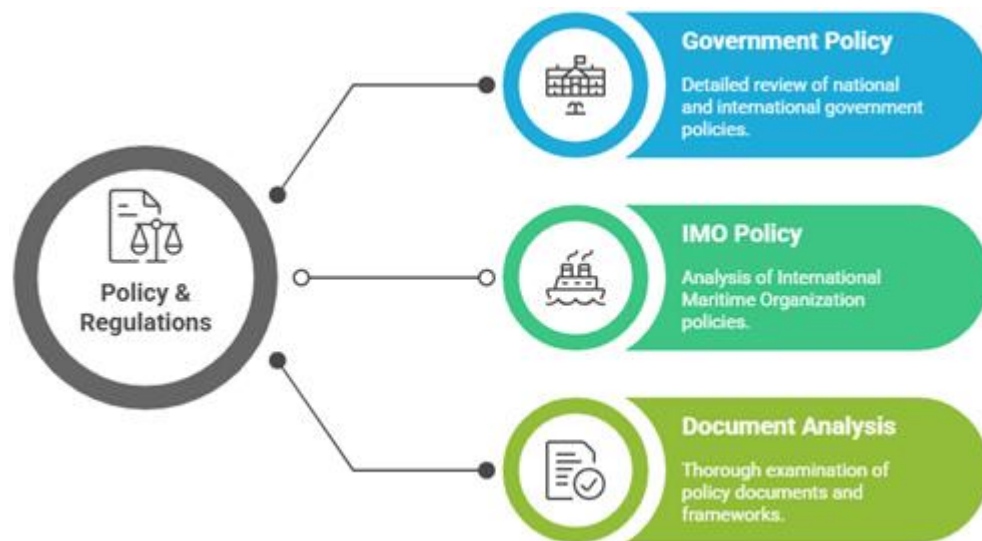


Figure 6: policy and regulation

ii. Environmental sustainability

Environmental sustainability data were used to evaluate the projects and port operations impacts on environment to ensure sustainable utilisation of the resources. The tools used analyze resource use and emissions emanating from the project was the Life Cycle Assessment (LCA). The study will focus on what will be effects of the project on the environment, and these effects include; GHG emissions, waste generated from the project and visual and noise pollution.



Figure 7: Environmental data - (Author)

The quantitative data used were:

I. Economic cost data

The economic cost data of the system configuration included all the cost of solar and wind system components, CAPEX and OPEX from system operation and LCOE if buying from the grid and the use of diesel generator.

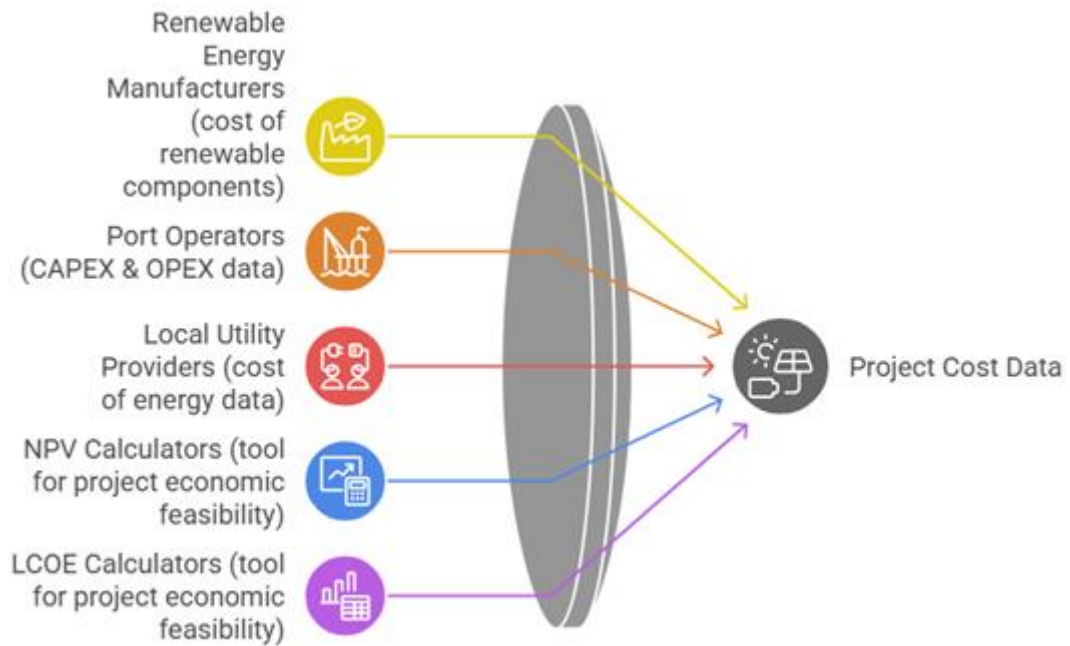


Figure 8: Project cost data

II. Renewable resource data

The renewable resource data included the weather information from weather database, which provide climatic data for the site. These climatic data are solar irradiance, wind speed and temperature. Computer tools (HOMER and Python) were used to collect the data from NASA weather database



Figure 9: Resource Data and Tools

III. Port energy consumption data

The energy consumption data from the port were collected through Port Authority which provide the monthly energy consumption of the port.

3.3. Research Phases

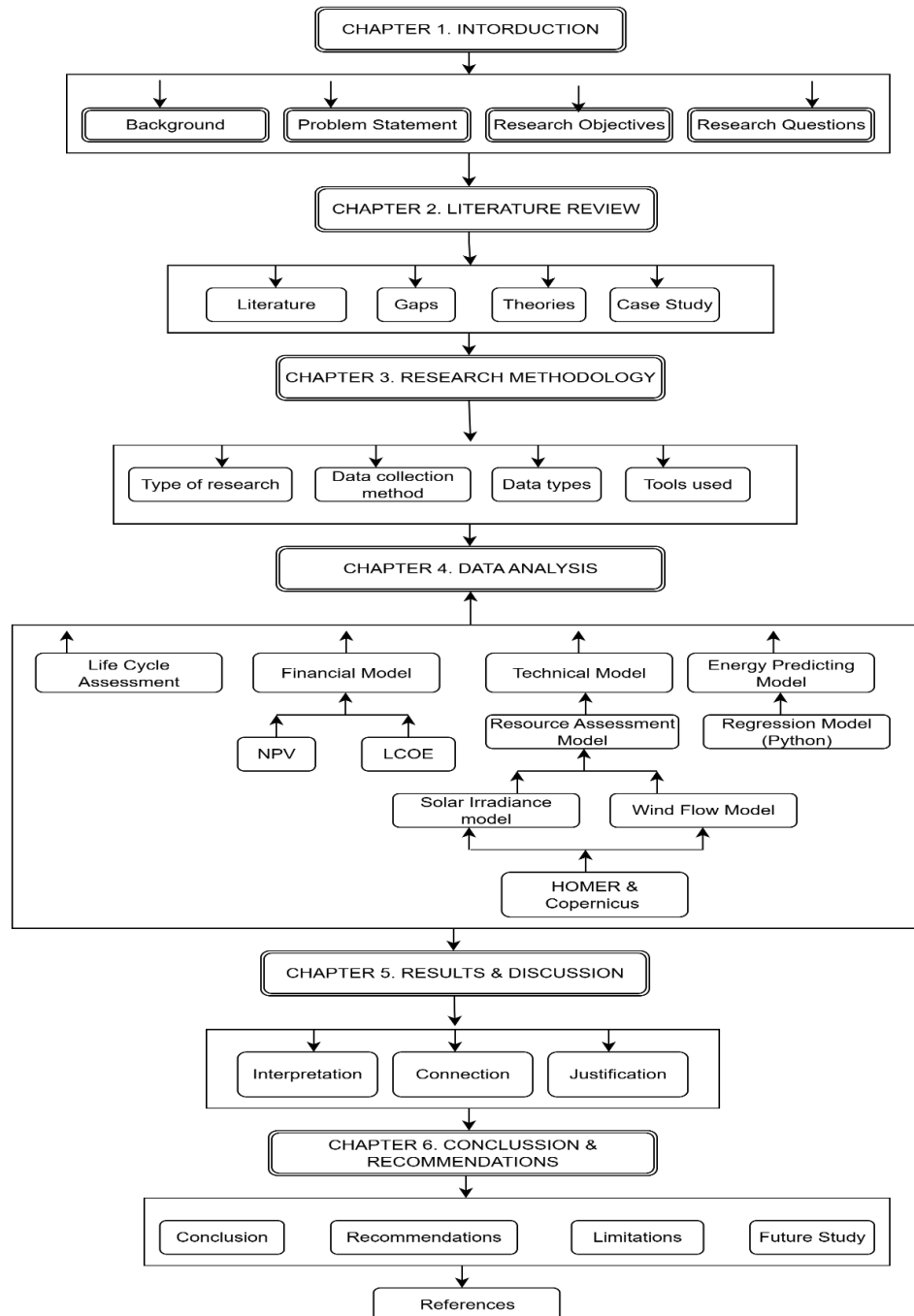


Figure 10: Research phases - (Author)

3.4. DATA COLLECTIONTECHNIQUE

Figure 11 presents the approach used for collecting data from the port. This approach has been chosen because of the nature of the study, where only energy demand data was used to identify a system that can meet the demand of the port. However, the approach was not in a representative sample since the port authority and utility provider portals did not provide all the needed data. The researcher used the port authority emails to get energy consumption data, Electricity Supply Corporation of Malawi portal to get the cost of electricity and NASA database to get solar and wind resource data.

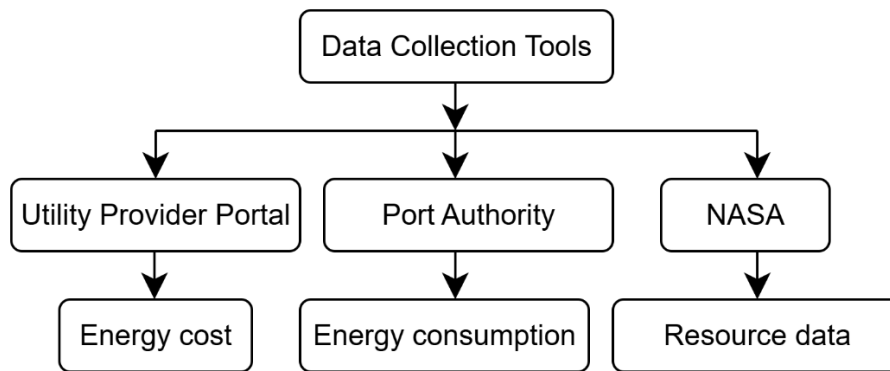


Figure 11: Data collection tools –(Author)

CHAPTER 4. SOLAR AND WIND-GENERATED ELECTRICITY CAPACITY AND FUTURE ENERGY PREDICTION

4.1. THE FEASIBILITY OF PV AND WIND-GENERATED ELECTRICITY AT MONKEY BAY PORT

A feasibility assessment is carried out to come up with system that is able to meet the demand of the port at the lowest cost. There are commercial computer software tools available that are used to model energy systems, conduct simulations, operation, cost optimisation and sensitivity analysis.

The study collected the energy demand data of the port at latitude -14.07° and longitude 34.05° . HOMER Pro was used, where system components, the loads, inflation rate, discount rate, project life and annual shortage capacity for the desired system were described. The interface also includes system constraints, system economics and CO₂ emissions.

Python was also used in this study to forecast the energy consumption of the port based on the energy data collected. It was also used to analyse the energy resource data from the port, the solar irradiation and wind speed data to come up with an average power from the resources per area.

4.2. PORT LOADS PROFILE (ENERGY DEMAND)

A load profile refers to the demand for electric or heat energy from the system or utility provider. Modelling of a microgrid system starts with the modelling of the loads that the system must serve. There are two types of loads and these are primary loads and shifting loads (Eko & Paul, 2021).

Primary Loads: These are the type of loads that need electrical power from the supply at a given time (Eko & Paul, 2021). This type of load needs the supply of electricity immediately when it is switched on, and it cannot be deferred.

Shifting Load: An electrical load that can be delayed or rescheduled within a certain time without significantly affecting the end-user's needs. These loads include heating/cooling, washing machine, dryers, water pumps, battery charging and some industrial loads which can be scheduled (Eko & Paul, 2021). Port of monkey bay the main loads that consume a lot of power are machineries, which include; cranes for cargo handling, dry docking operations and electricity usage in buildings (workshops, offices and warehouses) as shown in figure 12 below.

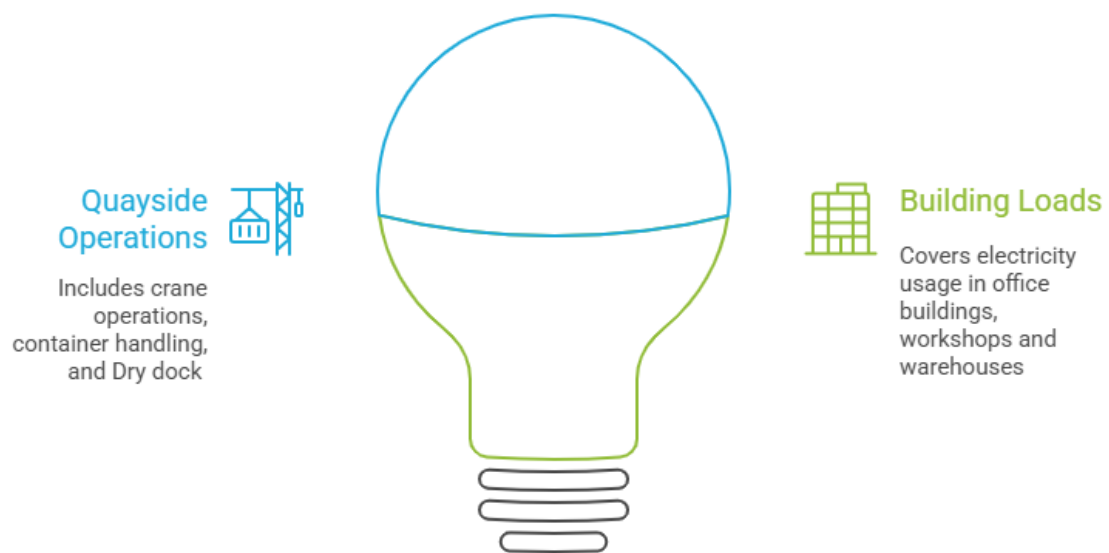


Figure 12: Port energy loads - (Author)

4.3. MONKEY BAY PORT POWER DEMAND

The study collected electrical load data from the port authority of Monkey Bay port. The electrical load was collected from port offices, warehouses, workshops, staff houses within the port and the dockyard. The port gets its electricity from a grid operated by the only power supply, Electricity Supply Cooperation of Malawi (ESCOM), which supplies the electricity on a post-paid basis. The port uses the energy and pays at the end of the month; the bill includes the amount of energy consumed in that particular month.

The energy data collected was for 10 years, from 2015 to 2024. Monkey Bay port, being one of the developing ports, has not been digitalised yet getting instantaneous hourly energy consumption was not possible. However, from the data collected, the calculated annual average consumption is 12715.6 MWh, and the actual annual demand for the year 2015 to 2024 is shown in table 2. The daily average consumption is around 31.15 MWh in 2019 and gradually increased to around 62.33 MWh in 2024, as shown in Figure 13, and the hourly average consumption is 1.29 MWh in 2019 and around 2.6 MWh in 2023 and 2024. It was noted that the energy consumption for the port was increasing gradually except for 2020 and 2021; this decrease may be attributed to the COVID-19 pandemic. As shown in Figure 13 the daily average consumption in the year 2024 was 62.33 MWh , and this was used as a baseline for this study.

The Malawi government and Ministry of Health issued guidelines on how to deal with COVID-19; among the guidelines was working from home; only those with essential duties were allowed to work physically at the work station. This reduced the number of people who were physically working at the port, hence reducing the number of activities carried out per day. This slightly reduced the port's energy consumption in these 2 years.

Table 2: Annual Port energy demand (MWh)

	2015	2016	2017	2018	2020	2021	2022	2023	2024
January	669.06	715.74	791.51	861.90	851.08	629.71	699.15	1575.26	2383.54
February	545.82	643.06	737.85	822.13	725.51	638.32	673.91	1288.65	1992.59
March	575.32	589.57	839.94	776.92	825.70	746.34	740.98	1395.68	2113.18
April	590.26	648.02	782.33	744.20	872.39	748.70	708.13	1289.86	1290.37
May	711.32	681.11	814.29	871.08	1044.37	742.14	654.80	1525.20	1874.50
June	673.43	721.43	848.40	923.43	1048.11	770.17	729.26	1262.00	2148.33
July	651.55	718.29	839.67	804.73	997.04	763.10	628.71	1567.30	1907.61
August	734.27	857.01	936.40	874.53	1069.63	721.37	619.50	1471.80	1708.27
September	575.94	623.65	821.90	743.62	992.04	757.71	722.34	1658.54	1838.56
October	623.46	716.45	768.13	712.76	827.60	724.39	753.44	1472.90	1644.42
November	666.28	720.06	676.87	733.22	1064.85	716.33	591.43	1768.75	1906.08
December	734.37	785.90	648.78	801.30	1054.29	656.84	710.71	1701.20	2054.26

Source: Author

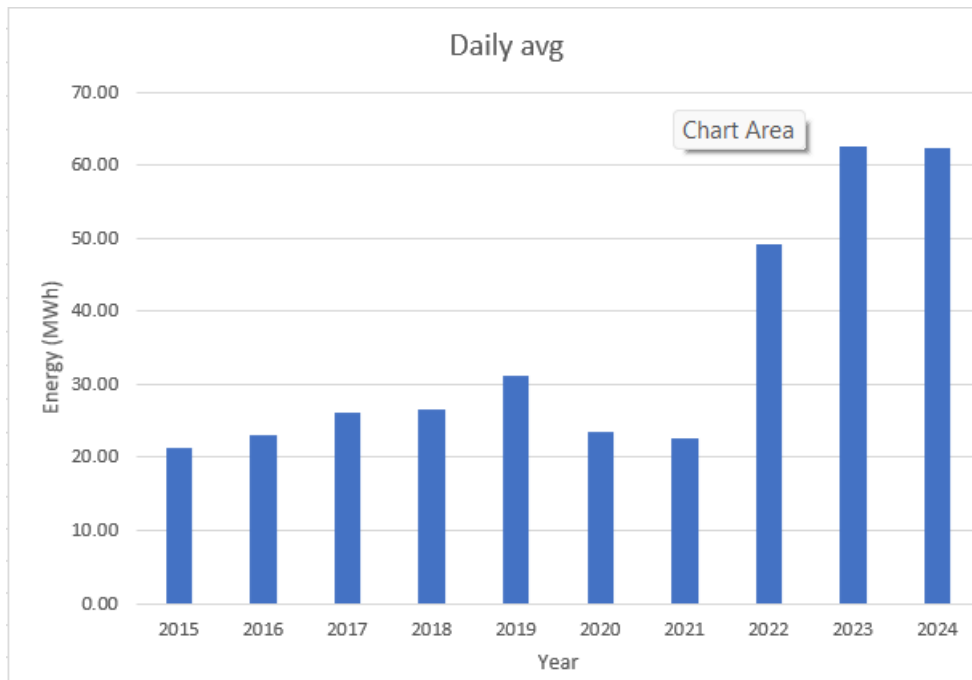


Figure 13: Daily average power demand (MWh) (Author)

4.4. SUMMARY OF THE SYSTEM COMPONENTS COST

The system initial cost, operation and maintenance cost, replacement cost and their sizes are shown in table 3 below.

Table 3: Cost of system components

System component	Size	Investment cost	O&M cost	Replacement cost	Reference
PV arrays	100 kW	\$883/kW	\$17.66/kW-year		Vakili & Ölçer, 2023
Wind turbine	50 kW	\$4000/kW	\$500/unit	\$3200/kW	Eko & Paul, 2021
Storage system	400 kWh	\$868.4	\$86.8/year		Vakili & Ölçer, 2023
Converter	5 kW	\$4650	\$120	\$4185	Vakili & Ölçer, 2023
Diesel generator	100 kW	\$17,353	\$0.02 per operation hour	\$15,617.7	Eko & Paul, 2021 Vakili & Ölçer, 2023

Source: Author

4.5. RENEWABLE RESOURCE DATA

A resource is anything that we get outside the system, used by the system to generate energy. These resources are solar, wind, biomass, hydro and any fuel used by the system components (Eko & Paul, 2021)

4.5.1 SOLAR ENERGY POTENTIAL

To model a system that integrates a PV array, the modeller must provide solar data from the area of interest. The data include global solar radiation; hourly average global solar radiation (kW/m^2) on a horizontal surface, hourly air temperature ($^{\circ}\text{C}$) and monthly clearness index, which is the measure of how clear the atmosphere is (Eko & Paul, 2021)

The solar resource data for Monkey Bay port used in this study was extracted from NASA database using an algorithm built in the HOMER modelling software, which can generate synthetic location hourly data for 12 months and over. Figure 14 shows the measured daily solar resource data for Monkey Bay port for the year 2024 from NASA, and on average, the port received a monthly average of about $5.33 \text{ kW/m}^2/\text{day}$ for the entire year. Figure 15 shows that solar power of about 500 W/m^2 , signifying the potential for harnessing from the sun.

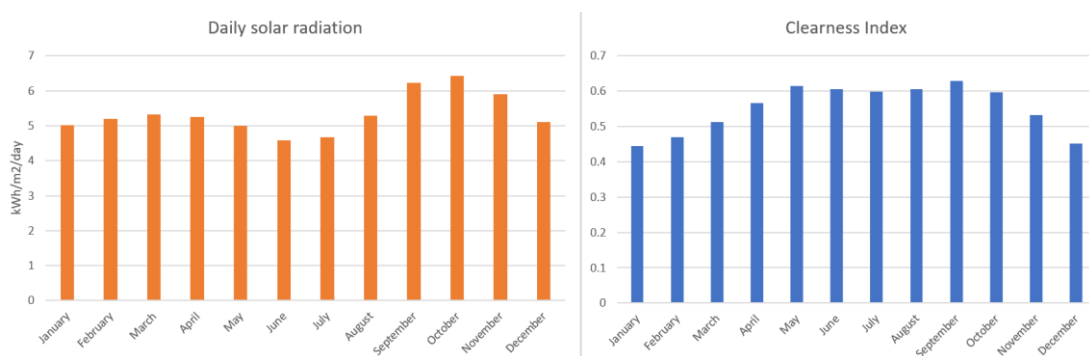


Figure 14: Daily Solar radiation and Clearness index - (Author)

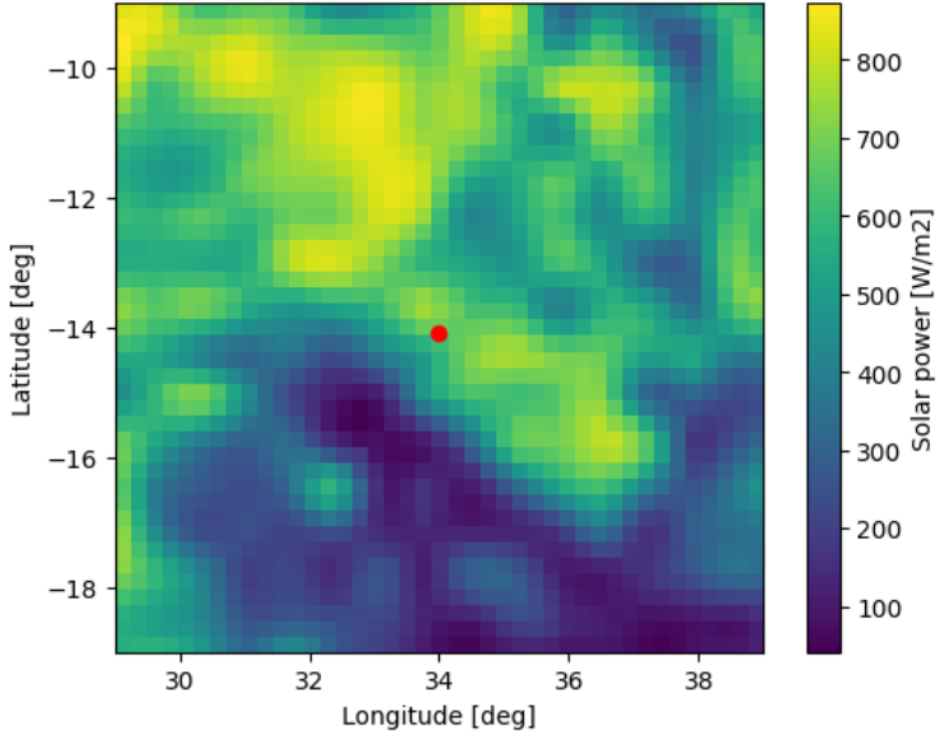


Figure 15: Solar irradiation (W/m²) - (Author)

4.5.2. PHOTOVOLTAIC POWER OUTPUT CALCULATION

This is denoted P , and is calculated by using the formula below.

$$P = \gamma f \left(\frac{G_t}{G_{t,STC}} \right) [1 + a_p (T_c - T_{c,STC})] \quad [1]$$

Where, γ is the power output at standard test conditions (STC), f is the derating factor, G_t is solar radiation on panel in kW/m² each time step, $G_{t,STC}$ is solar radiation on panel at STC, a_p is power temperature coefficient, T_c and $T_{c,STC}$ are PV cell temperature at current time step and at STC respectively (Eko & Paul, 2021). The derating factor is a constant that is used to reduce the PV output when affected by dust or shade.

In this study monocrystalline PV modules were used for simulation, mounted at a fixed tilt angle of 15° and 180° azimuth, without sun tracking technology.

4.5.3. WIND ENERGY POTENTIAL

Wind resources data for the port area were extracted from NASA database using an algorithm built in the HOMER modelling software, which can generate synthetic location hourly data for 12 months. Figure 16 shows the measured wind speed data for Monkey Bay port for the year 2024. On average, the port received an annual average of about 5.02m/s, signifying the potential for electricity generation.

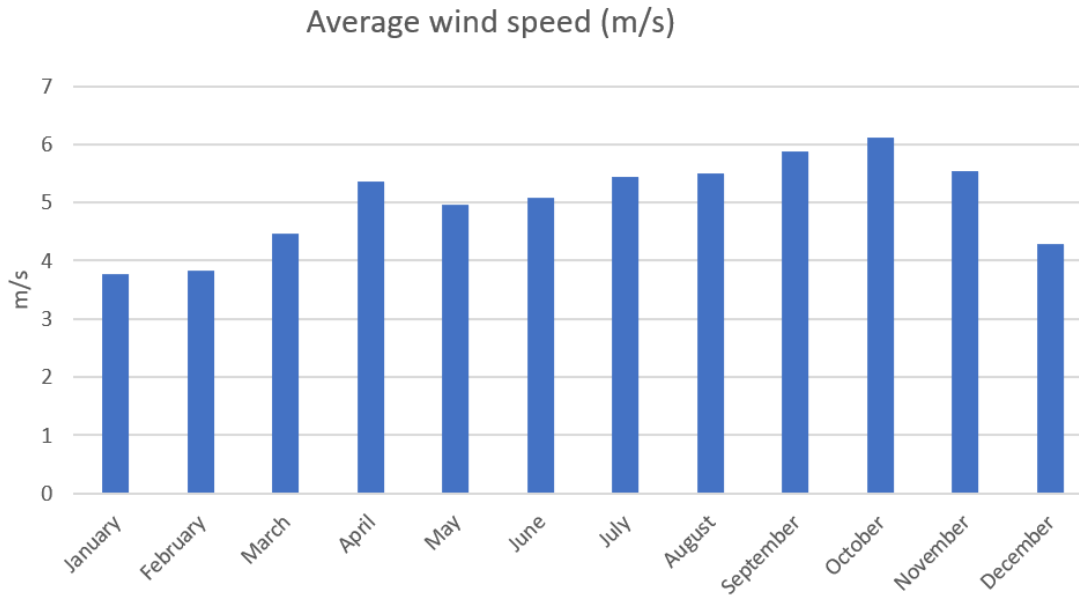


Figure 16: Monthly average wind speed (m/s) - (Author)

Power output calculation: In every calculation the software applies either the power law or log law for this adjustment, and this depends on how the user defines the profile of the wind shear. Equation below is to calculate wind turbine power P.

$$P = \frac{1}{2} \rho A V^3 C_p \quad [2]$$

Where, ρ is air density, A is the rotor swept area (m^2) and C_p is the power coefficient (Vakili & Ölçer, 2023).

4.6. BATTERY STORAGE SIZING

Energy storage is very important for solar and wind power output, which helps to compensate for the variations in power output due to weather and climatic changes (Vakili & Ölçer, 2023). The storage capacity of the system was calculated using the equation [3] below in ampere hour (C_{ah})

$$C_{ah} = \frac{(1-\theta)n_{day} \times E_{load}}{\eta_{beff} \times DOD \times V_{bat}} \quad [3]$$

Where θ is the power from PV to the load, n_{day} is the number of the autonomous day (days without solar irradiance), E_{load} is the daily energy consumption, η_{beff} is the battery efficiency, DOD is accepted depth of discharge and V_{bat} is the rated battery voltage (Kumar & Biswas, 2017). The capacity of the storage system was rated at 400kWh.

4.7. CONVERTER

Photovoltaic systems produce DC electricity. For it to be interconnected to the grid system, which is normally AC, there is a need to have a converter in the system. A converter is a device that converts DC electricity to AC and vice versa through the processes called inversion and rectification (Eko & Paul, 2021). When modelling systems in HOMER, the modeller has to specify the capacity of the converter, capital cost, annual operation and maintenance costs, and replacement cost over its lifetime.

4.8. THE GRID

The grid was used as a baseline system where the cost of the energy was calculated at \$0.167 per kWh, and when considering net metering, the price for selling the energy to the grid was estimated to be \$0.1 per kWh (ESCOM, 2024).

4.9. DIESEL GENERATOR COMPONENT

The diesel generator was sized to be 100kW; This component was considered in this study using grid system in time of load shedding and as also an aspect to consider when comparing GHG emissions from the grid-diesel configuration and PV, wind and battery storage configuration. The diesel generator specifications shown in table 4. Due to frequent power supply intermittent, the diesel generator was set to run for 5 hours 3 days per week.

Table 4: Diesel generator specifications

Component	Value
Capacity	100kW
Fuel type	Diesel
Fuel consumption	2.8L/hr
Fuel curve slope	0.253L/hr/kW
Carbon emissions	17.749 g/L fuel
Nitrogen Oxides	1.4235 g/L fuel
Sulfur content in fuel (%)	0.4
Particulate	0.0712 g/L fuel
Carbon content in fuel (%)	0.88

Source: Author

4.10. PORT ENERGY CONSUMPTION FORECASTING MODEL

Energy forecasting is the process of predicting the future energy demand by using the past energy demand data over a period of time. Forecasting helps the modeller to design a system that will meet the energy demand of the future to avoid oversizing and under sizing of the systems. Linear Regression model was used to predict the energy demand of the port, the model established the linear relationship between the input and output variables. Appendix 1 shows Python code used to predict the energy demand for the port of Monkey Bay from 2025 to 2029. From Figure 17, the graph shows that there will be an annual energy demand increase of about 24% in the next 5 years to come.

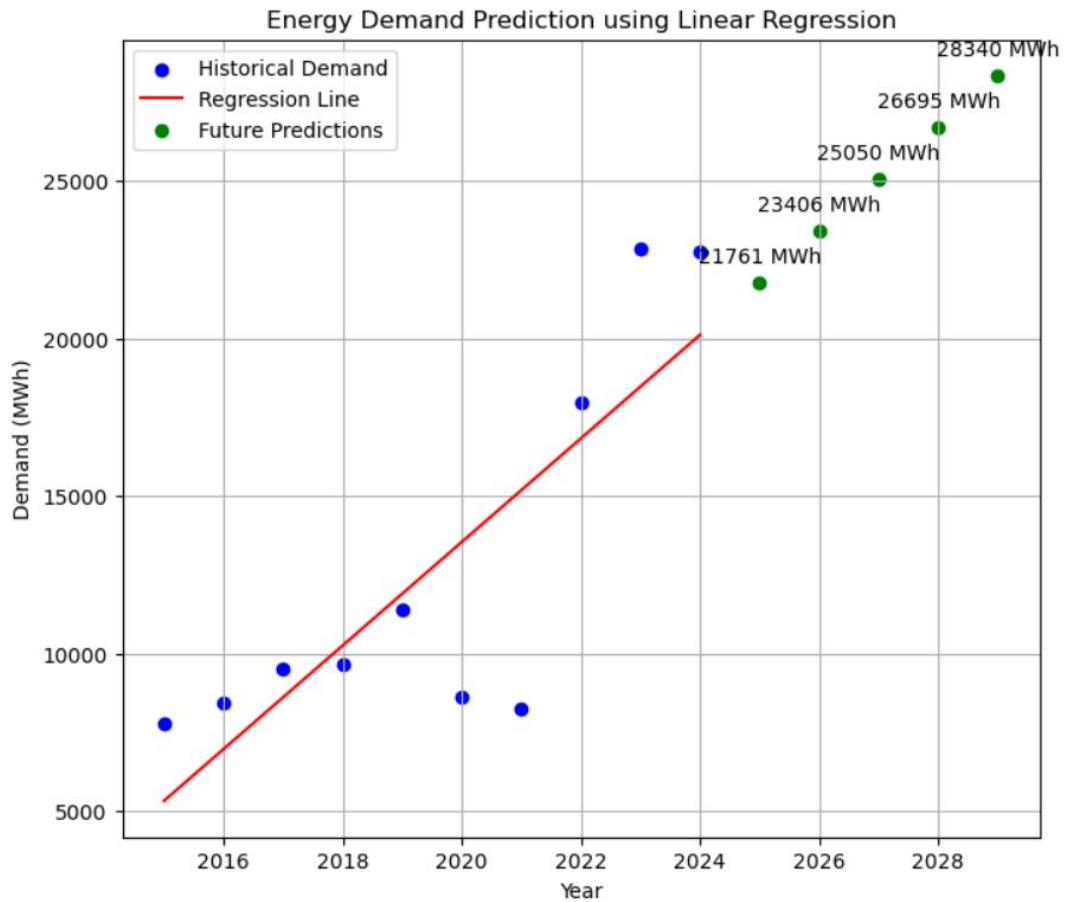


Figure 17: Energy demand forecast with annual and daily average (2025-2029) - (Author)

4.10.1 SUMMARY OF THE PORT ENERGY DEMAND AND SYSTEM MODELLING

For this study, the energy demand for the year 2024 and the forecasted demand were used to model the energy system that will meet the demands of the port now and in the future. Table 5 shows the 5 years predicted energy demand from 2025 to 2029.

Table 5: Forecasted energy demand

YEAR	Historical Daily Average Demand (kWh)	Forecasted Daily Average Demand (kWh)
2024	2589.93	
2025		2484.14
2026		2671.89
2027		2859.63
2028		3047.37
2029		3235.12

Source: (Author)

4.10.2 PHOTOVOLTAIC AND WIND MODEL CAPACITY

Considering the daily, monthly and annual consumption of the port, and the forecasted energy consumption, the following factors; renewable resource, initial cost, and O&M costs of the system components were considered when coming up with the system capacity. According to the 2024 energy consumption data, the port consumes around 2600 kWh per day and the forecasted daily average demand of 3230 kWh per day for the next 5 years. The forecasted daily average energy demand was used to model the optimal system configuration to account for uncertainties and future energy demand. For simulation, the PV and Wind system capacity was set at 100 kW and 50 kW respectively while the battery storage was set at 400 kWh, HOMER modelled the optimal system configuration based on this capacity.

4.11. INTEGRATING LIFE CYCLE ASSESSMENT (LCA) AND TECHNOECONOMIC ASSESSMENT (TEA) IN A FEASIBILITY STUDY

In this study, sensitivity analysis was employed in the HOMER simulation model, where variables were varied to determine the optimal configuration which balances both economic and environmental impacts. Due to data limitations from production, transportation, installation and operation of solar and wind systems, this study did not go into more detail in LCA; only emissions during the operation time of the system configuration were

4.12. ECONOMIC DATA

Economics plays a crucial role in HOMER optimising and simulation processes, where it determines the system configuration which has the lowest total NPV. The main parameters for economic modelling in HOMER are discount rate on capital, fixed operation costs, operation and maintenance costs and project lifetime (Eko & Paul, 2021). HOMER uses the total net present value to represent the total life cycle cost of the system which includes; fuel cost, cost of buying power from the grid, maintenance, pollution costs, initial capital cost, replacement cost and the any revue coming from selling and salvage (Eko & Paul, 2021).

CHAPTER 5. RESEULTS AND DISCUSSION

The previous chapter presents the findings of the study on technoeconomic assessment of PV and Wind applications at Monkey Bay port. The findings include port energy demand and predicted future energy demand, solar resource data, wind resource data and economic data for implementing the different energy system configurations.

5.1 OPTIMIZATION MODEL

This study focused on economic, technical and environmental objectives as the criteria for modelling renewable energy systems optimization. On economic objectives the total system cost and LCOE were evaluated, while system capacity, resource availability, system stability and efficiency were the technical objectives evaluated, and GHG emissions was the environmental objective targeted. The model deployed in this study was MCDM, which assessed the technical and economic viability of PV and wind generated electricity at Monkey Bay port. MCDM was used to come up with the optimal system configuration by using objectives and criteria, this was achieved by evaluating the alternatives in terms of economic and technical perspectives.

5.2. TECHNIQUE FOR ORDER OF PREFERENCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS)

TOPSIS is one of the techniques used in MCDM models to find the best alternative by considering those alternatives that very close to ideal solution and those far from negative ideal solution (Singh et al., 2022). It involves creating decision matrix where alternatives and criteria are weighted and compared, and calculate the relative closeness to the ideal alternative. TOPSIS then ranks the alternatives in order of how close the alternative is to the ideal alternative (Kizielewicz & Salabun, 2024). In this study the ideal system was the one with best value in energy cost, lowest NPV and the one with high efficiency. Table 6 below shows the model and algorithm used and its decision objectives and criteria.

Table 6: MCDM model and Algorithm

Decision Objective	Criteria	Algorithm
Economic	Investment cost, Replacement cost, and O&M cost	TOPSIS
Technical	Generation capacity, resource capacity, technology stability and efficiency	TOPSIS
Environmental	CO2 emission and LCA	TOPSIS

Source: Author

The model used HOMER as a tool to simulate and optimize the system configuration and rank the results in a descending order. The model inputs and outputs are shown in figure 18 below.

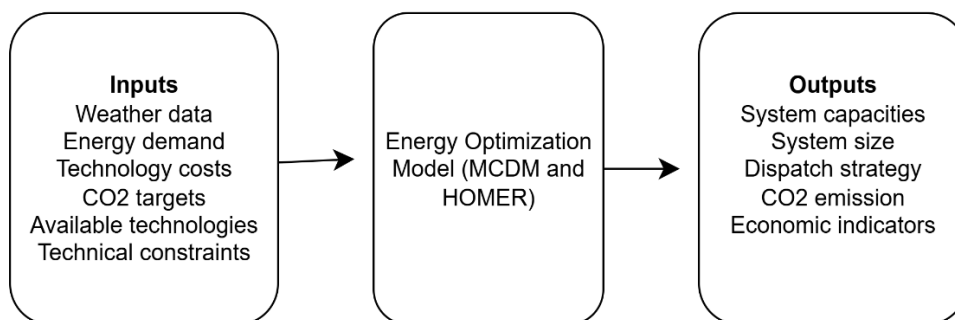


Figure 18: Inputs and outputs of the Model

5.3. THE OPTIMIZATION PROCESS

The optimisation process included the following decision variables in order to come up with the best system alternatives:

- i. PV array size
- ii. Wind turbines number
- iii. Generator size

- iv. The number of batteries
- v. The converter sizes
- vi. Dispatch strategy
- vii. Grid

5.4. OPTIMIZATION ALGORITHM

The optimization algorithm used in the study was the use of economic and technical models to come up with feasible system configuration that can supply the energy demand of the port. The economic and technical matrices were used in a computer software (HOMER) as a tool to calculate the cashflows, the generation capacity per year of the system configuration to find the NPV, LCOE and the generated GHG emissions per year.

The inputs into the tools were, total initial cost of the system component, total O&M cost per year of the system components, replacement cost of the system components, cost of energy from the grid, selling cost of energy to the grid, cost of fuel per litre, inflation rate, discount rate, cost of CO₂ per tonne emission, system size, system component efficiency and system lifetime. Using these inputs HOMER used the inbuilt algorithm to calculate the NPV, LCOE and the emissions for each system configurations under different optimizing conditions to come up with the best system with least cost. The results are then ranked in a descending order with the one with least cost at the top.

5.5. LEVELIZED COST OF ENERGY (LCOE) AND NET PRESENT VALUE (NPV) FOR SYSTEM CONFIGURATION

The economic elements considered in this study are the Levelized Cost of Energy (LCOE) and Net Present Value (NPV) for the system configuration, which depends on the total annualized cost of the system. The equation below was used to calculate the LCOE of the system (Hafez & Bhattacharya, 2020)

$$LCOE = \frac{C_{TAC}}{E_{sy}} \quad [4]$$

Where C_{TAC} is the total annualised cost of the system and E_{sy} is the total electrical energy produces. The LCOE of the system was found to be \$ 0.29 per kWh.

NPV is the total present value of project in a time series of cashflows used to appraise long term projects. The equation for calculating NPV is,

$$NPV = \sum_{t=1}^n \frac{R_t}{(1+i)^t} \quad [5]$$

Where R_t is the cash flow during period t , t is the number of projects periods, i is the discount rate (Wang, 2021). The NPV of the system configuration was found to be about \$3.15 million.

5.6. OPTIMISATION RESULTS FOR THE TECHNO-ECONOMIC ASSESSMENT OF PHOTOVOLTAIC AND WIND ENERGY MODEL FOR MONKEY BAY PORT

The optimization results are shown in Figure 19 below, the feasible system configurations are ranked in ascending order of their NPV, LCOE, O&M cost, initial cost and the renewable share. According to the simulation results, the system configuration at the first position has a NPV of \$3.15 million, LCOE of \$0.166 per kWh. From the optimization results, PV, battery storage and the grid is the most feasible configuration economically, however, for the purpose of this study PV, wind and battery storage was chosen, this was chosen because renewable energy is resource dependent, so when design a system you have to consider that. Energy resource mix is important to meet hourly energy demands of the port.

Optimization Results												☐ Categorized	
Export...		Export Details...		Double click on a system to see its Simulation Details.									
Architecture							Cost						
			Fron20 (kW)	Fron20-MPPT (kW)	EO25IIA	ESS.50.400.System (#)	Leon5 (kW)	Dispatch	NPC (\$)	LCOE (\$/kWh)	Operating cost (\$/yr)	CAPEX (\$)	Ren Fra (%)
			69.8	20.0	43	71	581	LF	\$3.15M	\$0.166	\$53,791	\$2.28M	100
			69.8	20.0	43	71	581	CC	\$3.15M	\$0.166	\$53,791	\$2.28M	100
			75.5	20.0	43	71	577	LF	\$3.15M	\$0.166	\$53,805	\$2.28M	100
			75.5	20.0	43	71	577	CC	\$3.15M	\$0.166	\$53,805	\$2.28M	100
			62.9	20.0	43	71	589	LF	\$3.15M	\$0.166	\$53,868	\$2.28M	100

Figure 19: Optimization results of the system configurations

5.7. OPTIMAL SYSTEM CONFIGURATION FOR MONKEY BAY PORT

The optimal system configuration for the port is the one that meet the electricity demand of the port at the least cost and environmentally friendly. From the optimization results, hybrid system configuration is the one that is economically and environmentally feasible. From the results, the hybric system has showed that it is economically viable, a reduction in lifecycle cost by around 96% and a reduction in environmental impacts by 96.41%. The system configuration is composed of the following components:

- i. A 100 kW of PV array
- ii. A 50 kW of wind turbines
- iii. A 400 kWh of battery storage
- iv. A 5-kW converter
- v. A load following dispatch strategy

Figure 20 shows the architecture of optimal system configuration

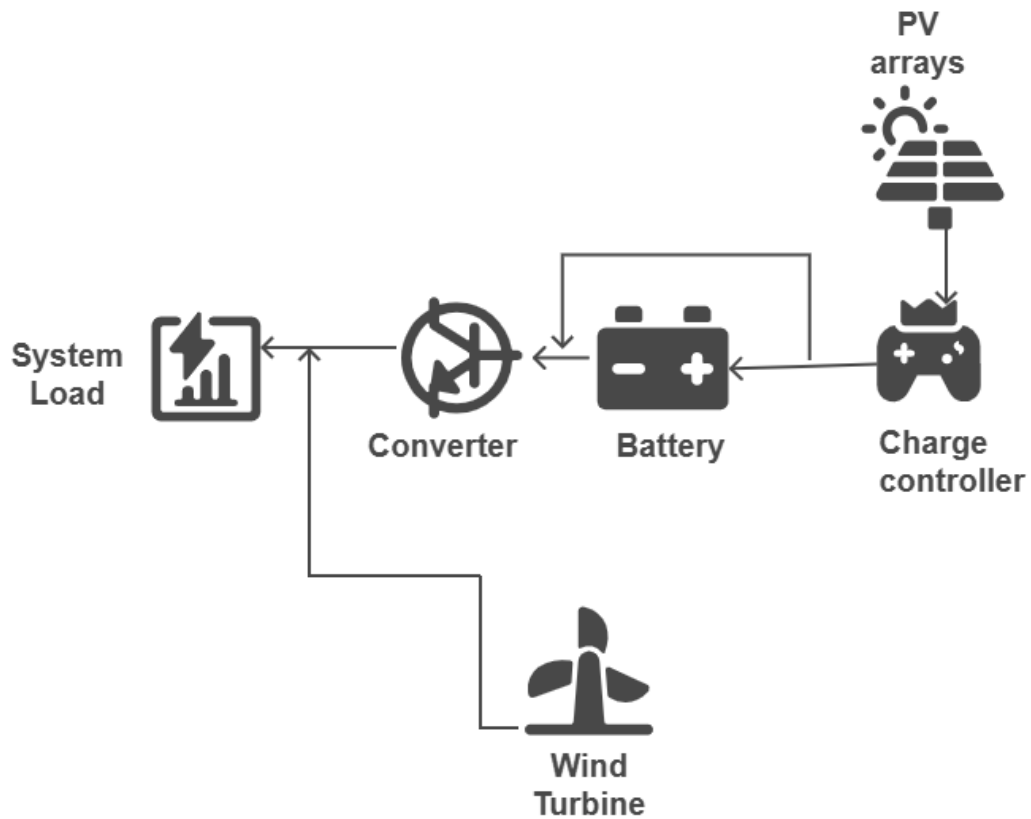


Figure 20: Hybrid system configuration

5.8. PHOTOVOLTAIC POWER OUTPUT AND BATTERY STORAGE STATE OF CHARGE

The results shows that PV system has a highest power output of about 20 kW between 09:00hrs to 15:00hrs of the day as shown in Figure 21, this is attributed to the positions of the sun, tilt angle and orientation of the system since the system had no tracking devices considered. The battery storage state of charge varied during the year as shown in the lower plot in Figure 22 below.

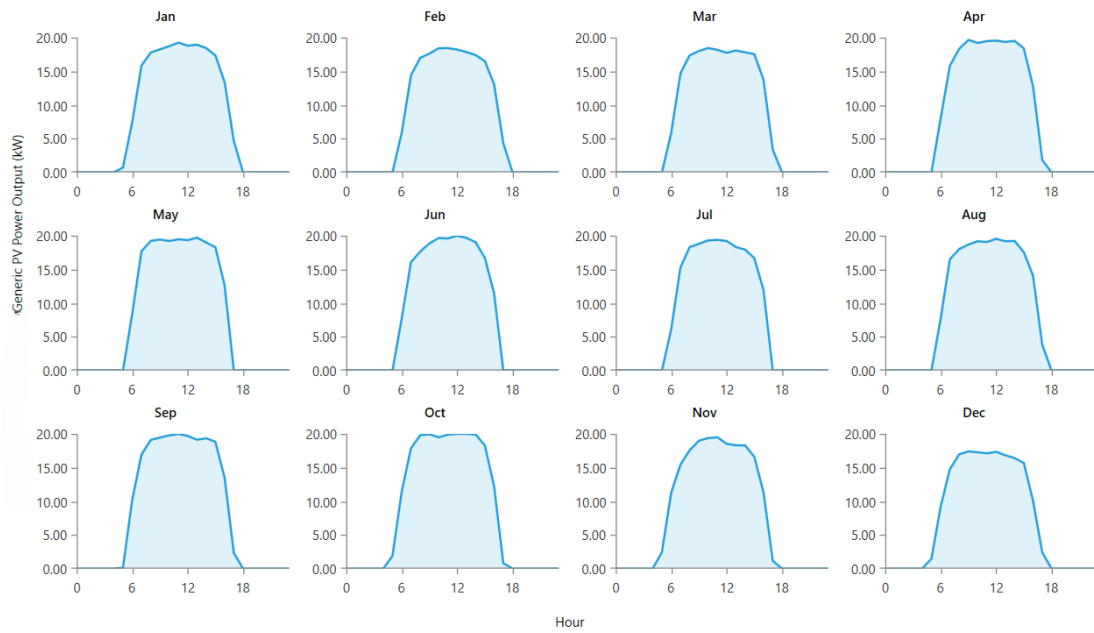


Figure 21: PV power output -(Author)

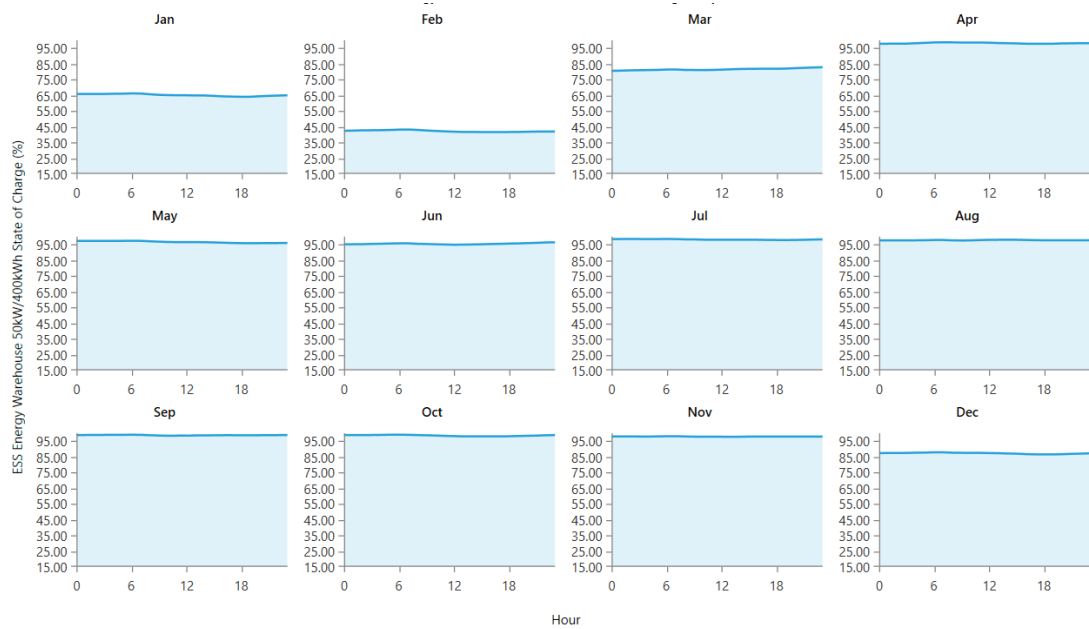


Figure 22: Battery state of charge - (Author)

5.9. WIND SPEED AND TURBINE POWER OUTPUT

From the results, wind turbine power output varied along the days of the year depending on the weather conditions on that particular day. The results show a varying power output from the wind turbine as shown in Figure 23 below. From the results it shows that the site has less wind energy potential as compared to solar energy potential. The turbine power output is dependent on the speed of the wind and Figure 24 shows this relationship.

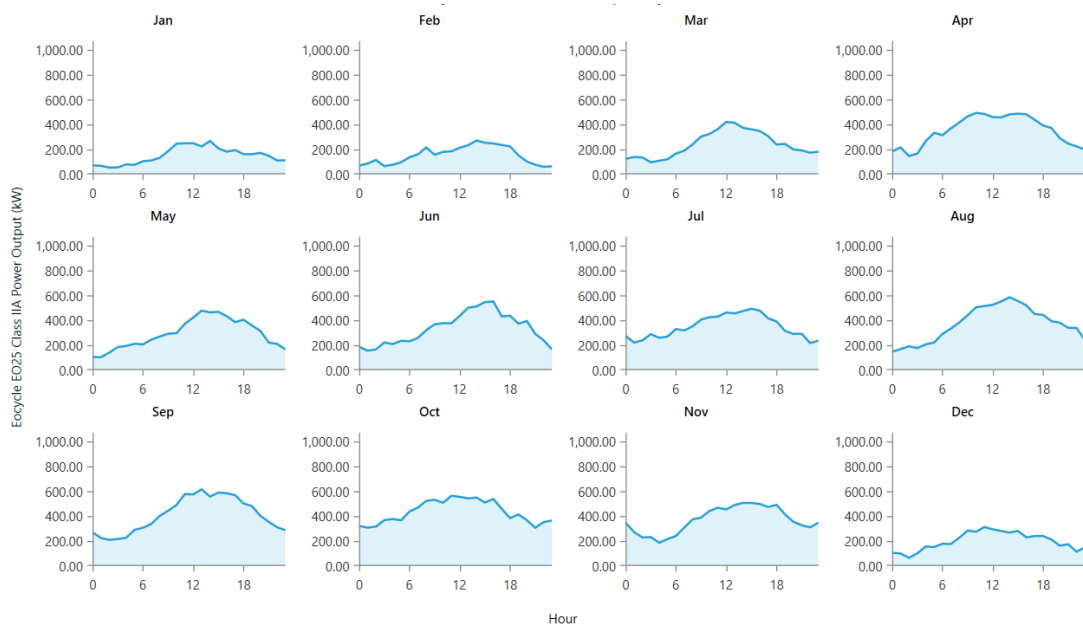


Figure 23: Wind turbine power output - (Author)

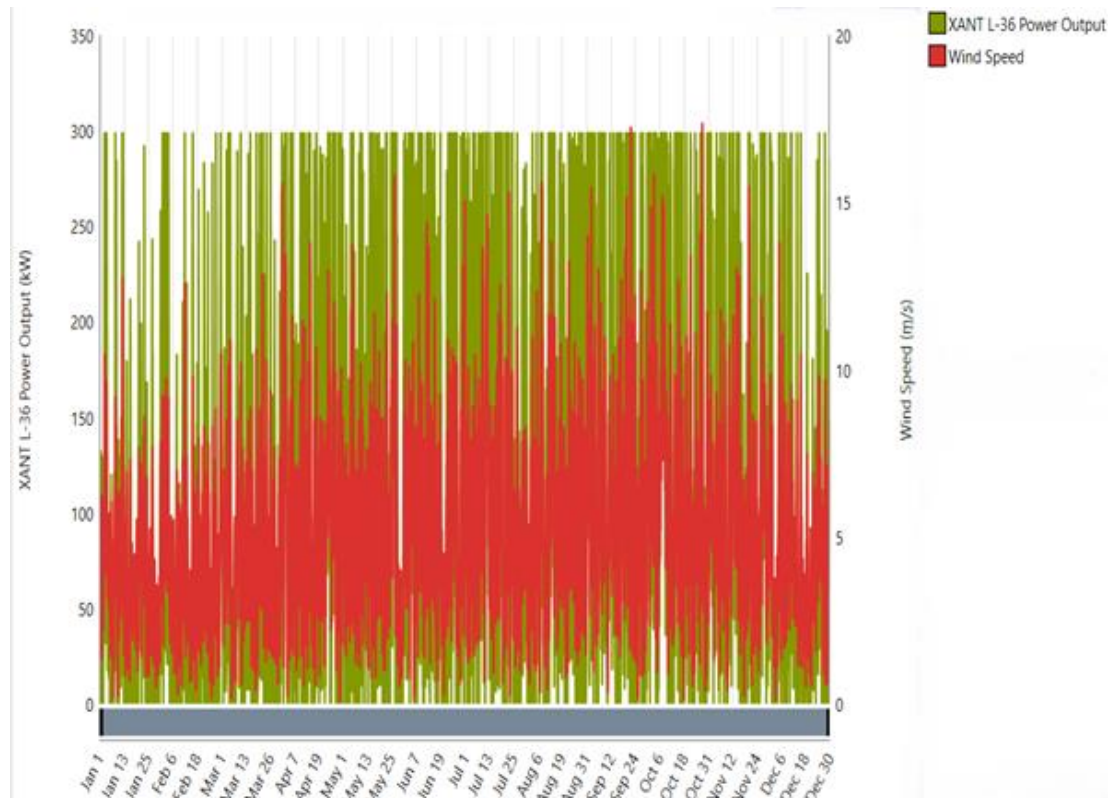


Figure 24: Wind speed and power output - (Author)

5.10. EMISSION FROM THE BASELINE SYSTEM AND HYBRID SYSTEM CONFIGURATIONS

The emissions from hybrid energy system (Solar, wind, battery storage and the grid) and the baseline system comprising of a diesel generator and grid only, are as follows; the baseline system configuration emitted 1,257,052 kg of CO₂, 5,450 kg of sulphur dioxide and 2,665 kg of nitrogen dioxide per year, whilst the hybrid emitted 45,130 kg of CO₂, 196 kg of sulphur dioxide and 95.7 kg of nitrogen dioxide per year as shown in table 7, showing a huge decrease in greenhouse gas emissions.

Table 7: Emissions comparison between baseline system and hybrid system configuration

Emissions	Baseline system	Hybrid system
Carbon dioxide	1,257,052 kg/yr	45,130 kg/yr
Carbon Monoxide	0	0
Nitrogen Oxides	2,665 kg/yr	95.7 kg/yr
Sulphur Dioxides	5,450 kg/yr	196 kg/yr
Particulate Matter	0	0
Unburned Hydrocarbons	0	0

Source: Author

5.11. COMPARATIVE ANALYSIS OF THE BASELINE SYSTEM CONFIGURATION AND HYBRID SYSTEM CONFIGURATION

The optimization results show the economic and environmental impacts when implementing different system configurations. It is showed that implementing baseline system, the lifecycle costs and environmental impacts (greenhouse gas emissions) have increased as compared to the hybrid system configuration. Section 5.2 and 5.3 explained the economic matrices of the baseline system and power output of the hybrid system configuration respectively. The lifecycle (NPC) of baseline system is \$71.5 million and LCOE of \$2.96 while that of the hybrid system is \$3.15 million and a LCOE of \$0.166. This indicate that the hybrid system configuration is economically more feasible than the baseline system.

Section 5.5 discussed the environment impacts of the two system configurations under similar simulation conditions. The model considered carbon dioxide, nitrogen oxides and sulphur dioxides. The results shows that baseline system emitted more greenhouse gas than hybrid system, baseline system emitted 1,265,167 kg of GHG while hybrid emitted 45,421.7 kg of GHG representing 96.41% reduction. Figure 25 below shows PV and wind electric production for the year 2024.

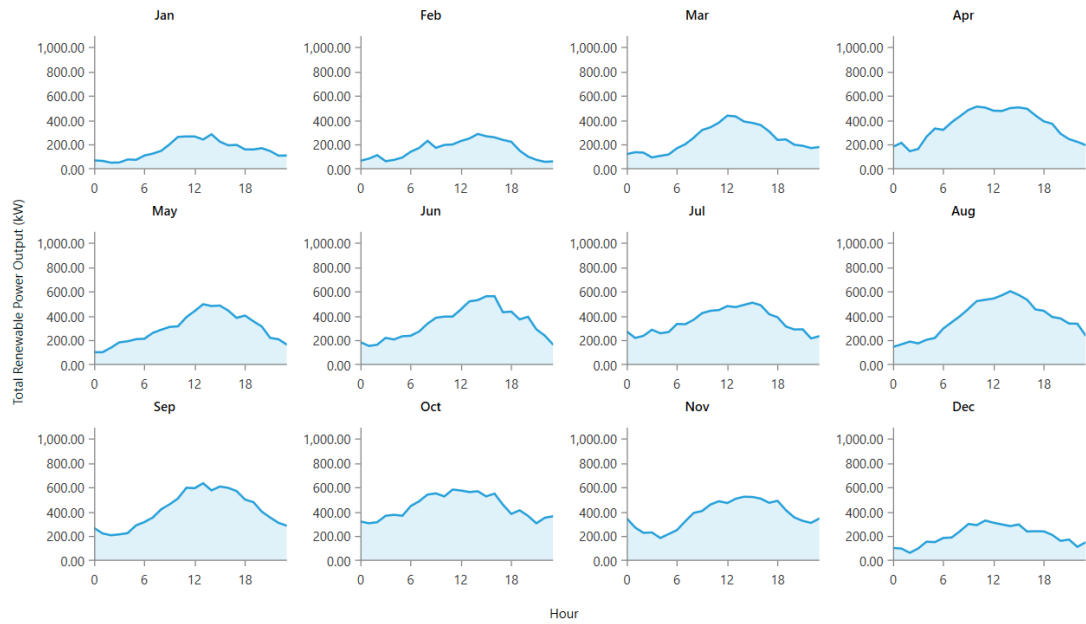


Figure 25: Monthly electricity production - (Author)

5.12. SENSITIVITY ANALYSIS IN HOMER

Sensitivity analysis is a process that was done to find out the effects of varying different system parameters over time. In this study, sensitivity analysis was done considering the fuel price, discount rate, and inflation rate. The main objective of sensitivity analysis is to analyse the effects of different parameter variations with time change, for example what will be the effect of change in fuel price on the cost of the energy. From the sensitivity analysis results, it was find out that increasing the fuel price, discount rate and inflation rate have similar effect on the LCOE and the NPV of the system configuration causing a rise in LCOE and NPV.

CHAPTER 6. CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

6.1.1. KEY FINDINGS

The following were the key findings of the study:

6.1.1.1. PORT ENERGY DEMAND

The study found out that the port consumes around 17977 MWh in 2022, 22861 MWh in 2023 and 22749 MWh in 2024. And the annual consumption will grow up to around 28339 MWh in 2029 as forecasted. From the trends of energy consumption from the port, it was noted that the port energy consumption will continue to grow in the upcoming years of which the grid cannot meet due to shortage in supply capacity.

6.1.1.2. ENERGY RESOURCES

Section 4.4.1 and 4.4.3 presents the proposed renewable resources for the port which are solar and wind resources. From the results, the port received solar irradiation of a monthly average of 5.33kW/m².day for the entire year of 2024, a potential for harnessing solar power of about 500W/m². The wind resource data from the port for the year 2024, indicated that on average the port received an annual average of about 5m/s. this speed is relatively enough for electricity generation on a small wind turbine. From the resource data, the port receives significant good solar and wind resources suitable for the production of electricity to meet the needs of the port.

6.1.1.3. PERFORMANCE OF PV AND WIND INTERGRATION

According to the simulation results, the system configurations that best meets the requirements of the port is the hybrid system produced 27,460.09MWh per year. This amount is higher than that of the average annual port energy consumption, indicating the technical feasibility of the system configuration. From the results the system configuration has an NPV of \$3.15 million, LCOE of \$0.166 per kWh, a decreased in NPV and GHG emissions of about 90% and 96% respectively over 25 years period as compared to baseline system configuration. This signifies the feasibility of the system configuration in terms economy and environment.

The study has found out that ports are the crucial hub for energy transition and decarbonization, achieving this needs a collective effort from both port authorities and all stakeholders involved in port operation including energy suppliers. The study revealed that implementing photovoltaic, wind and battery storage system for the operation of the ports has benefits both economic, technical and environmental as compared to relying on the grid supply which is not enough for the growing energy demand across the country. The study showed that integrating renewable hybrid system in ports has a lower lifecycle and emissions cost. This will help in economic boosts as well as complying to international regulations on climate change.

6.2. RESEARCH RECOMMENDATIONS

In this study, it was noted that getting instantaneous hourly energy consumption from port that was not possible, due to lack of new technologies that can record and keep the instantaneous data. Conducting further study on similar project using advanced data collecting system like Supervisory Control and Data Acquisition (SCADA) to collect the data would easily help the researcher to get instantaneous energy consumption data from the loads.

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Appendices

Appendix 1: Energy forecasting code

```
# Port Energy Consumption Forecasting

import numpy as np

import matplotlib.pyplot as plt

from sklearn.linear_model import LinearRegression

# Energy Consumption Historical data

years = np.array([2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023,
2024]).reshape(-1, 1)

demand = np.array([excel file])

# Create and train linear regression model

model = LinearRegression()

model.fit(years, demand)

# Predict historical values for visualization

predicted_demand = model.predict(years)

# Predict for future years (2025-2029)

future_years = np.array([2025, 2026, 2027,2028, 2029]).reshape(-1, 1)

future_predictions = model.predict(future_years)

# Create visualization

plt.figure(figsize=(8, 7))

plt.scatter(years, demand, color='blue', label='Historical Demand')

plt.plot(years, predicted_demand, color='red', label='Regression Line')
```

```
plt.scatter(future_years, future_predictions, color='green', label='Future Predictions')
```

```
# Annotate future predictions
```

```
    for i, year in enumerate(future_years):
```

```
        plt.annotate(f'{future_predictions[i]:.0f} MWh',
```

```
                    (year, future_predictions[i]),
```

```
                    textcoords="offset points",
```

```
                    xytext=(0,10),
```

```
                    ha='center')
```

```
plt.title('Energy Demand Prediction using Linear Regression')
```

```
plt.xlabel('Year')
```

```
plt.ylabel('Demand (MWh)')
```

```
plt.legend()
```

```
plt.grid(True)
```

```
plt.show()
```

```
# Print future predictions
```

```
print("Future Predictions:")
```

```
    for year, prediction in zip(future_years.flatten(), future_predictions):
```

```
        print(f'{year}: {prediction:.2f} MWh')
```

Appendix 2: ESCOM Tariffs

ELECTRICITY SUPPLY CORPORATION OF MALAWI LIMITED				
Electricity Tariff Schedule with effect from 1st February 2025				
Tariff Code	Description	Type of Charge per month	Old Rate (Mk)	New Rate (Mk)
ET1	Domestic , Prepaid , Single Phase Supply	First 50 kWh Unit Charge	61.50	71.35
		Above 50 kWh Unit Charge	94.00	109.05
		Fixed Charge	Nil	Nil
ET2	Domestic , Postpaid , Single Phase supply	First 50 kWh Unit Charge	54.40	63.10
		Above 50 kWh Unit Charge	89.00	103.25
		Fixed Charge	6,900.00	8,000.00
ET3	Domestic , Prepaid , Three Phase Supply	Unit charge per kWh	133.50	154.85
		Fixed Charge	Nil	Nil
ET4	Domestic , Postpaid , Three Phase Supply	Fixed Charge	16,600.00	19,300.00
		Unit charge per kWh	129.40	150.10
ET5	General , Prepaid , Single Phase Supply	Unit charge per kWh	195.00	226.20

		Fixed Charge	Nil	Nil
ET6	General , Postpaid , Single Phase Supply	Fixed Charge	15,630.00	18,130.00
		Unit charge per kWh	186.20	216.00
ET7	General , Prepaid ,Three Phase Supply	Unit charge per kWh	218.70	253.70
		Fixed Charge	Nil	Nil
ET8	General , Postpaid , Three Phase Supply	Fixed Charge	23,390.00	27,130.00
		Unit charge per kWh	202.25	234.60
ET9	Maximum Demand - Low Voltage Supply (Large power for industrial users , supplied at three phase supply and metered at 400 Volts)	Fixed Charge per Month	Nil	Nil
		On peak unit charge per kWh	242.65	281.50
		Off peak unit Charge per kWh	74.00	85.85
		Standard Unit Charge per kWh	101.45	117.70
		Capacity Charge per kVA based on the customer's annual declared demand	7,045.00	8,200.00
		Demand Charge per kVA based on actual monthly demand reading	17,615.00	20,430.00
		Fixed Charge per Month	Nil	Nil
		On peak unit charge per kWh	237.45	275.45
		Off peak unit Charge per kWh	70.20	81.45

ET10	Maximum Demand - Medium Voltage Supply (Large power for industrial users , supplied at three phase supply and metered at 11 kV or 33 kV)	Standard Unit Charge per kWh	96.55	112.00
		Capacity Charge per kVA based on the customer's annual declared demand	6,300.00	7,300.00
		Demand Charge per kVA based on actual monthly demand reading	17,192.25	19,950.00
ET11	Essential Service, Prepaid, Three Phase Supply, High Current Metering	Fixed Charge	Nil	Nil
		Unit charge per kWh	225.50	261.60
ET12	Special Agriculture, Three Phase Supply	Demand Charge per kVA based on actual monthly demand reading	14,800.00	17,200.00
		Standard Unit Charge per kWh	68.35	79.30
		On peak unit charge per kWh	204.35	237.00
		Off peak unit Charge per kWh	65.80	76.30
Standard, ON Peak and Off Peak Hrs for MD customers				

Standard hrs are from 12:00 hrs to 17:00 hrs from Monday to Friday
ON Peak Hrs are from Monday to Friday from 05:00 hrs to 12:00hrs and from 17:00 hrs to 21:00hrs
Off Peak hrs are from Monday to Friday from 21:00 hrs to 24:00hrs and 00:00 hrs to 05:00 hrs, All Saturdays , Sundays and
Public holidays are Off Peak hours

Appendix 3: Project cashflows

Years	0	1	2	3	4	5	6	7	8	9	10	11
Nominal												
Eocycle EO25 Class IIA												
Eocycle EO25 Class IIA												
Capital	-\$1,456,625											
Operating		-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133
Eocycle EO25 Class IIA Total	-\$1,456,625	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133
Eocycle EO25 Class IIA Total	-\$1,456,625	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133	-\$29,133
ESS Energy Warehouse 50kW/400kWh												
ESS Energy Warehouse 50kW/400kWh												
Capital	-\$61,656											
Operating		-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163
ESS Energy Warehouse 50kW/400kWh Total	-\$61,656	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163
ESS Energy Warehouse 50kW/400kWh Total	-\$61,656	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163	-\$6,163
Fronius Symo 20.0-3-M with Generic PV												
Fronius Symo 20.0-3-M with Generic PV												
Capital	-\$61,646											
Operating		-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233
Fronius Symo 20.0-3-M with Generic PV Total	-\$61,646	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233
Fronius Symo 20.0-3-M with Generic PV Total	-\$61,646	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233	-\$1,233
Leonics S-219Cp 5kW												
Leonics S-219Cp 5kW												
Capital	-\$539,977											
Operating		-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935
Leonics S-219Cp 5kW Total	-\$539,977	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935
Leonics S-219Cp 5kW Total	-\$539,977	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935	-\$13,935
Other												
Other												
Capital	-\$161,568											
Operating		-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328
Other Total	-\$161,568	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328
Other Total	-\$161,568	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328	-\$3,328
Nominal Total	-\$2,281,473	-\$53,791	-\$53,791	-\$53,791	-\$53,791	-\$53,791	-\$53,791	-\$53,791	-\$53,791	-\$53,791	-\$53,791	-\$53,791
Discounted												
Eocycle EO25 Class IIA												
Eocycle EO25 Class IIA												
Capital	-\$1,456,625											
Operating		-\$28,092	-\$27,089	-\$26,121	-\$25,188	-\$24,289	-\$23,421	-\$22,585	-\$21,778	-\$21,000	-\$20,250	-\$19,521
Eocycle EO25 Class IIA Total	-\$1,456,625	-\$28,092	-\$27,089	-\$26,121	-\$25,188	-\$24,289	-\$23,421	-\$22,585	-\$21,778	-\$21,000	-\$20,250	-\$19,521
Eocycle EO25 Class IIA Total	-\$1,456,625	-\$28,092	-\$27,089	-\$26,121	-\$25,188	-\$24,289	-\$23,421	-\$22,585	-\$21,778	-\$21,000	-\$20,250	-\$19,521
ESS Energy Warehouse 50kW/400kWh												
ESS Energy Warehouse 50kW/400kWh												
Capital	-\$61,656											
Operating		-\$5,943	-\$5,730	-\$5,526	-\$5,328	-\$5,138	-\$4,955	-\$4,778	-\$4,607	-\$4,443	-\$4,284	-\$4,131
ESS Energy Warehouse 50kW/400kWh Total	-\$61,656	-\$5,943	-\$5,730	-\$5,526	-\$5,328	-\$5,138	-\$4,955	-\$4,778	-\$4,607	-\$4,443	-\$4,284	-\$4,131
ESS Energy Warehouse 50kW/400kWh Total	-\$61,656	-\$5,943	-\$5,730	-\$5,526	-\$5,328	-\$5,138	-\$4,955	-\$4,778	-\$4,607	-\$4,443	-\$4,284	-\$4,131
Fronius Symo 20.0-3-M with Generic PV												
Fronius Symo 20.0-3-M with Generic PV												
Capital	-\$61,646											
Operating		-\$1,189	-\$1,146	-\$1,105	-\$1,066	-\$1,028	-\$991	-\$956	-\$922	-\$889	-\$857	-\$826
Fronius Symo 20.0-3-M with Generic PV Total	-\$61,646	-\$1,189	-\$1,146	-\$1,105	-\$1,066	-\$1,028	-\$991	-\$956	-\$922	-\$889	-\$857	-\$826
Fronius Symo 20.0-3-M with Generic PV Total	-\$61,646	-\$1,189	-\$1,146	-\$1,105	-\$1,066	-\$1,028	-\$991	-\$956	-\$922	-\$889	-\$857	-\$826
Leonics S-219Cp 5kW												
Leonics S-219Cp 5kW												
Capital	-\$539,977											
Operating		-\$13,437	-\$12,957	-\$12,495	-\$12,048	-\$11,618	-\$11,203	-\$10,803	-\$10,417	-\$10,045	-\$9,686	-\$9,340
Leonics S-219Cp 5kW Total	-\$539,977	-\$13,437	-\$12,957	-\$12,495	-\$12,048	-\$11,618	-\$11,203	-\$10,803	-\$10,417	-\$10,045	-\$9,686	-\$9,340
Leonics S-219Cp 5kW Total	-\$539,977	-\$13,437	-\$12,957	-\$12,495	-\$12,048	-\$11,618	-\$11,203	-\$10,803	-\$10,417	-\$10,045	-\$9,686	-\$9,340
Other												
Other												
Capital	-\$161,568											
Operating		-\$3,209	-\$3,095	-\$2,984	-\$2,877	-\$2,775	-\$2,676	-\$2,580	-\$2,488	-\$2,399	-\$2,313	-\$2,231
Other Total	-\$161,568	-\$3,209	-\$3,095	-\$2,984	-\$2,877	-\$2,775	-\$2,676	-\$2,580	-\$2,488	-\$2,399	-\$2,313	-\$2,231
Other Total	-\$161,568	-\$3,209	-\$3,095	-\$2,984	-\$2,877	-\$2,775	-\$2,676	-\$2,580	-\$2,488	-\$2,399	-\$2,313	-\$2,231
Discounted Total	-\$2,281,473	-\$51,870	-\$50,017	-\$48,231	-\$46,509	-\$44,848	-\$43,246	-\$41,701	-\$40,212	-\$38,776	-\$37,391	-\$36,056