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WORLD MARITIME UNIVERSITY
Malmö, Sweden

**MODELLING HYBRID RENEWABLE ENERGY
SYSTEM FOR PHILIPPINE MERCHANT
MARINE
ACADEMY:
A FEASIBILITY STUDY**

By

NAYAN GUIMPAYAN
Philippines

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
(MARITIME ENERGY MANAGEMENT)

2018

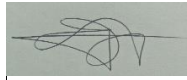
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DECLARATION

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

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

(Signature):



(Date):

18th September, 2018

Supervised by: **Professor Aykut I. Ölçer, PhD, MSc, BSc, MRINA**

Nippon Foundation Professorial Chair in Marine Technology and Innovation

Head, Maritime Energy Management (MEM) specialization

Head, Marine Technology and MEM Research Group (MarEner)

Editor-in-Chief of WMU Journal of Maritime Affairs (JOMA) and Book Series

Programme Coordinator, PG Diploma in Maritime Energy*

World Maritime University (WMU) of the IMO, a Specialized Agency of the United Nations

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ABSTRACT

Title of Dissertation **MODELLING HYBRID RENEWABLE
ENERGY SYSTEM FOR PHILIPPINE
MERCHANT MARINE ACADEMY: A
FEASIBILITY STUDY**

Degree **Master of Science (MSc)**

The purpose of this study was to provide a model of HRES to PMMA using the HOMER Pro Energy Software and feasibility analysis. The major HRES variables used in the comparison of the proposed models include initial capital cost, net present cost, Levelized cost of energy, internal rate of return and payback period. In terms of the feasibility analysis, the perception of the selected administrators was collected through a focus group discussion.

The feasibility analysis was limited to acceptability, implementation and adaptability. The results show that HRES Model A- the Solar PVs-wind turbine-battery storage connected to a grid is the most feasible hybrid renewables for the Academy. PMMA highly perceive the acceptability of the proposed model, anticipate the implementation of such energy source but uncertain for its sustainability considering that the Academy is a government-owned institution. The study strongly recommends to present finding to PMMA, conduct further study on possible enhancement of the proposed HRES models and conduct a higher level of feasibility analysis prior to implementation of the project.

KEYWORDS: **Renewables, HRES, educational institution, feasibility, Philippines**

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LIST OF ABBREVIATIONS

CSP	Concentrated Solar Power
DFA	Department of Foreign Affairs
GA	Genetic Algorithm
GW	Gigawatts
HOMER	Hybrid Optimization Model for Multiple Energy Resources
HRES	Hybrid Renewable Energy System
ICC	Initial Cost of Capital
IPO	Input-Process-Output
IRR	Internal Rate of Return
kW	Kilowatts
kWh	Kilowatts hour
LCOE	Levelized Cost of Energy
MET	Maritime Education and Training
MHEI	Maritime Higher Educational Institution
MPPT	Maximum Power Point Tracker
NPC	Net Present Cost
PMMA	Philippine Merchant Marine Academy
PN	Philippine Navy
PNS	Philippine Nautical School
PSO	Particle Swarm Optimization
PV	Photovoltaic
RE	Renewable Energy
REN21	Renewable Energy Policy Network for the 21st Century
SEU	Significant Energy Users
SPM	Smart Polygeneration Microgrid
STCW	Standard Training, Certification and Watch-keeping
USD	United States Dollar
WMO	World Meteorological Organization
ZAMECO	Zambales Electric Corporation

Chapter 1

1.0 INTRODUCTION

1.1 Background of the Study

Renewable energy is steadily increasing with an estimated global installed capacity of 2195 GW by the end of 2017. In the same year also when the largest annual installed capacity of 178 GW was established, recording an increase of about 9% from the previous year. Among the renewables, solar PV is a leading alternative for energy than the combined average of fossil fuels and nuclear power. Solar PV accounts for almost 55% of recently installed renewable energy followed by wind and hydropower that contributes more than 29% and almost 11% respectively (REN21, 2018).

Environmental concerns, evolving policies and the declining cost of renewable technologies are the drivers for the increased installation of renewable energy. Moreover, the use of renewable energy is becoming even more popular in school campuses due to its environmental, technical and economic benefits such as reduction of carbon dioxide emission, energy security and resiliency and savings in electricity bill (Park & Kwon, 2016).

However, intermittency in the supply is a challenge in the use of renewables such as the case of solar and wind energy system. Thus, the use of a single RE source is considered irregular and unreliable. Therefore, integrating different RE sources such as solar PV, wind turbine, conventional energy source, and an energy storage

resolves the intermittency of the renewables. This integration of different RE gave way to the development of Hybrid Renewable Energy System (HRES). HRES is an effective method to reduce the problem associated with the intermittent nature of the renewable energy sources.

Moreover, even renewables pose challenges in terms of intermittency of energy supply, there are still institutions who claim that there is much more benefit to the alternative sources. For instance, the Genoa - Savona Campus installed solar PV modules, combined heat and power gas turbine fuelled by natural gas, two small wind turbine, two parabolic concentrator system, storage systems, two charging stations for electric vehicles, thermal storage device, and absorption chillers to build the Smart Polygeneration Microgrid system of the institution. The system does not only function as a research facility as it also meets the electrical demand of the university (Bracco, Delfino, Pampararo, Robba, & Rossi, 2014). The authors reported that if the SPM is operated in an optimized program, it could result in a notable operating cost and carbon dioxide emission reduction when compared to conventional scenario.

The installation of an HRES at the Philippine Merchant Marine Academy (PMMA) can considerably reduce the emission of carbon dioxide and help realize savings in electricity consumption. At present, the electrical energy average consumption of PMMA is 3150 KWh/day at cost of 561 US\$/day and could peak to about 5300 KWh/day at USD944/day during the summer months of April and May. The Significant Energy Users (SEU) are the air conditioning units in the buildings, equipment used for teaching and training such as the simulators, laboratories, and machine shops. The Academy does not only offer a baccalaureate degree in maritime but also provides maritime training and assessment for aspiring seafarers and marine officers, thus, the full mission simulator for deck and engine are usually operating at maximum capacity. Furthermore, two machine shops are situated within the Academy that houses equipment that is typically found in the engine room machine shop of a merchant vessel such as lathe machines and welding machines.

Other notable electric load consumers within PMMA Complex are the structural buildings of administration, the College of Marine Engineering, College of Marine Transportation, Department of Midshipman Affairs, the Department of Naval Science and Tactics, the Academy's Hotel, the Mess Hall, the two buildings for the training and assessment activities, the four Dormitory Buildings for the cadets and the numerous housing units for the Academy's employees. These structures are fully equipped with technologies run by electricity from the local distributor. Moreover, because the cadets and the employees are housed within the Academy during school days and at times during the weekends the consumption of electricity is really significant. Lastly, the Academy's busiest halls include the newly built Amphitheater, Claveness and Alumni House where conferences, lectures, training, and other huge event and activities were conducted also consumes electricity higher than any similar facility.

Due to these reasons, the researcher is very well versed that indeed the Academy needs an alternative source of energy to effectively deliver its mandate to produce highly qualified and competent marine officers and seafarers while complying with the international regulations and standards required and set by the STCW convention, i.e. to train and equip maritime students with maritime principles, knowledge, and skills using a state-of-the-art facilities and equipment.

The proposed idea is to develop a Hybrid Renewable Energy System that can be installed within the vicinity of the 12.3 hectares vacant lot of the Academy. In addition, the strategic location of the Academy from the seashore gives a perfect and favourable set-up for the installation of wind turbines. The study believed to have a significant impact on the energy consumption cost and maintenance expenses of the institution and to aid the government in the operating expenses for the cadets.

The development of HRES models that will meet the expectations of the Academy in terms of energy supply is the main purpose of this study and the objective of the researcher.

1.2 Research Objectives

The main objective of the study is to develop and proposed a HRES to Philippine Merchant Marine Academy.

Specifically, the study sought an answer to the following research questions:

1. How does the present electricity consumption of the PMMA be described?
2. Using HOMER Pro, provide a HRES model that will suit with the PMMA needs and current situation.
3. From the proposed HRES model, identify which model is feasible and will provide an impact to the PMMA.
4. How do the PMMA administration perceive the proposed model of HRES in terms:
 - 4.1 Acceptability;
 - 4.2 Implementation; and
 - 4.3 Adaptation?
5. What is the implication of the HRES study in maritime sector as perceive by the PMMA Administration?

1.3 Significance of the Study

The Philippine Merchant Marine Academy solely rely on the generated electricity at the local energy supplier in the area. Because of that, the supply of the academy is mainly affected by the different circumstances and risks. In addition, the cost of the electricity and its maintenance is becoming higher for an institution that is subsidized by the government. This proposed HRES will possibly provide an alternative energy source for the academy to consider especially now that their growing maritime facilities, laboratories, and equipment are getting more sophisticated and advanced. In addition, the high maintenance cost due to the stability and reliability issues of the

local manufacturer will also be lessened. The possibility of a HRES in the institution will not only reduce and resolve the academy's cost of electricity, maintenance expenses, reliability issues but also adhere to the nations' objective to be responsible and sensitive to the environment. The opportunity of the implementation of this feasibility study will play an integral part on the operation and on the achievement of the academy's mission and vision to develop competent merchant marine officers and the like and improve the MET and research and remain to be the leading maritime institutions of the country.

1.4 Scope and Limitations

The purpose of this study was to provide a model of HRES to PMMA using the HOMER Pro Energy Software and feasibility analysis. The study proposed two (2) models which meet the requirements, aligns with the present conditions and comply with the expectations of the target user in terms of energy supply. The development of the proposed models was accomplished with the aid of an energy software capable to analyse renewables capability and energy-related output. A deeper analysis was done to identify if the proposed models are feasible for the Academy.

The study also focused on the perception of the target user towards the feasibility of the proposed models in terms of acceptability, implementation, and adaptation. Furthermore, the study also gathered the insights of the select institution on the impact of HRES in a MET setting.

The source of data and information as per this feasibility study is concerned includes electric consumption cost of the Academy last 2017, current inventory of facilities, laboratories and equipment, the HOMER Pro HRES analysis report/output, and the selected administrators of the institution who participated in the focus group discussion facilitated by one of the researcher's mentor.

The study is limited to the variables stated in research objectives and on other factors which may have been neglected and may cause an effect on the overall results of the study.

Chapter 2

2.0 FRAMEWORK OF THE STUDY

2.1 Literature Review

2.1.1 Energy and Renewable Energy

Energy is a crucial human need that is very necessary for carrying out day to day activities. Energy is linked directly to the economic, environmental and social development of any country. The overall functions of trade, productions and economies cannot be possible without energy (Chalvatziz & Ioannidis, 2017). Different forms of energy include mechanical, electrical, hydraulic, wind, solar, geothermal, nuclear and chemical energy. With the aid of technological advancement and equipment, these forms of energy can be converted into another form, for instance, wind energy into electric energy. However, the process of converting energy poses a huge threat to the environment in many different ways. Accordingly, the increasing concentration in the atmosphere of greenhouse gasses such as methane, chlorofluorocarbon, nitrous oxide, carbon dioxide, and peroxyacetyl was brought by the process of converting energy into one form to another. Because of these, the greenhouse gasses increased and the earth's surface temperature increased in the last decades paving the way to climate change. The principal greenhouse gas that contributes to climate change is carbon dioxide which has an estimated presence in the atmosphere of 403.3 part per million (WMO, 2017). Some authors argued that these were a result of human activities. (Ritchie & Dowlatabadi, 2017) Argued that one of these activities is the production of energy i.e. burning of fossil fuels. Fossils

fuels, although considered as the main source of greenhouse gas emission, remains as the major energy production method until the introduction of renewable energy.

The introduction of renewable energy plays an important role to at least divert the market from dependency to the fossils fuels (Lind et al., 2013). Renewable energy sources are being promoted in a global scale although challenged with severe entry barriers such as research and development limitations, restrictive practices, insensitivity to changes demand, and high initial investment costs (Alfonso, Marques & Fuinhas, 2017). Despite these barriers, the global capacity of renewable energy has increased in the last decades.

Renewable energies are those energies from other sources that do not have a finite end, or those can be recycled which are typically from natural sources like solar power, wind power, water power and others. Accordingly, the discovery and utilization of renewable energy traced back in the history of civilization when the fire was discovered by our ancestors (Bowman et al. 2009). Before the discovery of coal deposits around the time of Industrial Revolution, most of the energy we used for lighting and heating was from renewable sources. Throughout the history, we burned what would today know as biomass, and this became an important fuel source in the long period of time (McLamb, 2010).

It was in the 1970s that people began to look back towards these ancient methods and technologies to provide power sources for the future. Peak oil and peak coals were the first theorized source of energy. The concepts of solar technology revolved even during the Industrial Revolution in the preparation of post-coal world. Theories and investment in solar technology lasted until the outbreak of World War I. During the end of the 20th century, energy security has been a major concern to world leaders. The concept that national security and the availability of resources for energy production consumption are strongly linked to each other. Thus, the global scientist pushes and continuously working hard in the development of renewable energy technologies (Mahmud, 2017). Mahmud also argued that the International Energy Agency reported that the increase in the amount of electricity produces from

renewable sources increased from over 13% in 2012 to 22% in 2013. The agency predicts that the increased will hit 26% in 2020. Most long-term forecast models predict that the use of renewables will be tripled until 2040.

Renewables are unlimited because its natural, however, it is important to note that not all forms are environmentally friendly. Most common types of renewables are hydroelectricity, tidal/water power, solar power, wind power, geothermal, and biofuel and biomass.

Hydroelectricity is one of the cleanest forms of energy. It is produced by processing and controlling the flowing water through a dam. Hydroelectricity is one of the lowest cost forms of energy as it requires no fuel; this means no mining, no processing, and no transportation cost and gives a significant reduction of carbon emissions. It was commonly used in developed and developing countries. The negative effect is that the building of a dam for these renewables may alter or destroys the landscape and changes the ecology downstream. The potential for failure of a dam is also catastrophic and may lead to flooding- more ecological damage and possible loss of human lives (Worldwatch Institute, 2018).

Tidal or water power demonstrate the possibility to generate electricity at sea. This is a common power generation from across the Atlantic and some part of Europe. This comes in four general types: the stream generators that uses water flow to power a turbine that generates electricity; the tidal barrage that uses small dam-like structures alongside natural features underwater that seize the potential energy as the water flows in and converts it to mechanical energy as it flows out; the tidal lagoons which works similarly as barrage but are completely artificial; and the dynamic tidal power which has not been tried because it requires building of dams that are ten kilometres long to regulate water flow. Tidal power is more predictable than any other renewables and provides a high degree of accuracy. The source is unlimited because the volume of water on the planer is fairly constant and unlikely to run out. It also offers low input to high output production. However tidal power technology has not been taken up due to the high cost, and it is mostly in the development stage. It may

also alter the underwater ecologies and disrupt the natural marine landscape forever (Copping et al., 2011).

Solar energy, on the other hand, offers more economic benefits because it's free, abundant and the most environmental-friendly energy source. The world energy market is investing in research and development for various technologies that will harness solar power and convert it into energy. Although the sun has a finite end, the fact that it has some 4.5bn years of life left is not a worry at all.

There are two basic types of solar energy. First, the most common-the Photovoltaic (PV), which converts the light of the sun into electrical energy and which in return, can be used to power electrical devices. The second is the Concentrated Solar Power (CSP), which uses a solar array with a large number of curved panels. It looks like PV but they work differently in a way that concentrated beam of sunlight draw from the reflection of system mirrors. The heat generated activates a turbine that produces electricity through a conventional generator. While PV produces energy from light, CSP produces energy from heat (Knier, 2002). Because solar energy lasts as long as the sun will last, it is considered the most flexible energy source. It cannot only generate electricity but can be used to heat water directly and be a source of light. Solar energy also provides the most cost-effective renewables among the alternative sources. On the other hand, solar efficiency drops during cloudy days, winter and during storms. Placement of solar panels considered its disadvantages; thus, careful and strategic placement is necessary to maximize the efficiency of solar panels. In case of strategically located panels, the over captured energy became useless because PV panels gathered energy endlessly making it less efficient (Greenmatch, 2018).

Wind power has been widely utilized to generate electricity through wind turbines. These giant windmills capture the power of the air and generate electricity through a turbine of wind farms, sea or land. For some, it ruins the attractive natural view, other thoughts that it is a great way of harnessing an unlimited resource by the planet's weather systems. Many of these are at sea where most of the wind power is produced. Wind is constant thus it is a limitless source of energy if properly

harnessed. It is efficient and like solar energy is a very low cost compared to other renewables. The limitations of wind power include the need of a huge investment in the infrastructure to transport the energy from one place to another because windmills usually located best out at sea of wind farms where there are no cities, which far from the settlements that need it. It also varies from season to season. The generation of energy is geographically limited as mentioned earlier (Jacobsen, 2016).

Likewise, a geothermal energy is the process of harnessing heat from under the surface of the planet, which is produced as a result of geological processes such as natural heat loss, volcanic activity, or natural processes such as radioactive decay. This is also one of the cleanest forms of energy production as of this date. The planet being a hotbed of geological activity produces constant and renewable energy (Renewable Energy World, n.d.). Geothermal power offers lower production cost, which means lower maintenance costs and lower end costs to the energy manufacturer. Thus, it is also considered as of the cheapest form of energy. The disadvantage of this type of energy is its geographical issues. Where geothermal plants are present they can produce limitless supply, but in other areas, it may not be profitable and economic-wise as an alternative source of energy and would be relatively expensive to the end user (Gillapsy, n.d.).

Alternatively, biofuel is the production of energy utilized for automobiles which are commonly extracted from plants or other organic matter rather than fossils. Biofuel is can be produced by (1) directly processing a raw plant, which comprised of extraction of natural oils and processing it into a fuel, and (2) extraction of residues or decomposing matter as a result of natural anaerobic processes. Biomass, on the other hand, is different in such a way that it is a waste of organic material such as wood and other plant matter, and not a derivative by-product that results from processing. The source of biomass includes chopped woods, grasses, leaves, brush and other raw organic material such as animal dung and manure that may burn and produce energy. The flexibility of source is a considerable advantage, especially when producing liquid fuels such as ethanol. When location is strategically

identified, biofuel can easily produce. Another advantage of these fuels is that it tends to localize supply. Biofuel and biomass production in a shorter radius offer lower carbon footprint and increases energy security. The downside of both biomass and biofuel is that these are not a finite resource. It may lead to deforestation and alter the planet ecological system. The energy output of these energies is much lower than the conventional fossil fuels making them less efficient (Daniel, 2011).

2.1.2 Hybrid Renewable Energy Systems

The scarcity and depletion of source of power and fuels demanded an urgent need for alternative sources of energy. This is also an immediate response to reduce the effect of global warming phenomenon. From the previous literature, the environmentally friendly power generation technologies really play a role in the future source and supply of energy. Indeed, the renewable energy technologies such as hydroelectricity, tidal/water power, solar power, wind power, geothermal, and biofuel and biomass will definitely shape the future of the world's energy supply. According to (Negi & Matthew, 2014) these alternative sources of energy benefitted the energy market in terms of supply security, reduced carbon emission, improved power quality, reliability and employment opportunity to the local people.

Since the renewable energy sources are unlimited but intermittent, the combinations of two or more renewables also known as Hybrid Renewable Energy System (HRES) can improve system performance (Nelgi & Matthew, 2014). HRES combines two or more renewables with one or more conventional source along with storage in order to supply the demand of a certain area or equipment.

2.1.3 Existing Studies on Hybrid Renewable Energy Systems

Indeed, HRES and the interconnection of different energy sources such as wind power, photovoltaic power, fuel cell, and micro-turbine generator power to local

energy loads decreases the dependence on fossil fuels. HRES is believed to be a better option for modelling of modern electrical systems. The promising benefit also includes economic, environmental and social advantage (Krishna & Kumar, 2015).

A number of previous researches focusing on the combination of two or more renewables and modelling a hybrid renewable have been established around the globe. For instance, (Bajpai, 2012) reviewed unit sizing, optimization, energy management and modelling of the hybrid renewable energy system components. He developed models of hybrid energy resources for PV systems, backup energy systems for a fuel cell, battery, ultra-capacitor, and diesel generator, power conditioning units for MPPT converter, buck/boost converters, and battery charges and techniques for energy flow management.

Krishna and Kumar (2015) also conducted a comprehensive reviewed of optimal sizing, energy management, operating and control strategies and integration of different renewable sources into a hybrid system. Their study was focused on the feasibility of the different controllers as loop feedback mechanism for power regulation.

In the same manner, another comprehensive review was conducted in various aspects of HRES. This includes feasibility analysis, optimum sizing, modelling, control and reliability issues of the hybrid renewables. In addition, the applications of evolutionary technique and theory in hybrid renewable have also been one of the major focus of previous researchers (Khare, Nema & Baredar, 2015).

In addition, a comprehensive review was also conducted on the recent trend in the optimization of HRES. One of the trends is the use of artificial intelligence in the provision of good optimization of the system especially in the cases where long-term weather data is not available. The results were based on the review of published literature on the current and existing state of optimization techniques for small and isolated power system (Bhandari, Lee, Cho, & Ahn, 2015).

Similarly, (Agustin & Lopez, 2009), revised the simulation and optimization techniques to simulate and design stand-alone hybrid systems such as PV-wind-battery and PV-diesel-battery in terms of generation of electricity. This revision is in lieu of stand-alone hybrid RES ability to incur lower costs but provides higher reliability than a single renewable system such as photovoltaic or wind systems.

(Neeves & Silva, 2014), on the other hand, reviewed several types of projects developed in different micro-communities which includes small islands and remote villages. Accordingly, the design of the present energy system, the availability of reliable energy storage system, and the demand for electricity influenced the achievement of higher percentages of the renewable source in small islands. The common and most popular among islands HRES is the combination of diesel-wind-photovoltaic. On the other hand, in remote villages, higher percentages of the renewable source are met easily in cases of low demand, unstructured previous electric supply, and the capability storage batteries. The configuration of photovoltaic-diesel-batteries is more popular in remote villages. The authors argued that detailed demand information, data on local renewable resources and adequate storage system are the most critical aspects for the design and reliable application of the renewable system.

(Deshmukh & Deshmukh, 2006), also emphasized that the popularity of HRES among the remote areas is driven by the renewable energy technologies and subsequent increase of petroleum products. In the case of this study, the HRES trends design show that the hybrid PV-wind energy systems are really gaining popularity in these areas. However, the issue related to penetration in the present distribution network still needs further studies.

(Askarzadeh & Coello, 2015), also optimized and developed a model with most suitable size as stand-alone HRES for a certain remote area of Iran. The authors considered the system components such as the total area to be occupied by the PV panels, a total swept area of rotation of turbines blades, and the number of batteries that will store the power. The authors utilized the Particle Swarm Optimization

(PSO) to configure the proposed HRES. Accordingly, PV-Wind Turbine-Battery system is the most cost-effective and more promising results than any PSO variants.

Lastly, the study of (ArulFigna, Ramachandaramurthy & Rajkumar, 2014) used stand-alone and grid-connected HRES to supply AC load. The configuration and interfacing power converters in generating energy from sources to AC was established. Authors highlighted the development in HRES to maximize the power generated from renewable energy sources.

Because HRES needs multiple generation systems, HRES analysis is complex and requires to be analysed thoroughly. Thus, the development of HRES requires software tools that provide efficient design, analysis, optimization, and economic viability of the proposed systems. These tools are continuously evolving as HRES development and innovation leads the energy market into manufacturing environmental-friendly energy. There are many HRES software's that have been utilized in the optimization of HRES configuration in the past decades. (Sinha & Chandel, 2014), identified and analysed the features and current status of nineteen (19) HRES software in 2014. These include HOMER, Hybrid2, RETScreen, iHOGA, INSEL, TRNSYS, iGRHYSO, HYBRIDS, RAPSIM, SOMES, SOLSTOR, HySim, HybSim, IPSYS, HySys, Dymola/Modelica, ARES, SOLSIM, and HYBRID DESIGNER among others. The authors conducted a comprehensive review of the utilization of these HRES software at different locations worldwide and presented the current status, capability, limitations, availability, and areas of further research of these softwares.

Another study that utilized HRES is the study of (Maleki, Khajeh & Ameri, 2016) of wind speed and solar radiation power systems. The authors used the Monte Carlo Simulation Method and Particle Swarm Optimization Algorithm and configured an off-grid hybrid multisource system (photovoltaic–wind–battery). The hybrid system was modelled, optimally sized, and compared of different seasons in terms of the total annual cost and uncertainty in WS, SR, and electricity demand.

2.1.4 Predicting the Capability of Hybrid Renewable Energy System using HOMER

Bahramara, Moghaddam & Haghifam, (2016), reiterated that renewables are the most appropriate alternatives to meet the demand of energy consumption, more specifically electricity. Moreover, to have minimal investment and operation costs while meeting the technical and emission constraints, optimization of equipment should be definite and absolute. HOMER offers optimal planning of HRES and was duly recognized and widely used by many researchers around the globe.

For instance, (Diaf & Behar, 2015), investigated the performance of hybrid PV-wind-diesel-battery configuration of Algeria using an HRES HOMER software. The authors utilized the global solar radiation data, ambient temperature and speed of wind for a year. The authors found out that optimization of the proposed hybrid using HOMER was successful. The optimization process considered the renewable resources potential and energy demand while maximizing the renewable electricity use and save fuels. The study also came up with a mathematical model that ensures the efficiency of energy management on the basis of different operating strategies. The proposed configuration was able to supply 70% of the energy demand. Wind power provided 43% of the annual electricity production followed by 31% from diesel and 26% from PV. The authors argued that the PV and wind systems depends on the weather condition and are very unlikely reliable without capacity storage devices. When hybridized with another system together with the provision of storage, their reliability increases. The study further argued that optimal sizing of system components is an integral part of a hybrid power system.

Also, Khare, Nema, and Baredar (2016) worked on the simulation and optimization of the non-conventional energy system in Central India. Using the HOMER, the authors considered the meteorological data of solar insolation and hourly wind speed and suitably modelled the optimization of the HRES.

Similarly, (Sundaramoorthy, 2014), investigated the economic feasibility and technical reliability of a proposed HRES of an optimal unit sizing which aims to

minimize total cost for the hybrid energy systems. The feasibility studies and sensitivity analysis has been made up using HOMER optimization models. The author found out that the optimal hybrid energy system is more economical than the existing model.

Khare & Soni, (2014), also utilized HOMER in the optimization of HRES for a remote rural area in Bhopal. The authors used the meteorological data taken from the area and the pattern of load consumption in the design and optimization process. The HOMER identified the most suitable design and model such as the optimal architecture and control strategy of the hybrid system. The optimization result was validated through Genetic Algorithm during a follow-up study. The objective of the study is to minimize the total capital cost. The studies have proved that the GA converges very well and the feasibility of hybrid power systems is identified.

Likewise, the study of (Joshi, Ashok & Chandel, 2016), utilized HOMER in the simulation and economic analysis of HRES consisting of photovoltaic arrays, along with wind turbines and battery systems. Accordingly, the sensitivity variables such as global solar, wind speed, and fuel price play a vital role in the optimization of HRES.

2.2 Conceptual Framework

The study utilized an Input-Process-Output (IPO) approach in the conduct in the development of the proposed HRES models for the PMMA. An IPO approach is a graphical representation of all the factors that make up a process. An IPO diagram includes all of the materials and information required for the process, details of the process itself, and descriptions of all products and by-products resulting from the process. The figure below shows the conceptual paradigm of the study.

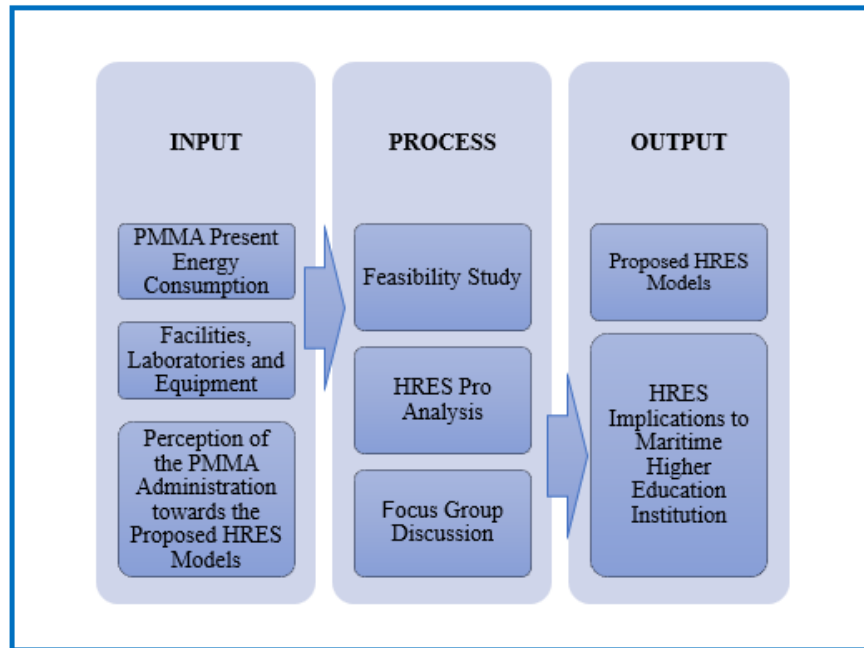


Figure 1. The Conceptual Paradigm of the Study

The conceptual paradigm of the study as shown in the IPO framework above shows that integral research process of this feasibility study. The first box comprised of the input variables which include the PMMA present energy consumption, academy's existing facilities, laboratories, and equipment, and the perception of the PMMA administration towards the proposed HRES models. The second box comprised the processes undertaken in the conduct of the study. These include the feasibility analysis of the proposed HRES models for the academy. The process box also comprised the focus group discussion as part of the collection of relevant data pertaining to the acceptability, implementation, and adaptation of the proposed HRES model. The output box presents the objective and purpose of the study- the developed HRES models and the identified implications of HRES to Maritime Higher Education Institutions.

The IPO framework together with the construct and concepts of this feasibility study were utilized in order to effectively present the purpose of the study.

Chapter 3

3.0 METHODOLOGY

3.1 Research Design

The integration of energy software, the HOMER Pro with feasibility analysis was the foundational design of this project. The optimization of proposed HRES was achieved and presented viable with the aid of a feasibility analysis. Accordingly, the feasibility study design comprises a set of multidimensional set of actions that analyse and evaluate the feasibility of a proposed project, programs, processes or interventions. It is also used to determine whether the proposal is subject for further testing to test and validate its relevance and sustainability. The assessment under feasibility analysis is used to determine whether the proposal is likely to deliver a successful outcome considering the practical and technical aspects of managing the proposed project. It also identifies the strengths and weaknesses of a proposed project and may present directions of activities which will improve the project and achieve the desired results.

Bowen et al (2009) argued that there are eight (8) general areas of focus addressed by feasibility studies. This refers to acceptability, demand, implementation, practicality, adaptation, integration, expansion and limited efficacy testing. In line with this project, the researcher delimited the feasibility analysis of the proposed HRES models in terms of acceptability implementation and adaptability. Acceptability focuses on the reaction and perception of the beneficiaries or intended recipient towards the proposed project, implementation, on the other hand, is focus on the extent, likelihood, and manner where the proposed project can be fully

implemented as planned, and lastly adaptation focuses on the readiness of the recipients towards changing the existing procedures and processes to be appropriate with the proposed project.

3.2 Instrumentation

This feasibility study utilized the Hybrid Optimization Model for Electric Renewable (HOMER Pro) as the main research tool in modelling the HRES for Philippine Merchant Marine Academy. HOMER is a simulation model developed at the National Renewable Laboratory of the US Department of Energy. The HOMER's software design is not only intended to identify a viable combination of various renewable components but also identify the system that is most economically feasible which consistently meet the expectations and requirement of the target user. Using HOMER, the users can input renewable variables such as size and type of components they wanted to be in their system, there is also a sensitivity analysis that allows the users to see the effect of uncertain parameters. The software examines all possibility of integration of system types in a single run and offers optimization according to the variable of choice. HOMER Energy is a global standard for optimization of microgrid design in all sectors, from village power and island facilities to campuses and military bases.

3.3 Research Locale

The Philippine Merchant Marine Academy (PMMA)

The Philippine Merchant Marine Academy (PMMA), the pioneer institution in maritime education in the country is supported by government funds with help from the shipping industry. It is the proud mother of the finest Filipino merchant marine officers. For many years, it has produced many master mariners, chief engineers,

shipping executives, naval officers, excellent educators and trainers now serving in marine and maritime related industries in our country and abroad.

Originally named "Escuela Nautica de Manila", created by virtue of a Spanish Royal decree issued on January 1, 1820, the school was inaugurated on April 5 of the same year. It was initially located at Calle Cabildo, Intramuros, Manila until 1863. It was renamed as the Philippine Nautical School (PNS) during the American occupation. In 1963, Republic Act 3680 converted it into the Philippine Merchant Marine Academy. It began offering maritime programs leading towards a B.S. degree in Marine Transportation and B.S. degree in Marine Engineering. Since 1996, PMMA has been offering master's degree programs namely Master in Shipping Management and Master in Maritime Education and Training.

The Academy has been over different locations through the years. From Intramuros, Manila to the site of the DFA along Roxas Boulevard, Pasay City, to a seven-hectare lot in Fort Bonifacio. Now presently resting on a sixty-hectare land at the former American Radar Base in San Narciso, Zambales, the PMMA continues to uphold its mission of producing competent and qualified merchant marine officers that are honoured and respected in the sea-lanes of the world.

The PMMA's mission is to develop competent merchant marine, naval and coast guard officers for shipboard and shore-based positions; and to spearhead the improvement in maritime education, training and research. With this the Academy envisions itself to be an educational institution with a strong presence in leading the country's maritime education, training and development. The achievement of the desirable mission and vision is anchored with the goals and objectives of the institution which include (1) to confer the degree of Bachelor of Science in Marine Transportation and Bachelor of Science in Marine Engineering to deserving PMMA midshipmen; (2) prepare and qualify PMMA midshipmen as commissioned officers of the Philippine Navy (PN) before their graduation in the Academy; (3) to train and upgrade merchant marine officers in shipboard and offshore positions as shipping executives and technical consultants; (4) to offer post graduate studies in maritime

education and shipping business; (5) to train student apprentices in various shipboard or shore facilities rank and file billets through the offering of practicum classes; (6) to conduct research and development projects positively affect the education and training of PMMA midshipmen and post graduate students and in the pursuit of new information and knowledge of value to the maritime industry; and (7) to provide assessment services to qualify candidates for the deployment of highly competent and globally competitive Filipino maritime manpower.

Below is the physical layout of the PMMA.

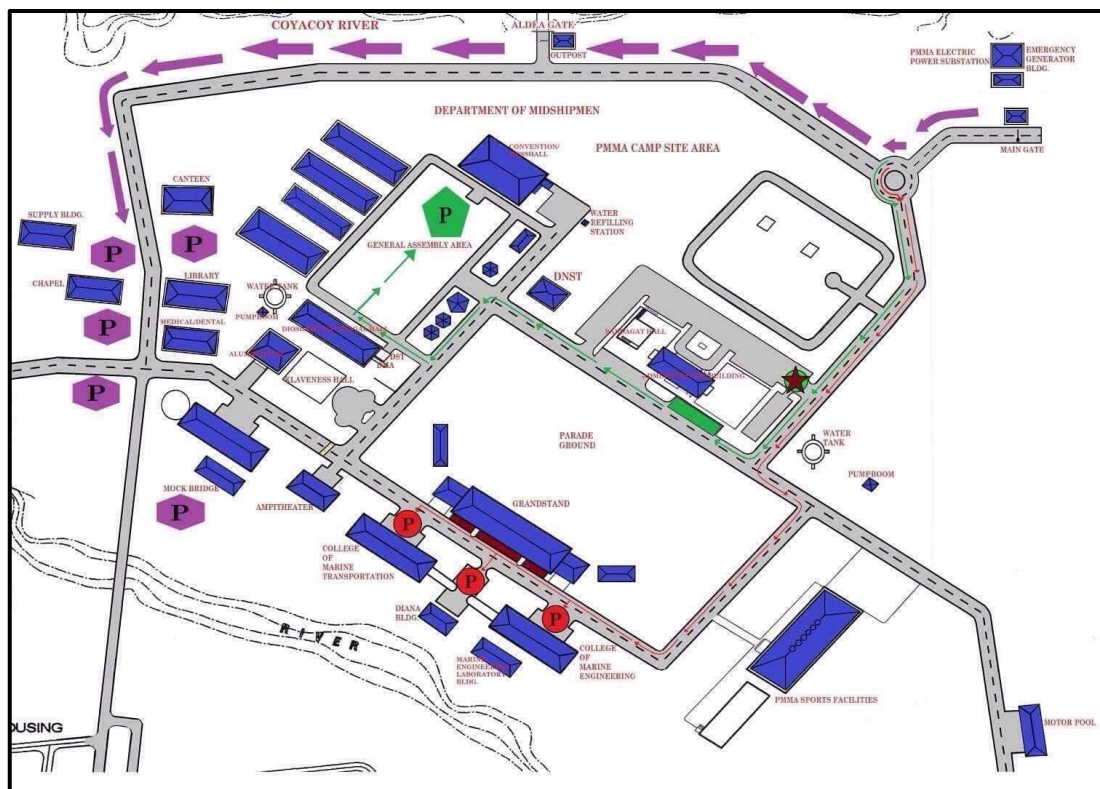


Figure 2. Philippine Merchant Marine Academy Physical Layout

Chapter 4

4.0 CASE STUDY AND DISCUSSION OF RESULTS

4.1 Data Gathering and Analysis

The data collection procedure started with the gathering of 2017 energy consumption expenses of the Academy. The annual electricity expenses serve as baseline data in the utilization of the energy software. The study also required the general inventory of the Academy's physical consumers of electricity-the collection of maritime facilities and equipment. Similarly, the development plan consisting of the proposed projects for the next 3 years was also collected.

Aside from the monthly energy consumption from local power grid provider, the researcher also requested the additional fuel consumption for standby diesel generators.

The implications of proposed HRES were collected from the perceptions of selected administrators and concerned personnel of the academy. Other data and information which are deemed important to this study was provided by the Office of the PMMA-PMO.

4.2 PMMA Facilities

The pioneer maritime institution of the country with its state-of-the-art facilities continuously strive for excellence with the aid of modern and advanced Maritime Education on Training physical requirements.

The PMMA has two (2) 2-storey 32 classrooms instructional building fully equipped with advanced technologies for teaching and learning process, two (2) machine shops for practical workshop of engineering and navigation students; 2-storey simulator's building with one (1) full mission bridge simulator and one (1) full mission engine room simulator; newly built 180-seater Amphitheatre fully equipped with advance audio-visual equipment for conferences and trainings; one (1) 2-storey Training Center with fully air-conditioned classrooms and laboratories; 20-bed capacity Medical Unit with isolation ward which can cater up to 5 patients; fully furnished Library with mini-conference room and 40-units computer laboratory; Alumni House with four (4) fully furnished luxury rooms/cabins and 50-capacity functions rooms capable of housing 6-8 families; 150-capacity 2-storey PMMA Hotel with 2 suites and an average sized of conference/dining hall adjacent to fully furnished kitchen; four (4) dormitories with bed capacity of 1000 cadets; a 1000-capacity Mess Hall equipped with fully furnished kitchen, storage rooms and reefers; DNST Headquarters, 2-storey Barber Shop; Water Filtering Station, 2-storey Administration Building, Safety Training Center with conference room adjacent to Safety Shop, Fire House, Free Fall, and Davit Launch Lifeboats, Gymnasium, water pump station, Chapel, a large-size swimming pool; a Motor Pool; and the PMMA Housing Facility having 60 housing units capable of accommodating more than 120 families.

With highly recognized maritime curriculum and accredited training programs, the Academy with this ownership of facilities provides the best MET for future seafarers.

In addition, the PMMA established a developmental project with the portion of vacant lots in the next three years. These includes the construction of PMMA Sports Complex, additional academic and laboratory buildings, additional housing for officers and staffs, wharf area for laboratory and training centre, other infrastructures such as roadways, canals and pipes, expansion of extra barracks/dormitory, and a building for other proposed maritime courses.

Indeed, with the current developments and physical ownership of the Academy, it is deemed important to note and consider the acquisition of a HRES.

4.3 Academy's Electricity Cost

The academy solely relies on the electricity provided by the national grid, the Zambales Electric Corporation (ZAMECO) within the province. ZAMECO is the only electric power distributor nearest to the Academy. Figure 2 gives the summary of the 2017 electric energy average consumption of the academy.

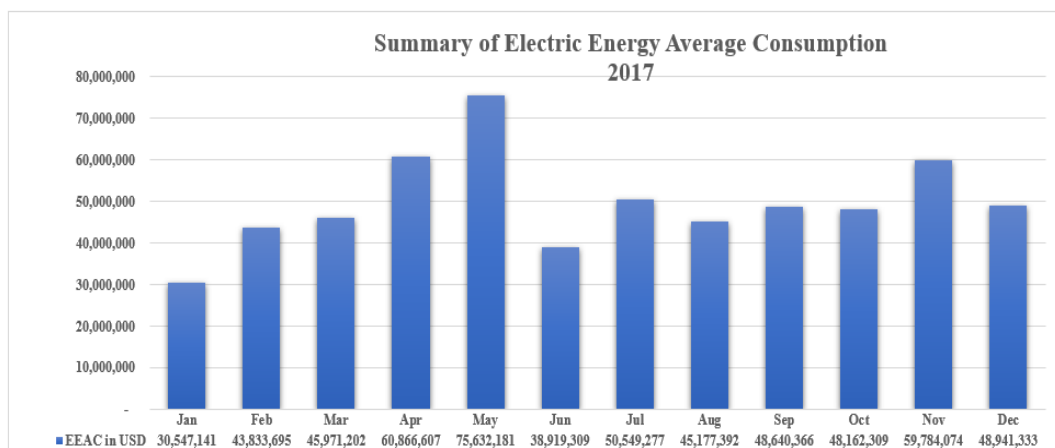


Figure 3. The PMMA Summary of EEAC, 2017

Figure 3 shows the monthly EEAC of academy last 2017. It can be observed that during the months of April and May are the highest consumption. Accordingly, during these months the PMMA Training and Assessment Center usually scheduled their training and assessment examinations. During also these months where air-conditioning unit services is at its peak because of dry and humid weather in the area.

The monthly average of EEAC is USD 17, 093 and annual average of USD 205, 121. The monthly average EEAC is not the only electrical expenses of the Academy. As mentioned earlier, the stability and reliability of the national grid supply was not a good advantage in the part the Academy's demanding operation. Thus, stand-by diesel generators are necessary to cope with the unstable source of power and fluctuations incidents during the onset of weather disturbance. Below shows the three-year fuel consumption of stand-by diesel generators.

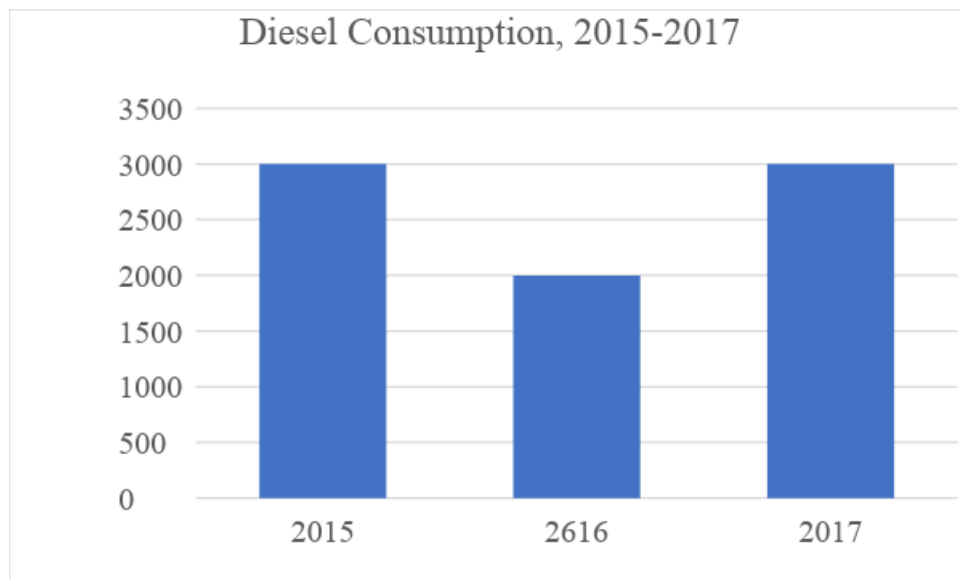


Figure 4. PMMA Diesel Consumption, 2015 - 2017

The fuel consumptions cost in 2015 is USD 4,446.22, USD 2,964.15 in 2016, and USD 4,446.22 last year. Another additional operating costs of which the proposed HRES aimed to eliminate.

4.4 HRES Models for PMMA

The HOMER Pro simulation report provided two HRES model for the PMMA. The first model (Model A) architecture is a combination of solar PV panels, wind turbine,

battery energy storage, and converter connected to the grid while the second model (Model B) architecture is a solar PV panels with converter connected to the grid.

The proposed HRES explores the possibility of using solar photovoltaic and wind turbines alternative sources of energy to supply the power demand of the academy, Furthermore, battery energy storage, converters and the grid were integrated in the system.

To determine the viability of the proposed HRES, the study analyse five (5) major factors related in the design, creation and establishment of HRES. These include Initial Capital Cost (ICC), Net Present Cost (NPC), Levelized Cost of Energy (LCOE), Internal Rate of Return (IRR) percentage and Payback Period (PP) in years. These variables are utilized to be able to describe and show how feasible the proposed HREIS or any renewable energy project to the target recipients and beneficiaries. The values of these metric indicators serve as the basis for the approval and implementation of the any proposed HRES, more particularly its components. Component or components refers to any part of the system that generated, stores, or transfers electric or thermal energy, and the size or quantity of which is an optimization variable. Photovoltaic panels, diesel generators and wind turbine, converters, electrolyze and grids are examples of components.

The ICC of a component is the total installed cost of that component at the beginning of the project, this is also known as capital cost. The NPC or life cycle cost of a component is the present value of all the costs of installing and operating the component over the project target timeframe, minus the present value of all the revenues that it earns over the project duration. LCOE also known as Levelized Energy Cost (LEC) is the net present value of the unit cost of electricity over the lifetime of a generating asset. It is often taken as a proxy for the average price that the generating asset must receive in a market to break even over its lifetime. Homer defines it as the average cost per kilowatt-hour of useful electrical energy produced by the system. IRR also referred as economic rate of return or discounted cash flow rate. It is a metric used in capital budgeting to estimate the profitability of potential HRES. Payback period on the other hand is the length of time required for institution

to recover from its initial outlay in terms of profits or savings. The table below shows the significant metric values of the two proposed models for the PMMA.

Table 1. The Proposed HRES Model Using HOMER Pro

Metric/Value	MODEL A Solar-Wind-Bat-Con-Grid	MODEL B Solar-Con-Grid
Initial Capital Cost (ICC)	2,183,165.89	5,534,934.47
Net Present Cost (NPC)	2,093,460.43	1,755,996.61
Levelized Cost of Energy (LCOE)	0.12	0.04
Internal Rate of Return (IRR, in %)	7.25	6.99
Payback Period (PP, in Years)	10.31	11.40

Model A explores the possibilities of using solar PV and wind turbines as alternative sources of energy to supply the power demand of the PMMA. Additionally, battery bank, converter and grid would be integrated in the system and the best combination of the components or one energy source would be selected based on economics. REC Solar340REC340PEM 72 BLK is the PV module used and manufactured in Singapore. This component was derived from HOMER, with a capital cost of \$2493/kW and operation and maintenance (O&M) cost of \$19kW/yr. were drawn from the Distributed Generation Renewable Energy Estimate of Costs from NREL 2016.

Norvento nED 22 (100 kW) wind turbines, manufactured in Spain, were selected for this model. The capital cost is US\$3751/kW with operation and maintenance of US\$31 kW/yr. as per NREL 2016. Replacement cost is 20% less than the initial capital cost to account for materials and equipment that will not be totally replaced together with the wind turbine at the end of its useful life.

The battery energy storage used is sonnenBatterie 7kW-10kWh which specifications and price are drawn from the HOMER database. The battery Lithium-ion. This brand of battery is not new to the Philippines as it has already installed a 2MW BES in the

country (Alvarez, 2018). The battery specifications are shown in Table ... with a lifespan of 10 years thus the replacement cost of US\$2,823.

Solarmax 75TS-A converter was selected as the interface between AC and DC bus that conforms to the parameters of the national grid. The specifications are given in Table with ICC of US\$108,291 and replacement of US\$45,945 whereas the O&M is zero.

Table 2. Characteristics of Model A

Characteristics	Wind Turbine	Solar PV	Battery	Converter
Model	Norvento nED 22	Solar340REC34OPEM 72 BLK	sonnenBatterie 7kW-10kWh	Solarmax 75TS-A
Nominal Capacity (kWh)	-	340	200	361
Nominal Voltage	-	38.5	240	-
Expected Lifetime (years)	20	20	10	-
Capital Cost (US\$)	750,200	1.32M	6,000	108,291
Replacement Cost (US\$)	-	-	2,823	45,945
O&M (US\$)	3,706	116,383	-	-
Total Production (kWh/yr.)	519,970	763,445	-	-
Mean Output (kW)	59.4	87.5	-	81.2
Capacity Factor %	29.7	16.5	-	22.5
Hours of	7,220	4,286	-	5020

Operations (hrs/yr)				
Levelized Cost (US\$/kWh)	0.125	0.162	-	-
Rated capacity	200	529	-	-
No. of Batteries	-	-	20	-
No. of Strings	-	-	20	-
Autonomy (hr)	-	-	1.52	-
Energy In (kWh/yr)	-	-	66,619	748,609
Energy Out (kWh/yr)	-	-	57,478	711,179
Lifetime throughput	-	-	619,796	-
Battery wear cost (US\$/kWh)	-	-	0.00270	-

Model B consist of solar PV, converter and grid. The ICC is US\$5.16 million and \$379,800 respectively. The replacement cost for the converter is US\$213,290 with O&M of zero whilst solar PV has an O&M of US\$618,896.

To determine the viability of the proposed HRES, the study analyse five (5) major factors related in the design, creation and establishment of HRES. This includes Initial Capital Cost (ICC), Net Present Cost (NPC), Levelized Cost of Energy (LCOE), Internal Rate of Return (IRR) percentage and Payback Period (PP) in years. These variables are utilized to be able to describe and show how feasible the proposed HRES or any renewable energy project to the target recipients and beneficiaries. The values of these metric indicators serve as the basis for the approval and implementation of any of the proposed HRES, more particularly its components. Component(s) refers to any part of the system that generated, stores, or transfers electric or thermal energy, and the size or quantity of which is an

optimization variable. Photovoltaic panels, diesel generators and wind turbine, converters, and grid are examples of components.

Table 3. Characteristics of Model B

Characteristics	Solar PV	Converter
Model	Solar340REC340PEM 72 BLK	ABB Micro-0.3HV-I-OUTD-US-208
Nominal Capacity	340	1,266
Nominal Voltage	38.5	-
Expected Lifetime (years)	25	-
Capital Cost (US\$)	5.16M	379,800
Replacement Cost	-	213,290
O&M	618,896	-
Total Production (kWh/yr.)	2,962,165	-
Mean Output (kW)	338	315
Capacity Factor %	16.4	24.9
Hours of Operations (hrs/yr)	4,286	4,286
Levelized Cost (US\$/kWh)	0.124	-
Rated capacity	2,068	-
Energy In (kWh/yr)	-	2,873,340
Energy Out (kWh/yr)	-	2,758,407

4.5 Feasibility of the HRES Models

Comparing the two models, model B is more economically feasible as it has the lowest LCOE of USD.036 and NPC of \$1.76M. However, the component of the system consists only of the solar PV connected to the grid. In this regard, it does not help solve the problem of energy unreliability associated with the intermittent nature of the environment. Furthermore, the ICC of USD 5.53M is a substantial investment that a government subsidized MHEI will have a difficulty in acquiring as HRES requires upfront investment. Model A on the other hand comprise of two RE sources, solar PV and Wind turbine, including a battery energy system making the system more reliable in terms of electricity production ensuring a continuous supply. Additionally, the initial cost for model A at USD2.18M is an investment that is cheaper to finance by the government. Model A can significantly reduce the emission of carbon dioxide as 85% of electrical load of the academy is from RE sources

Based from the discussion with the select PMMA administrators, they believed that harvesting renewable source of energy has its significant value in its environmental aspect of use and adaptation, reducing greenhouse gas emissions compared to conventional energy provided by diesel, fossil fuel and coal fired thermal power plants. Highly sought nowadays by local households and small farm industries as a substitute to capitalize on significant decrease on electrical energy provided by the local power grid, subsequently reducing dependence on its use. In the aspect of its implementation to the institution, it has a high regard for its economical and industrial value, for the Academy itself is highly dependent on electrical use for most of the technological equipment used for education together with the facilities are dependent on electricity.

Funding will be a challenge being a Government ran institution, but through research-based studies to back up a proposal, its feasibility would justify the probable outcome where the potential benefits would manifest. Such project may be proved tedious with due consideration not only by funding but also with the technological know-how of its maintenance and operation. This challenge could also be taken as an opportunity for the institution to be engaged in a technological advantage in learning

more about the use of renewable energy by means of research to further understand and improve the efficiency of its use. As the Academy has its support and ties with various international shipping agencies, enticing a partnership would provide the Academy with financial support for the project. As most of the ship owners are also inclined with use of renewable energy, if it would be practiced in the institution, the student itself will have the proper orientation as well before boarding their vessels that are equipped with such technology.

Chapter 5

5.0 Conclusions

To conclude, the on-hand master thesis the research proved that the application of using the renewable resources as a primary source of power in small plants as mentioned in the proposed study is a valid, feasible and applicable solution. The models support the analysis which covers the potential benefits of using renewable energy in independent power generating plants. The decision making process depends on affordability.

Firstly, renewable resources use will help the Philippines government to meet its proposed GHG reduction plan and consequently will fulfilling its political commitment regarding UN 2030 agenda. As a result of applying the proposed system the amount of the consumed fossil fuel will drop significantly and consequently the air pollutants. Also, the air quality improvement around the place, therefore, the citizens' health expected to be improved. Less consumed fuels and fewer emissions will reduce the carbon footprint which serving the purpose to save the environment by help in slowing down the global warming and climate change symptoms. The Philippine government would discover the significant benefits of applying such systems that may draw to their attention to modify and improve the current legal framework with higher flexibility, applicability measures and incentives to encourage more organisations to utilise this promising project. Moreover, the

international concern to support the use of renewable energy and to share the know-how for it between nations for such contemporary technology will improve the Philippines national industrial sector capabilities.

Secondly, as a consequence of using renewable energy sources, the load on the national electricity grid will be reduced, therefore increasing savings in electricity bill and consumption and reduce GHG emissions for PMMA. The two models yield a LCOE of US\$0.124 and US\$0.03 and payback of 10 and 11 years respectively. This shows that the projects are viable investment. However, Model A ICC is USD2.18M while Model B is over 5M which make the latter the acceptable option for this institution. The study concludes that the proposed HRES Model A, the Solar PVs-wind turbine-battery storage connected to a grid is the most feasible hybrid renewables for the Philippine Merchant Marine Academy. The institution would be spending less on electricity cost which can be utilized for other expenditures of the academy. It also shows that the PMMA highly accepted the idea of the establishment of HRES, and positively viewed that the Academy can implement the project when financial support is available. However, the PMMA worries how to sustain the project in the long run

5.1 Recommendations

1. The feasible model should be presented to the target beneficiary.
2. Although feasibility was established, a conduct of a deeper analysis on the proposed HRES model is necessary.
3. Conduct a higher level of feasibility analysis for the implementation of the proposed HRES.

Appendices

A. HOMER results in Excel (Model A)

	0	-2183165.89	-2183165.89		Payback period	
	1	212261.67	211236.75		212261.67	-1970904.22
	2	212261.67	211236.75		212261.67	-1758642.55
	3	212261.67	211236.75		212261.67	-1546380.88
	4	212261.67	211236.75		212261.67	-1334119.21
	5	212261.67	211236.75		212261.67	-1121857.54
	6	212261.67	211236.75		212261.67	-909595.87
	7	212261.67	211236.75		212261.67	-697334.2
	8	212261.67	211236.75		212261.67	-485072.53
	9	212261.67	211236.75		212261.67	-272810.86
	10	207261.67	206236.75		207261.67	-65549.1901
	11	212261.67	211236.75		212261.67	146712.4799
	12	212261.67	211236.75		212261.67	358974.1499
	13	212261.67	211236.75		212261.67	571235.8199
	14	212261.67	211236.75		212261.67	783497.4899
	15	103971.13	102946.21		103971.13	887468.6199
	16	212261.67	211236.75		212261.67	1099730.29
	17	212261.67	211236.75		212261.67	1311991.96
	18	212261.67	211236.75		212261.67	1524253.63
	19	212261.67	211236.75		212261.67	1736515.3
	20	284455.36	283430.44		284455.36	2020970.66
		4204136.55	4183638.15			
IRR		7%	7%	PBP	10.31	years
MIRR		7%	6%			
NPV		2,275,313.40	2,264,225.66			

NET PRESENT COST									
apital	o&m			replacement	salvage		discount factor		Total
	solar PV	wind turbine	grid					grid	
2183165.89									2183165.89
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.9444	-9416.2973	-9416.2973
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.8920	-8893.1697	-8893.1697
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.8424	-8399.1047	-8399.1047
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.7956	-7932.4878	-7932.4878
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.7514	-7491.7940	-7491.7940
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.7097	-7075.5832	-7075.5832
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.6702	-6682.4953	-6682.4953
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.6330	-6311.2455	-6311.2455
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.5978	-5960.6208	-5960.6208
	10050.07	320.00	-20340.27	-9970.20	5000	0.058823529	0.5646	-5629.4752	2823.1514 -5629.4752
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.5333	-5316.7266	-5316.7266
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.5036	-5021.3529	-5021.3529
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.4757	-4742.3888	-4742.3888
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.4492	-4478.9228	-4478.9228
	10050.07	320.00	-20340.27	-9970.20	108290.54	0.058823529	0.4243	-4230.0937	45944.8421 -4230.0937
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.4007	-3995.0885	-3995.0885
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.3784	-3773.1392	-3773.1392
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.3574	-3563.5203	-3563.5203
	10050.07	320.00	-20340.27	-9970.20		0.058823529	0.3376	-3365.5470	-3365.5470
	10050.07	320.00	-20340.27	-9970.20	-72193.69	0.058823529	0.3188	-3178.5721	-23015.8790 -3178.5721
									-115457.6252
								NPC (\$)	2093460.3794

[illegible]

36

22		39289.03	289653.05	-250364.02		0.039215686	0.4290	-107410.4811		-107410.4811
23		39289.03	289653.05	-250364.02		0.039215686	0.4128	-103857.2554		-103857.2554
24		39289.03	289653.05	-250364.02		0.039215686	0.3972	-99456.9816		-99456.9816
25		39289.03	289653.05	-250364.02		-126600	0.039215686	0.3823	-95703.8880	-48393.9834
total	5534934.47	982225.75		379800	-126600			-3943833.3933		-3943833.3933
		618,896.39 kr	4,562,729.78 kr						NPC (\$)	1755996.6343

LEVELIZED COST OF ELECTRICITY

Component	Capital	Replacement	O & M	Salvage	Total	Component	Capital	Replacement	O & M	Salvage	Total
	\$	\$	\$	\$	\$		\$	\$	\$	\$	\$
Converter	24110.61665	13540.13253	0	-3072.16614	34578.583	Converter	379800.0000	213289.54	0.0000	-48393.98	544695.6
Grid	0	0	-289653.0537	0	-289653.054	Grid	0.0000	0	-4562729.8300	0	-4562730
solar PV	327260.3238	0	39289.0313	0	366549.355	solar PV	5155134.4700	0	618896.4100	0	5774031
System	351370.9404	13540.13253	-250364.0224	-3072.16614	111474.884	System	5534934.4700	213289.54	-3943833.4200	-48393.98	1755997
Production	Kw/yr	%	Consumption	Kwh/yr	%						
solar PV	2962165	89.84	AC primary load	1149223	59.11		i=discount rate	0.0600	Rproject (yr)	25.0000	
Grid purchase	335064	10.16	Grid sales	1944248	62.85		inflation	0.0200	in real discount	0.03921568627	
Total	3297230	100.00	Total	3093471	121.96		CRF	0.0635			
LCOE (\$/KWh) 0.036035536											
COE = (C _{ANNUAL,TOT} - C _{BOILER} H _{BOILER})/E _{SERVED}											
C _{ANNUAL,TOT} = Total annualized cost (\$/yr)						111474.884					
C _{BOILER} = Boiler marginal cost (\$/Kwh)						0					
H _{BOILER} = Total thermal load reserve (Kwh/yr)						0					
E _{SERVED} = Total electrical load served (Kwh/yr)						3093471					

0	-5534934.47	-5534934.471
1		485593.2087
2		485593.2087
3		485593.2087
4		485593.2087
5		485593.2087
6		485593.2087
7		485593.2087
8		485593.2087
9		485593.2087
10		485593.2087
11		485593.2087
12		485593.2087
13		485593.2087
14		485593.2087
15		105793.2087
16		485593.2087
17		485593.2087
18		485593.2087
19		485593.2087
20		485593.2087
21		485593.2087
22		485593.2087
23		485593.2087
24		485593.2087
25		533987.1887
		11808424.2
IRR		6.99%
MIRR		6.39%
NPV		525,374.92

LCOE (\$/KWh) 0.036035536																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							</
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CCC	Replacement	O & M	Grid sales	AC primary low	Salvage	Excess E.	Real discount factor	Replacement	O & M	Grid sales	Consumption	Salvage		
553439.47													Nominal	
	-39289.0313	289653.12	218352.37			168676.75	0.962264151	-37806.42635	278722.8137	210118.17	16239.89		485593.21	
	-39289.0313	289653.12	218352.37			168675.76876	0.9215922797	-36875.76876	268204.9717	202188.18	15607.07		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.89102061971	-35804.0061971	258046.134	194554.34	15037.36		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.8573487656	-33685.93004	248435.0059	187212.6	14669.92		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.825033405	-32414.76326	238973.4998	180148	13923.88		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.793100006	-31191.56466	229955.6139	173350	13398.45		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.7638951876	-30034.52449	221278.0616	166885.3	12891.85		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.735113392	-28881.8009	212927.9459	160511.8	12406.33		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.707373457	-27792.01788	204892.5288	154566.7	11938.16		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.6806808119	-26743.2625	197611.1202	148628.1	11487.67		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.654949077	-25734.08719	189721.0780	143035.9	11035.47		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.630277312	-24762.86513	182047.9191	137623.2	10617.09		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.606499372	-23828.53306	175672.6679	132429.2	10254.63		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.583606732	-22929.34314	169043.5106	127431.9	9849.385		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.561583836	-22064.08492	162664.1033	122623.2	9477.71		100793.21	
	-39289.0313	289653.12	218352.37			168676.75	0.540391993	-21323.47794	156526.2269	117989.9	9100.061		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.51998842	-20545.2801	150601.3352	113354.2	8707.507		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.500377277	-19659.33576	144953.8193	109258.5	8444.741		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.481495049	-18917.47404	139466.3531	105336.6	8126.072		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.463252424	-18203.6071	134623.6548	101168.7	7819.427		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.4456815784	-17516.67854	129116.67854	97350.54	7524.355		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.429017241	-16855.6718	124266.1823	93676.93	7240.417		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.412827911	-16219.60872	119576.8925	90141.95	6967.193		485593.21	
	-39289.0313	289653.12	218352.37			168676.75	0.397249449	-15607.58092	115064.5569	86740.37	6704.28		485593.21	
	-39289.0313	289653.12	218352.37			48933.98	0.382258952	-15018.5895	110722.4982	83467.15	6451.289	18499.03	533987.19	
								-213289.541	745466.409	618986.418	456273.8873	349375.2	265863.3	NPB
								1915931.938						11.40

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