Prospects and Design Assessment of a Hybrid Renewable Energy Microgrid for an Indigenous Community in Bangladesh

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List of Acronyms

SDG	Sustainable Development Goals
PV	Photovoltaic
NASA	National Aeronautics and Space Administration
GHI	Global Horizontal Irradiance
NPC	Net Present Cost
Gen	Diesel Generator

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Abstract

The Thuisa Para indigenous community living in the hill tracts of Bandarban, Bangladesh, has never experienced the miracles of electricity, as most of the remote hilly areas of Bandarban are still not under the National Energy Grid coverage. These indigenous people are deprived of the blessings of electricity and, their socio-economic advancement is being obstructed. The Sustainable Development Goal 7 (SDG7) program under the UN aims to diminish such energy access inequalities. It is possible for communities like Thuisa Para, which are located in remote areas, to acquire an adequate supply of electricity by utilizing the available renewable energy resources. But before implementation, thorough analyses regarding the geographical factors, cost-effectiveness and durability for a particular location is required to ensure that the energy system fulfills the demands adequately. Therefore, this paper aims to propose the most affordable and most reliable hybrid renewable energy microgrid design for the Thuisa Para Community upon completion of thorough comparative analyses of the available design options. For design and simulation purposes, HOMER software has been used. Elements considered for this microgrid are specifically solar-PV panels, kinetic batteries, wind turbine, diesel generator and converter. The results obtained from the simulation were used to compare the viable design choices in terms of their respective energy production capabilities, per-unit electricity costs, net present costs (NPC) and a few other important factors. Additionally, a multiyear sensitivity analysis regarding the net present cost has been conducted for the ease of choosing the suitable project lifetime of the Thuisa Para microgrid.

Chapter 1

Introduction

1.1 Overview

In recent decades, a lot of advancement has been made in enabling the people of the world to reliable energy access, but some regions remain particularly under-served. The UN Sustainable Development Goal 7 (SDG7) aims to ensure affordable, reliable, sustainable, and modern energy for all by 2030 [1]. This SDG7 goal also aims to expand and upgrade technology infrastructure to supply modern and sustainable energy services, especially for the energy-deprived regions.

The indigenous community of Thuisa Para, Bandarban, has zero access to electricity. The community is deprived of all the facilities of modern life, such as quality healthcare, cellular network service, food storage, and electricity. Most of the families are severely impoverished, and kids are in the dark from the light of education. All the acute problems of the community are innately connected with the one core element of modern life, which is electricity.

In Bangladesh, the primary source of energy for consumption is natural gas. Despite having a massive stock of gas resources in Bangladesh, the people of Bangladesh suffered from a gas shortage of 142 million cubic feet per day (mmcfd) in 2011, and it is estimated that the lack of gas will increase to 171.4 mmcfd by 2019– 2020 raising huge concern about gas production [2]. The article referenced in the previous line states that Bangladesh imported a minimum of 500,000 kWh of electricity from other countries, which makes Bangladesh 107th amongst the electricity importing countries in the world. According to the article, satisfying the soaring energy demand of Bangladesh as well as ensuring energy access to the distant regions of the country, production of energy from various renewable resources like solar, wind, biomass and biogas, geothermal, sea wave, and hydroelectricity might be feasible in particular regions of Bangladesh depending on the geographical resources the different regions provide. All the energy-deprived communities like Thuisa Para in Bangladesh have the chance to acquire electricity if the specific renewable energy resources suited for the different communities are thoroughly analyzed and adequately utilized accordingly.

The community of Pukur para is an indigenous one. Sadly, the community does not have any facility to sustain modern life such as network services, food storage, medicine storage, quality healthcare. But truly, all these innate problems are connected very closely to a major one, which is, unavailability of electrical energy. Bandarban of Bangladesh has a stellar potential of harvesting solar as well as fuel cell energy (to some extent). Yet, most of the communities of this hilly district are deprived of the most needed facility, that is, electricity. The socio-economic condition is pretty impoverished due to this major factor. Access to electrical energy has the potential to improve the living conditions of the habitats of Bandarban, by major degrees. Producing clean energy depends majorly on several geographical factors, namely-global horizontal irradiance, tilt angle, etc.

1.2 Motivation

Improvement of the overall socio-economic condition of a community massively depends on energy access. Reduction of poverty and access to a better life is achievable if access to electricity can be ensured. As the location of Thuisa Para has vast potential for energy production from solar power (according to the NASA database obtained through HOMER software), a hybrid renewable energy microgrid will bring a wave of improvement in all the key components of poverty such as health, education, income, and social environment, etc. Access to electricity will enable medicine and food storage, local industry development as well as narrow down the digital divide resulting from the inability to use information and communication technologies [3]. The education scenario will also improve drastically as lighting appliances will enable studying at night and invest time in various extra-curricular activities.

Depletion of water resources are caused by many reasons. But one thing is an unadmissable fact, that is, depletion of water resources is a severe threat for a sustainable civilization. Scarcity of energy is also a major problem that requires continuous advancement [8]. Rural electrification, in other words, remote electrification has quite a number of pain points. The considerable challenges are – the micro or mini hybrid grids may turn out to be obsolete because of main grid extension, no proper advantageous scope for revenue generation by the means of commercial application, a very low number of consumers who are actually

willing to use a considerable amount of electrical energy, even agreeing to pay higher than the existing price of grid electricity [9].
A country, containing much similar type of geological and sociological context, is Venezuela, where the residential use of hydrogen energy-based systems are being studied [10]. In the system that was studied, hydrogen was produced via electrolysis. The energy was supplied by the means of hydroelectricity powered microgrid. The hydrogen that was produced, was stored and then again was transformed into transmittable form of electrical energy.

Hydroelectricity possesses the potential to contribute in meeting the ever- increasing demand of energy in Bangladesh [11]. Other existing means of harnessing renewable energy might also be quite feasible in suitable geographical regions [12]. One thing must be taken into consideration in this regard, which is, in reaching the left-out consumers outside the jurisdiction of national grid, can be majorly backed by harnessing green energy [13].

1.3 Objectives

This work aims to find the most optimal hybrid renewable energy microgrid design choice for Thuisa Para through simulation in HOMER software and analyses regarding various available design choices comparing their economic aspects and energy production capabilities. Near-similar Geographical conditions have been proved to possess sufficient resources for successfully operating a hybrid renewable energy microgrid stated in [4], [5], [6]. This paper suggests a different approach than the works stated in the previous line, while load profiling ensures the excellent reliability of the hybrid microgrid. This paper also highlights the enormous potential of harnessing solar energy in Thuisa Para as well as Bandarban hill tracts in Bangladesh.

In the Pukur Para work, studies have been conducted regarding a floating PV system. The overall system included an electrolyzer module, a hydrogen fuel cell, floating PV array, and all these were connected to the DC bus. A hydrogen tank was included for the purpose of storing the hydrogen that was produced by the electrolyzer. Also, power was supplied to the load in DC form. For all the simulation and design purposes, HOMER Pro was used. Prevention of water resource depletion, avoidance of the ground preparation cost, considerable amount of land conservation from PV array installation, and lastly, integration of a hydrogen gas tank as an energy storage are the prime factors that inspired this study.

Chapter 2

Methods

2.1 Simulation software

While designing a power system, numerous decisions are to be taken regarding the configuration of the system. Components to be used, their sizing, alternative design choices- all these are needed to be optimized appropriately depending on the variation in technology costs and available energy resources. HOMER is the abbreviation of Hybrid Optimization of Multiple Electric Renewables, a reliable design and evaluation tool to account for assessing various technology costs and the prospect of energy resources [7]. According to the HOMER Pro Version 3.7 User Manual, HOMER performs the energy balance calculations for each system configuration considered. It then determines whether an arrangement is feasible enough and accounts for installation costs and costs for keeping the system functional over the project's lifetime, as mentioned in the user manual.

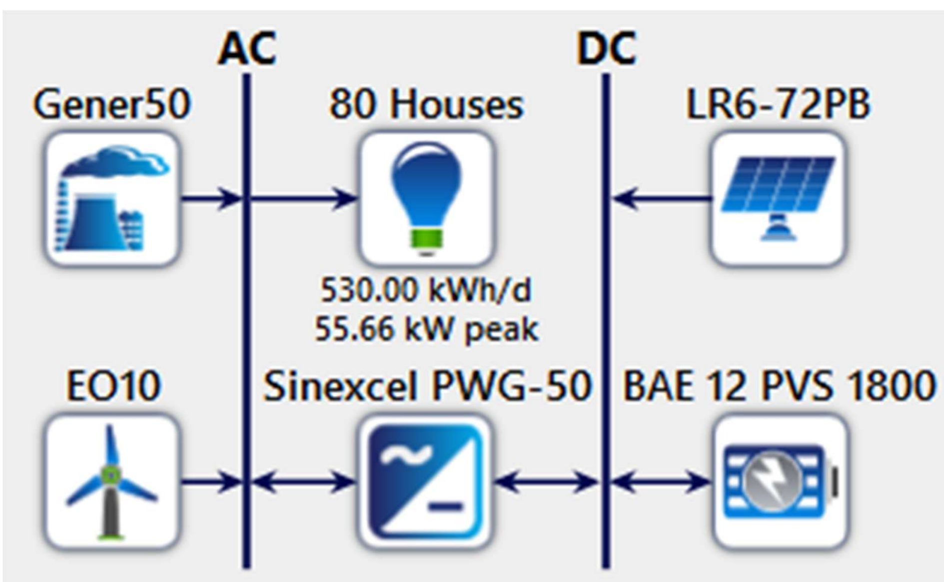

Figure 2.1: Schematic of hybrid microgrid of Thuisa Para

The system cost calculation comprises various expenses like capital, replacement, operation and maintenance, fuel, etc. HOMER has two optimization algorithms. The HOMER Pro manual states that the original grid search algorithm simulates all of the feasible system configurations defined by the Search Space and HOMER Optimizer uses a proprietary derivative-free algorithm to search for the least cost system. HOMER then displays a list of configurations, sorted by Net Present Cost (NPC), that can be used to compare amongst the system design options. In this work, both the Search Space and the HOMER Optimizer have been used for estimation purposes depending on the component type.

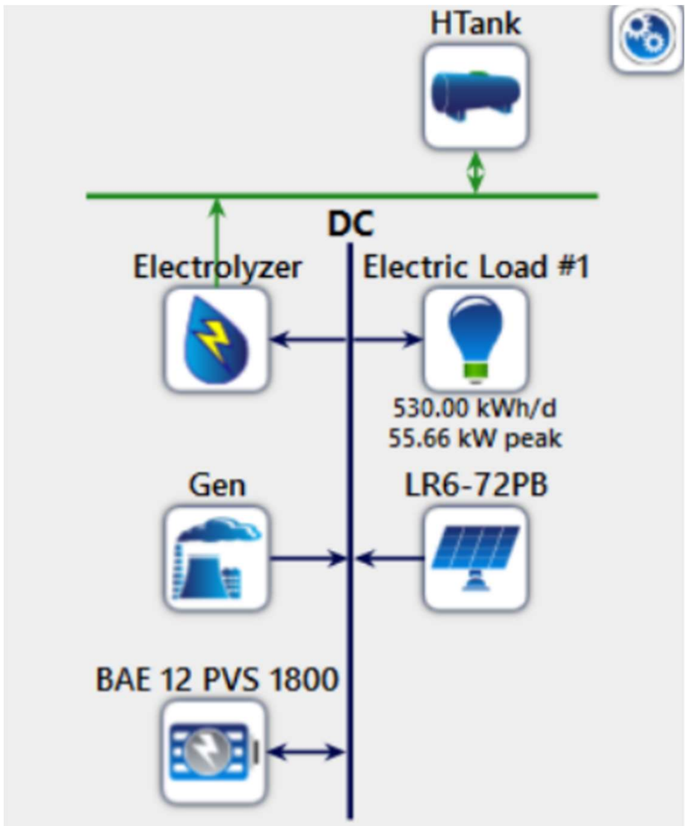

Figure 2.2: Design Schematic for Pukur Para

In short, to take the cumbersome comparative design decisions regarding each component, an automated tool can prove to be quite useful. HOMER Pro is such a tool that provides industry standard solutions for microgrid design choices. The underlying HOMER optimizer algorithm generates numerous solutions and then categorizes the best chunk of solutions in terms of their befitting feasibility parameters.

2.2 Available Energy Resources

Renewable energy resources considered for our case study location Thuisa Para, Bandarban (21.765151° N, 92.532815° E) are solar and wind. HOMER can directly import the Global Horizontal Irradiation (GHI) Resource data for Thuisa Para from the NASA Prediction of Worldwide Energy Resource (POWER) database. The Global Horizontal Irradiation (GHI) Resource is used to calculate flat-panel PV array output. GHI is the sum of beam radiation (direct normal irradiance or DNI), diffuse irradiance, and ground reflected radiation [7]. The geographical wind resource database is also accessible by HOMER. Fig. 2.2 shows the geographical location of the Thuisa Para hybrid Micro-grid.

Figure 2.3: Project Location for Thuisa Para hybrid renewable energy microgrid

Pukur Para (22°1.2’ N, 92°32.8’E), Bandarban was the specific geographical Position of the case study location. The GHI (Irradiation) resources’ data for the specific location of Pukur Para, Bandarban in Bangladesh. This solar irradiance data is provided by the POWER database from NASA. For calculating floating PV array output, the HOMER Pro simulator, solely depends on this crucial data [7].

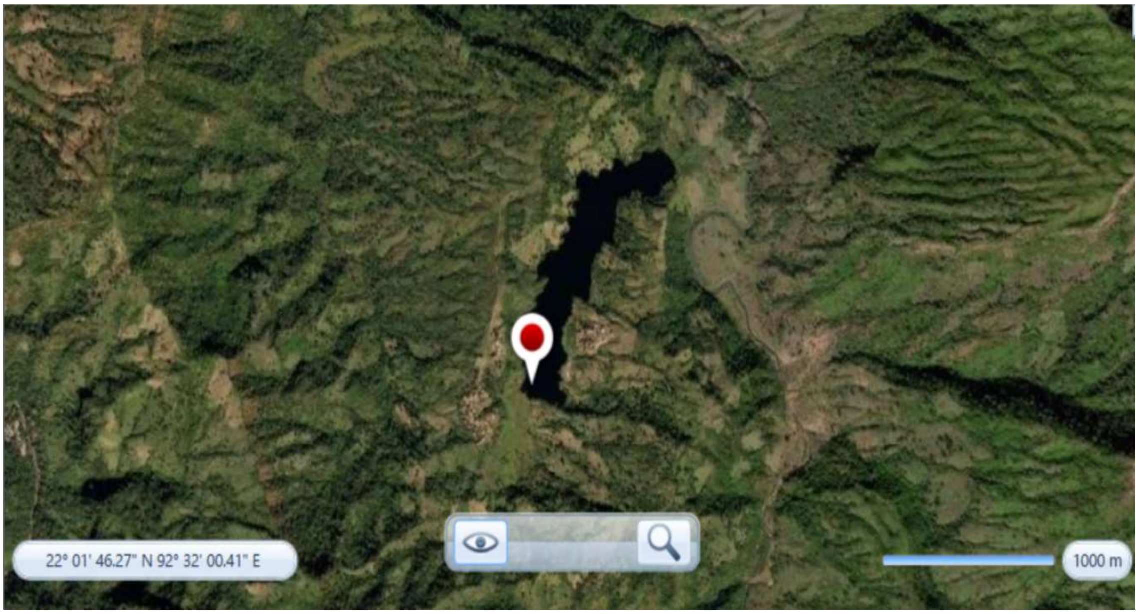

Figure 2.4: Project Location for Pukur Para microgrid

2.3 Load Profile

The community load profile has been created through a field survey to Thuisa Para, befitting the indigenous lifestyle of the community. The community holds about 75 family houses. Firstly, the load profile for one house was created to meet the peak month's load demand. The found daily load average is 6.59 kWh/day for each house, which can be multiplied by the total number of houses to find the daily community load average. The community load average input given in HOMER is (6.59 X 80 = 527.2 kWh/day) 530 kWh/day approximately, and the daily peak load found is 55.66 kW. Then this peak month's load profile has been taken as a standard for the whole year (depicted in Fig. 3), and the micro-grid has been designed (in HOMER) to meet the community load consisting of 80 houses. The reason behind this is to ensure the ultimate durability of the micro-grid in terms of energy supply.

Table 2.1 Daily Maximum Load Profile for 1 Family in Thuisa Para

Load name	Number of loads	Wattages (W)	Usage time (h)	Daily demand (KWh)
Fridge	1	120	24	2.88
Lamp(Normal)	2	2 × 40= 80	6	0.48
TV(LED)	1	100	5	0.5
Fan	3	3 × 75= 225	5	1.35

Lamp(LED)	3	3 × 10= 30	6	0.18
Power point(Socket)	3	3 × 100= 300	4	1.2

This approach enables the micro-grid to meet a few additional loads if necessary, without any expansion. Also, energy demand may increase a bit for each house as time passes by a little and the community adapts to the electricity-oriented lifestyle. Additionally, doing so prevents the micro-grid from not meeting peak demand during a bad weather condition. For considering the effect of randomness, the day-to-day and time-step-to-step value is taken as 5%.

Table 2.2 Component Specifications

Component Type	**Name**	**Rated Capacity**
PV Panel	LONGi Solar LR6-72PB	0.37 kWh
Kinetic Battery	BAE SECURA SOLAR 12 PVS 1800	2.93 kWh
Converter	Sinexcel PWG-50	50 kW
Wind Turbine	Eocycle EO10	10 kW
Generator	Generac 50kW Protector	50 kW

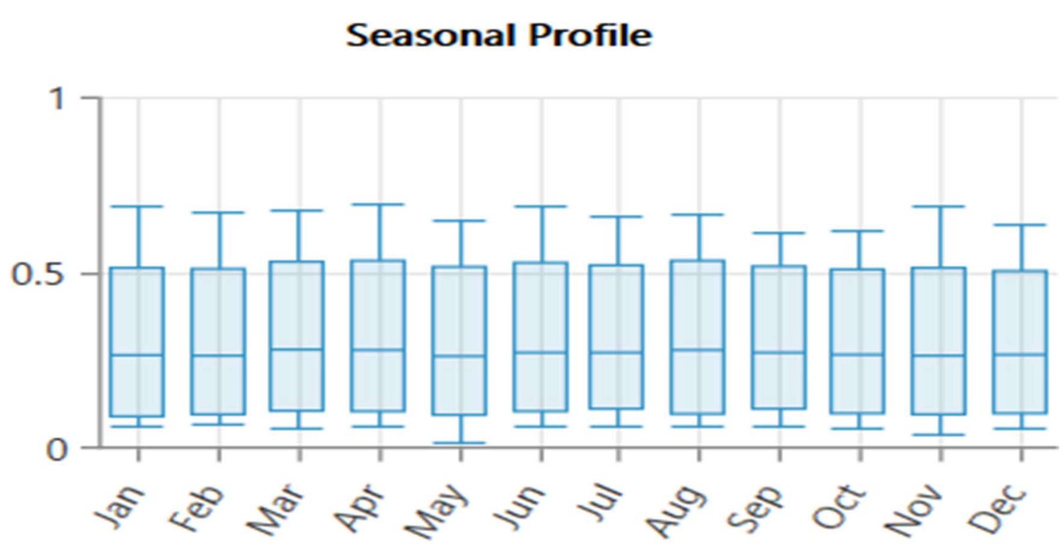

Figure 2.5: Hourly load consumption for 1-family in Thuisa Para (Y-axis represents kW)

Fig. 2.6 presents the load profile for each home for Pukur Para, vividly. This load profile data has been gathered through a field survey to the location. This is to be kept in mind that, the load profile was designed using the peak month's demand. This approach ensures better reliability of the hydrogen based hybrid microgrid.

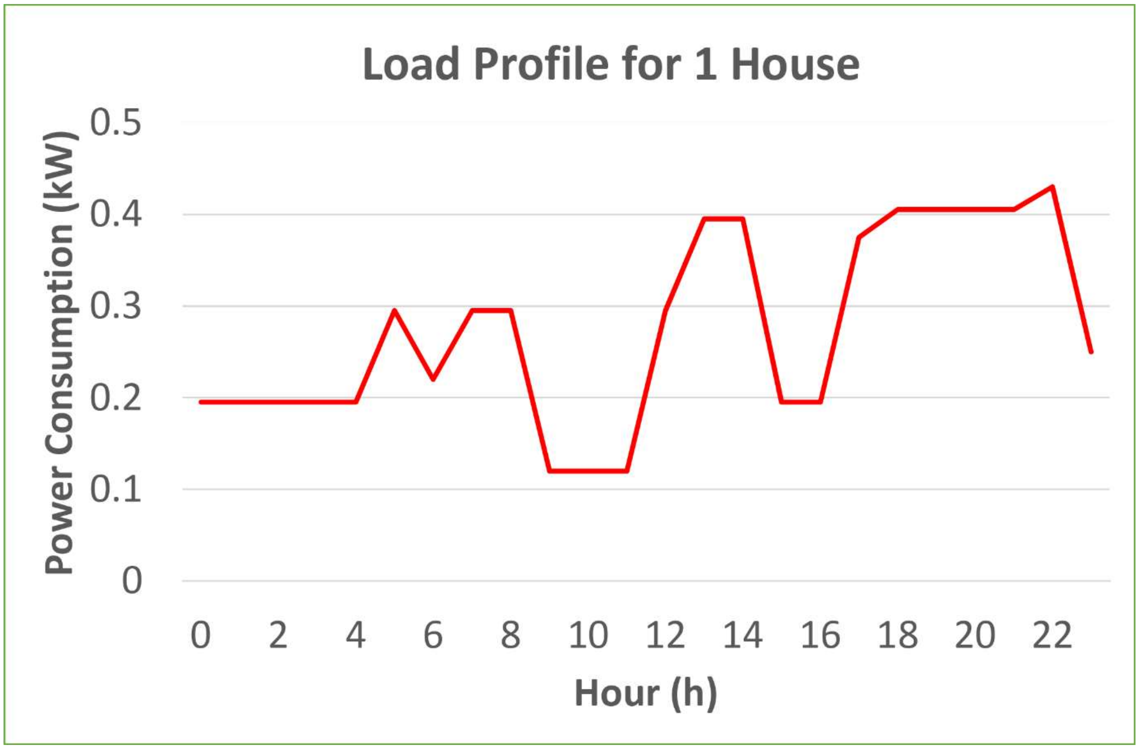

Figure 2.6: Load Profile for Pukur Para

2.4 Facts Regarding the Fuel Cell

Hydrogen is a versatile energy carrier that can be employed to meet almost any end-use energy requirement. The fuel cell is an efficient energy conversion device. The ability to harness and use hydrogen's power is crucial. Static fuel cells can be used for backup power, remote current generation, distributed electricity generation, and cogeneration of electrical energy (the utilization of the extra amount of heat generated throughout the generation of electricity for other purposes) [14].

An electrolyte is sandwiched between two electrodes, an anode and a cathode, in a single fuel cell. Bipolar plates on both sides of the cell assist in gas distribution and serve as current collectors. Hydrogen gas passes via connections to the anode of a Polymer Electrolyte Membrane (PEM) fuel cell, which is commonly considered as the most promising for light-duty transportation [15]. A catalyst causes hydrogen molecules to separate into protons and electrons. Only protons are allowed to enter through the membrane. That is how it generates power.

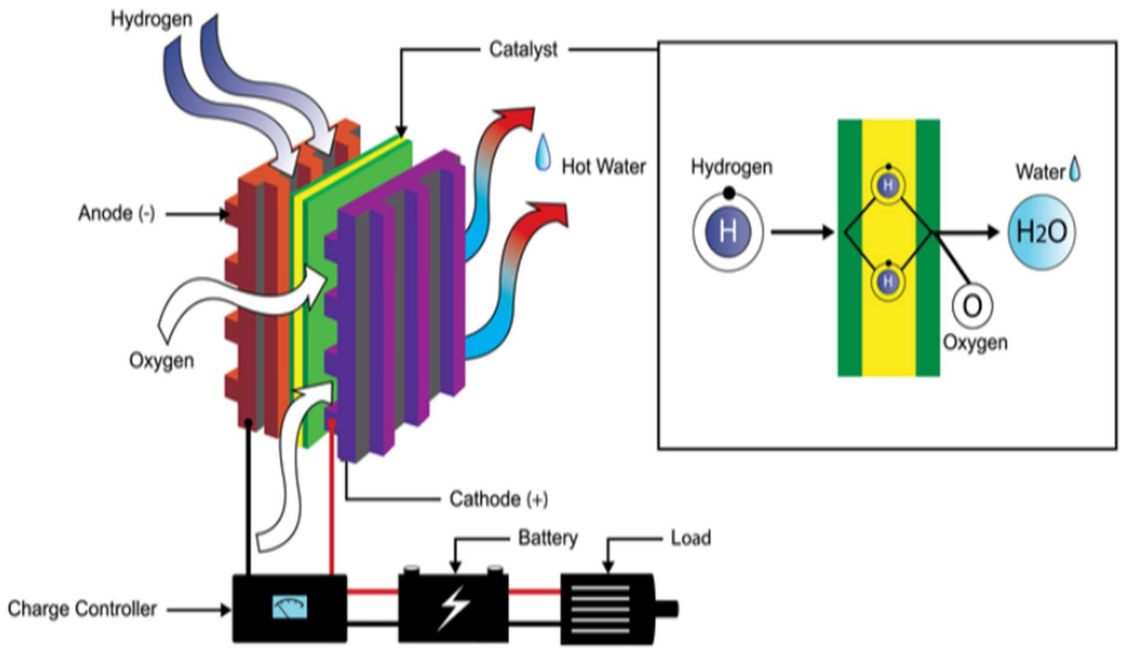

Figure 2.7: Hydrogen fuel cell working mechanism

2.5 Importance of using a Hydrogen Fuel Cell

Fuel cells directly convert the chemical energy in hydrogen to electricity, with pure water and potentially useful heat as the only byproducts. Hydrogen-powered fuel cells are not only pollution-free, but also can have two to three times the efficiency of traditional combustion technologies [16].

A conventional combustion-based power plant typically generates electricity at efficiencies of 33 to 35 percent, while fuel cell systems can generate electricity at efficiencies up to 60 percent (and even higher with cogeneration) [17]. In addition, fuel cells operate quietly, have fewer moving parts, and are well suited to a variety of applications.

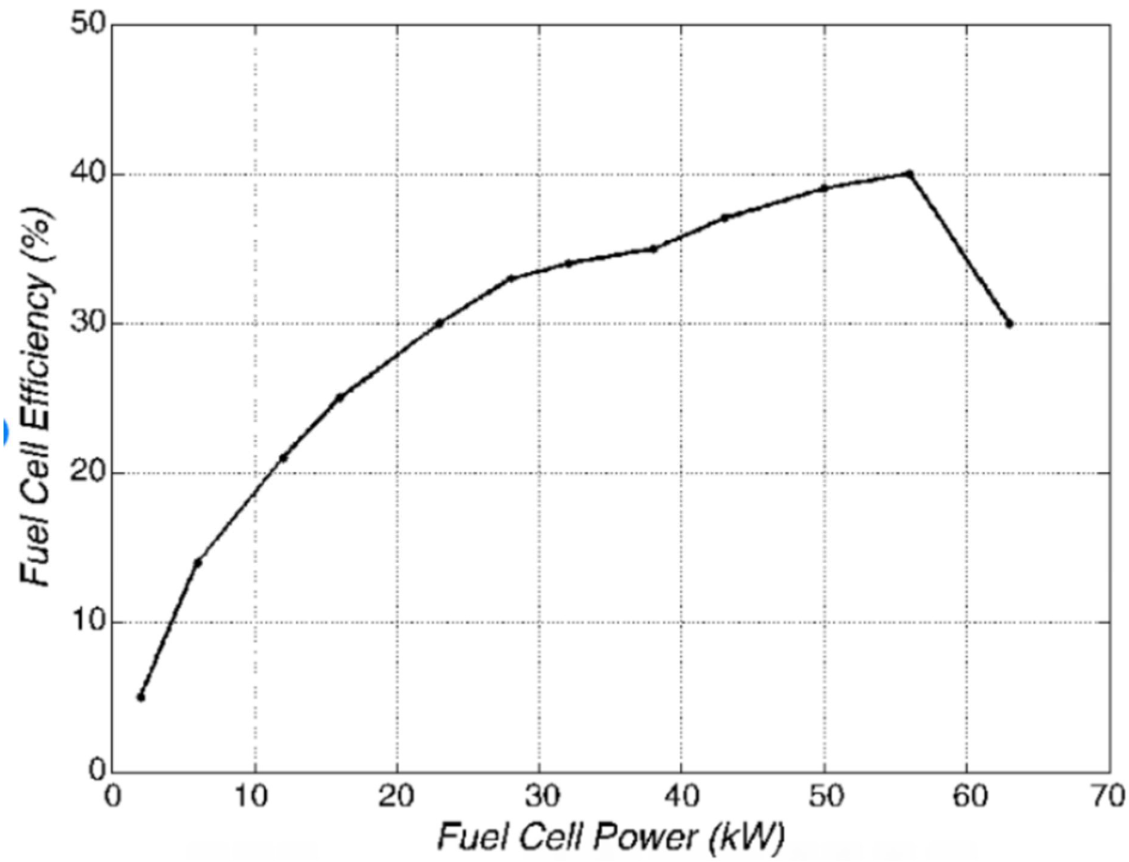

Figure 2.8: Fuel cell efficiency curve

2.6 Chemical Reactions in a Hydrogen Fuel Cell

An electrolyte is placed in between two electrodes, an anode as well as a cathode structure, in a single fuel cell. Bipolar plates on both sides of the cell assist in gas distribution and serve as current collectors. Hydrogen gas passes via channels to the anode of a Polymer Electrolyte Membrane (PEM) fuel cell, which is commonly regarded as the most promising for light-duty transportation. A catalyst causes hydrogen molecules to separate into protons and electrons. Only protons are allowed to enter through the membrane. The protons are transported through the stream of negatively charged electrons which travels over the cell membrane to the cathode via an external connection. This flow of electrons is electricity, which may be used to perform tasks like driving a motor [18].

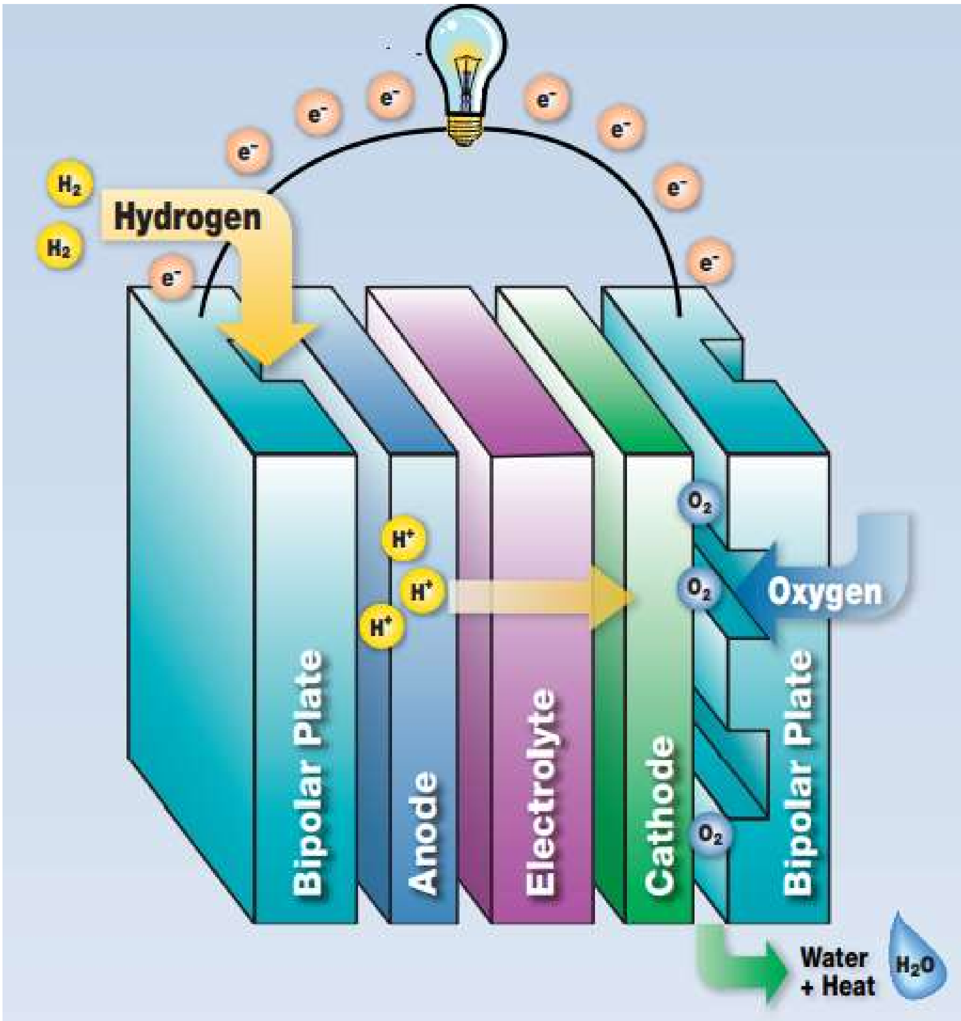

Figure 2.9: Reactions in different sublayers of a fuel cell

On the other side of the cell, oxygen gas travels through channels to the cathode, which is normally obtained from the outside air. When electrons return to the cathode after accomplishing work, they combine with oxygen and hydrogen protons (which have passed through the membrane) to make water. This process is exothermic, meaning it produces heat that can be used outside of the fuel cell [19].

The amount of power generated by a fuel cell is determined by various parameters, including the fuel cell's type, size, operating temperature, and gas supply pressure. A single fuel cell produces about 1 volt or less, which is insufficient for even the most basic uses. Individual fuel cells are connected in sequence to form a stack to enhance the quantity of electricity generated. (The word "fuel cell" is frequently used to refer to both the entire stack and individual cells.)

A fuel cell stack can have a few or hundreds of individual cells placed together, depending on the application.

2.7 Floating PV Structure

In the case of PV array installation, an unavoidable cost is the ground preparation cost. But if the PV arrays are afloat on water, this ground preparation cost can easily be avoided [22]. Therefore, this work aims to design an affordable, as well as a durable microgrid for the Pukur Para community of Bandarban. As the community holds a large open water body, the floating PV array can be integrated with a fuel cell and Hydrogen production unit that can support the loads. This microgrid has the following elements – solar PV panels, Batteries, Hydrogen Tank, Electrolyzer, and Hydrogen fuel cells. Homer pro software was used for all the design and simulation purposes [20].

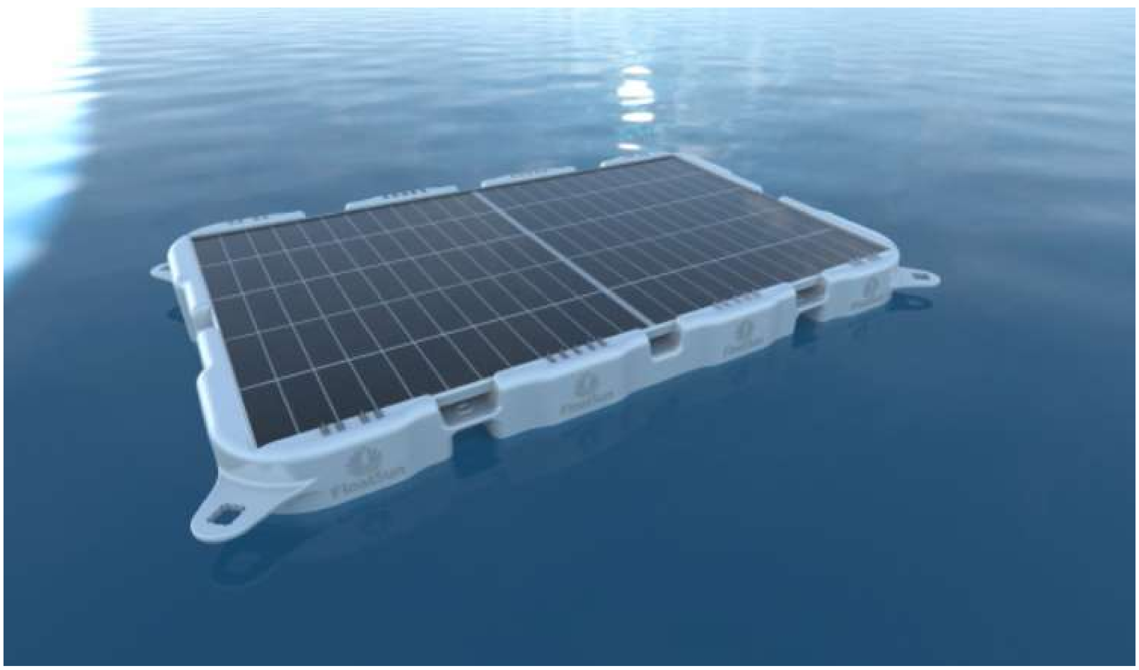

Figure 2.10: Floating PV Structure

As plastic and different type of readily available rubber polymer materials are easily afloat, floating structures can be easily created by using this type of materials. Even vacant plastic container or torn out car tires can be used for creating a makeshift floating structure very easily.

Even coconut shells has good floating capability. An environment friendly approach could be, the use of coconut shells as a floating structure [23].

Chapter 3

Results and Discussion

For modeling the Thuisa Para hybrid renewable energy micro-grid, the used components are solar panel array, kinetic battery, wind turbine, diesel generator, and converter. HOMER simulated a total of 33,112 solutions, considering various component combinations, and categorized 26,446 of them as feasible. HOMER ranked the feasible solutions by the lowest NPC. The best four design solutions considered are – PV array + kinetic battery + converter (PV), PV array + diesel generator+ kinetic battery + converter (PV-Gen), PV array + wind turbine + kinetic battery + converter (PV-Wind) and PV array + wind turbine + diesel generator + kinetic battery + converter (PV-Wind-Gen). All these systems are thoroughly analyzed, comparing their cost-effectiveness, energy production, and system reliability. It is to be noted that all these design simulations have been simulated, considering the project lifetime to be 20 years. The inflation rate is taken as 5.5%, and the fuel price is taken as $0.77, considering the real scenario of Bangladesh during this work.

3.1 Cost Comparison

Fig. 3.1 depicts a comparison of different costs for each type of system configuration considered in this work. Amongst the four combinations, the design solution termed PV requires the lowest NPC ($478,008), and PV-Wind-Gen requires the highest ($658,652). But both PV-Gen and PV-wind require investing quite similar amount of NPC ($565,690 and $569,914, respectively). The cause behind this is, for PV-Gen & PV-Wind, the accounted costs are similar to some extent. Fig. 4, makes it evident that the PV-Wind-Gen configuration requires investing the highest amount of initial capital, whereas PV-Wind requires the lowest ($377,786 and $319,463, respectively). The PV-Gen configuration requires $336,463 as initial capital. Although the PV configuration has the lowest NPC value, it is noticeable that it needs to invest the second highest amount of initial capital. The PV system design requires spending the lowest operating cost per year ($6476) and PV-Wind-Gen the most elevated amount ($13,355). Both PV-Gen and PV-Wind systems' yearly operating costs are similar enough ($10,900 and $11,909 consecutively), but way higher than the PV system.

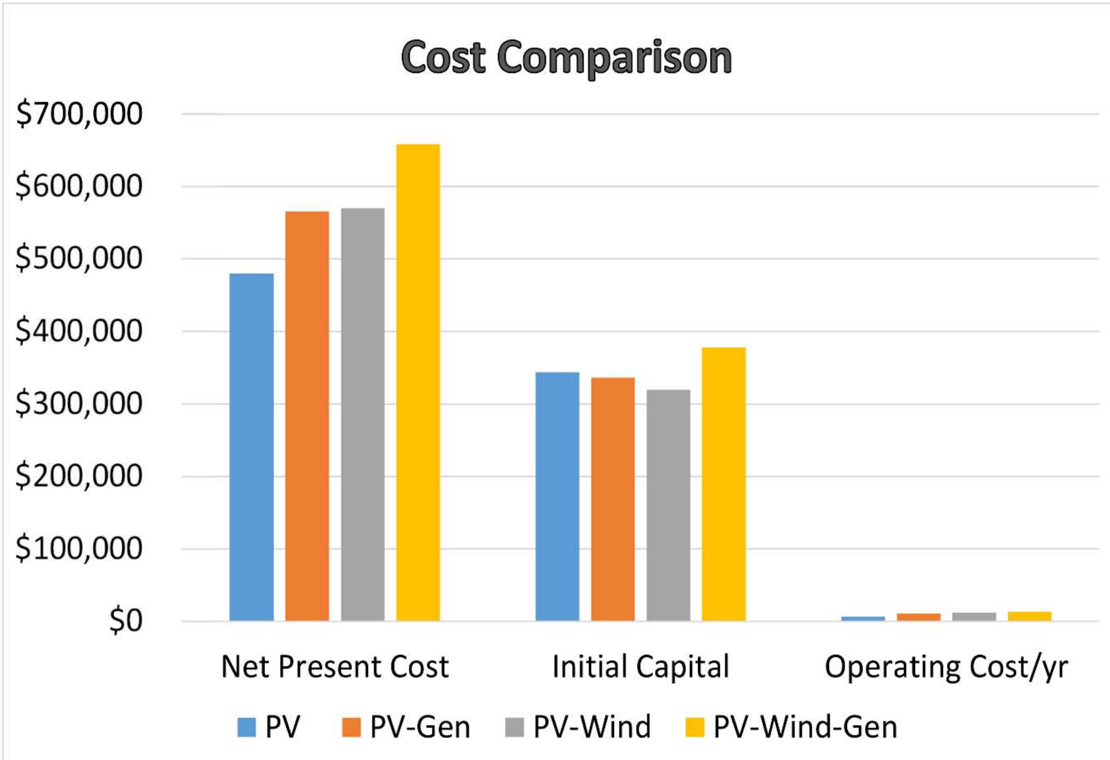

Figure 3.1: Cost comparison

3.2 Energy Production Comparison

The energy production comparison is given in Fig. 3.2. In both PV and PV-Wind, the predicted energy production is not so different from each other (246,364 kWh/yr and 254,090 kWh/yr). This similarity is due to the low energy contribution from the wind turbine to the PV-Wind system. The PV-Gen configuration stands out from the others in the Fig. 5 as the system is projected to produce the highest amount of energy per year (322,526 kWh/yr). Even the PV-Wind-Gen system produces less energy yearly than the PV-Gen system. Hence, it is vivid that the PV-Gen system outperforms all the other design choices in yearly energy production.

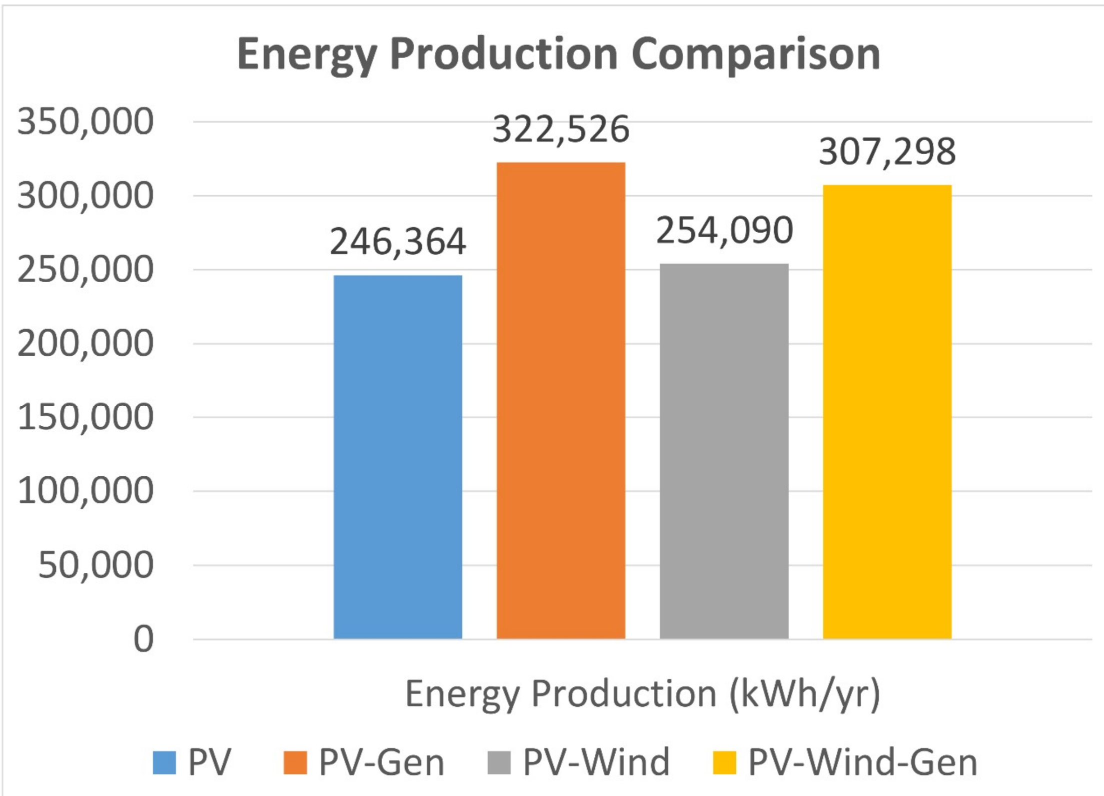

Figure 3.2: Energy Production Comparison

3.3 LCOE Comparison

In Fig. 3.3, the Levelized Cost Of Energy (LCOE) is compared for all the considered system types. The lowest LCOE value is projected for the PV system and the highest for the PV-Wind-Gen system. The PV-Gen system's LCOE is $0.14 per kWh, and in the PV-Wind system, the LCOE is $0.16 per kWh. From all the results mentioned so far, it is a noticeable fact that the PV-Gen system not only produces the most significant amount of energy each year but also has an affordable LCOE value.

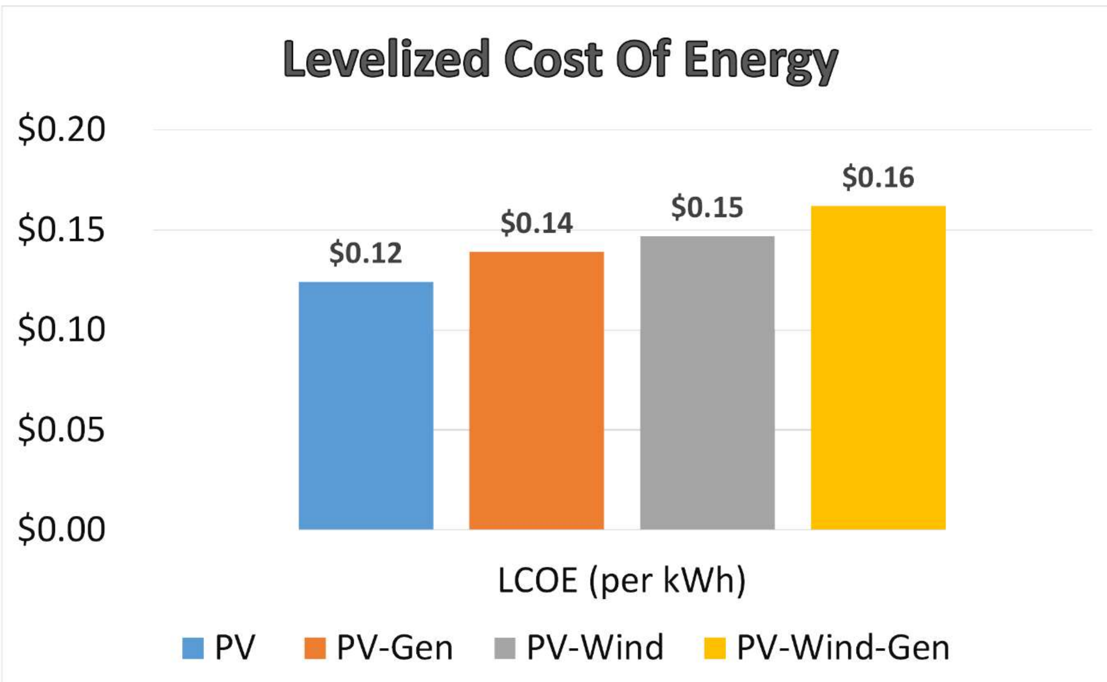

Figure 3.3: LCOE Comparison

3.4 State of charge and Other Related Factors

If going for the 100% solar resource-dependent PV system is an option, Fig. 3.4 gives an essential insight into the system's reliability. In Fig. 3.4, the State Of Charge of the integrated battery string connected to the DC-bus is depicted for each day of the year as well as each hour of the day in the exact figure (simulated by HOMER). Fig. 3.4 represents that, during the mid and later mid part of the year, the battery is at a state of low charge percentile (mostly between 20% to 36%). During the rest of the period of each year, the battery charge percentile remains healthy. It is to be kept in mind that the state of charge of the battery string solely depends on the energy production of the solar panels. From the beginning of June till mid-September, the whole region of Bangladesh, especially the hilly areas, is subjected to significant rainfall. As the clearness index of the sky becomes lower (for cloudiness), so as the production of energy from the solar panels. All these results in a low percentile 'State Of Charge' of the battery. Hence, Fig. 3.4 addresses a critical reliability issue for the PV system during the months of heavy rainfall.

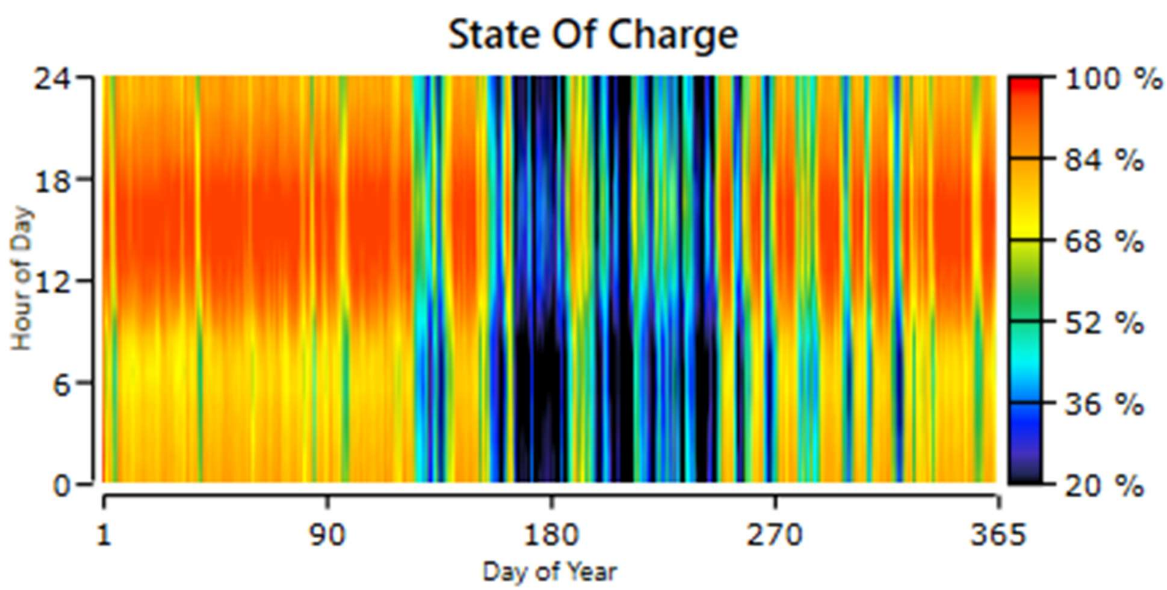

Figure 3.4: State of charge of the battery

All the aforementioned findings of this paper clarify that the PV-Gen system design is the most feasible solution considering all the economic and durability concerns. Looking at various costs associated with the project (Fig. 3.1), the PV-Gen system seems to be the best option for implementing in Thuisa Para, considering all the additional benefits (reliability & affordability) this choice will be able to provide.

Then, delving deeper into the properties of the proposed PV-Gen system, a multiyear sensitivity analysis regarding NPC of the hybrid microgrid has been done, as depicted in Fig. 3.5. For the investigation, the generator runtime considered in HOMER is a minimum of 120 minutes per day. The assumed project lifetimes in HOMER are 10, 15, 20, and 25 years respectively. This sensitivity analysis may assist in choosing the suitable project lifetime for the microgrid, depending on the budget, as it gives a clear picture of the NPC for different lifetime durations.

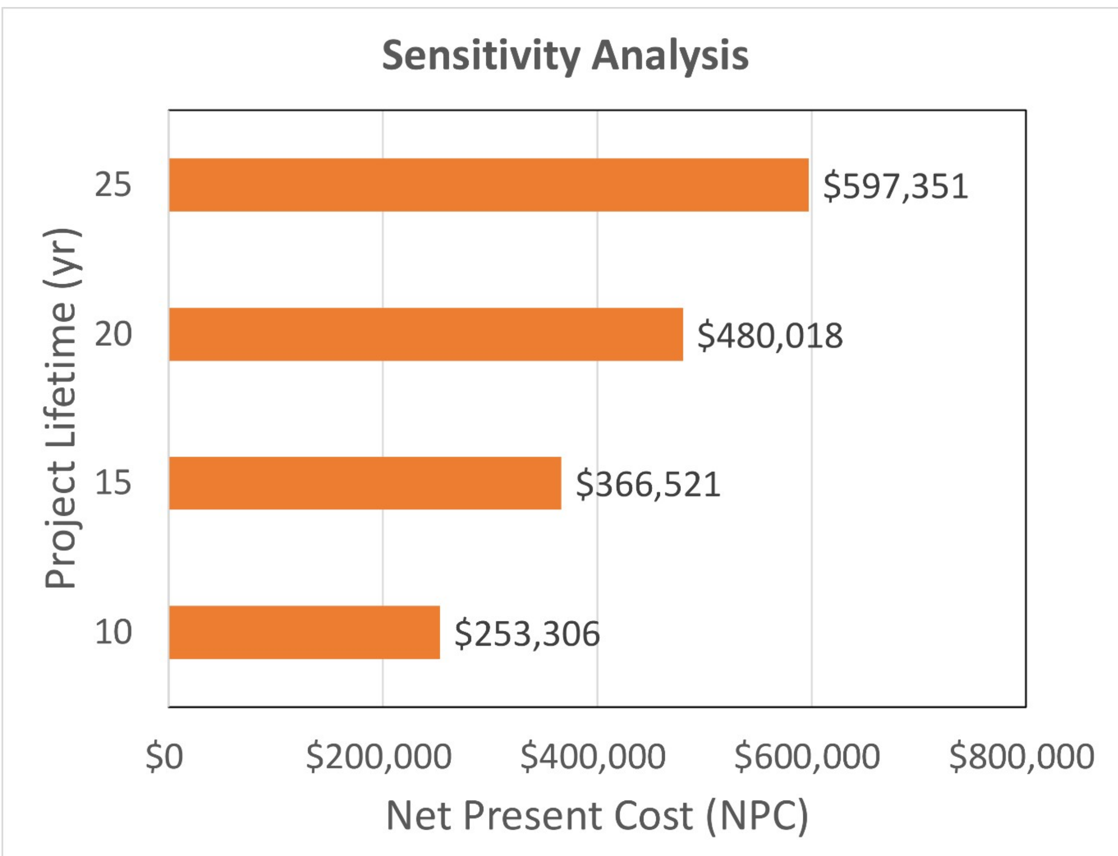

Figure 3.5: Sensitivity Analysis

3.5 Findings of Pukur para

The Pukur para hydrogen based microgrid location provided adequate amount of solar resources. The considered components are namely- floating PV array, solar batteries, hydrogen fuel cell and an electrolyzer. An additional hydrogen gas tank was integrated in the simulation model for using it as a mean of energy storage. Produced hydrogen, from the electrolyzer, will be sucked into the hydrogen tank. This stored hydrogen was later used to produce electricity by the means of a hydrogen fuel cell.

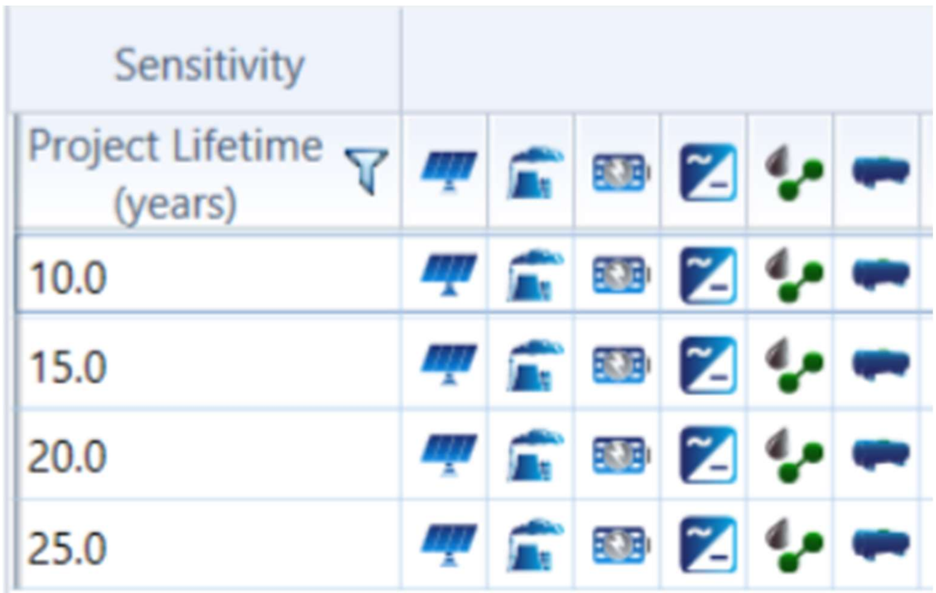

Figure 3.6: Design Combinations of Pukur Para

HOMER Pro presented total 22,317 solutions, in other words, design choices. The number of feasible microgrid solution types were found to be 17,522 in number. HOMER optimizer algorithm ranked the most desirable solutions from best to worst by the lowest COE (Cost Of Energy) and NPC (Net Present Cost) combinations. The best four design solutions are shown in fig. 5. The considered project lifetimes were 10, 15, 20, and 25 respectively.

For considered lifetime as 10, we have the highest COE and lowest NPC as shown in fig. 6. The projected NPC is $438,068. The levelized cost of energy (COE) was found to be $0.236. It is to be noted that, for all the four prime design considerations, initial capital was exactly the same, that is, $684,223. For considered lifetime as 15 years we have an even larger NPC value ($551,733). But the cost of energy (COE) is significantly downsized if we consider the lifespan to be 20 years, the net present cost of energy (COE) is significantly downsized.

If the lifespan is considered to be 20 years, the net present cost (NPC) increases even further. The cost of energy, again gets a bit downsized for this case ($0.175). Lastly, for 25 years as the considered lifetime, we get the largest value of net present cost (NPC). The found value of the NPC is $784,209. But this may turn out tobe the most considerable design choice as we have the lowest cost of energy in this case ($0.163). Although we will have to bear $3758 as the operating cost, this can be regarded as the most feasible solution only because of the lowest value of COE amongst all.

NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)
$438,068	$0.236	-$23,978	$684,223
$551,733	$0.196	-$8,501	$684,223
$666,243	$0.175	-$854.93	$684,223
$784,209	$0.163	$3,758	$684,223

Figure 3.7: COE Comparisons of Pukur Para

For additional considerations, the minimum runtime of the fuel cell was considered to be 180 mins per day. Also, the lowest allowed level of hydrogen tank was set to be 20%. All these findings, gives a clear picture about the design choices for implementing a floating hydrogen fuel cell based hybrid microgrid in Bangladesh.

Chapter 4

Conclusion

This paper scrutinized the prospects of a hybrid renewable energy microgrid in Thuisa Para, Bangladesh, considering the available design choices' economic aspects and energy production capabilities by using HOMER software. PV solar panel array, battery, wind turbine, diesel generator, and converter – all these components have been put into various combinations. The best four design choices found through the optimization process of HOMER have been analyzed regarding their cost-effectiveness and energy supply capabilities. It has been found that integrating a wind turbine in the Thuisa Para microgrid is not economically feasible compared to its energy output. Energy access can be ensured for the Thuisa Para Indigenous community by a proper realization of the findings of this paper which can massively upgrade their socio-economic condition.

This paper reveals that Thuisa Para has a great solar energy potential. Although going for the PV-only microgrid has been seemingly an economically attractive option, this paper addresses a vital reliability issue concerning this specific design choice. One of the most crucial findings of this work is that an additional diesel generator integrated with the PV-only microgrid ensures excellent reliability and produces the highest energy yearly amongst the other design choices. Moreover, LCOE, NPC, and other economic aspects for this PV-Gen hybrid microgrid have been quite affordable compared to the different design considerations. Finally, a sensitivity analysis regarding this proposed PV-Gen hybrid renewable energy microgrid project's lifetime has been done to get a clear idea about the NPC for various lifetime durations. In future, we wish to explore the design considerations using an effective optimization algorithm, which may prove to be more efficient than HOMER's algorithm. We wish to test the outcomes using a different algorithm than the HOMER Optimizer itself for example, Ant-lion optimizer, Grey-Wolf optimizer etc.

In case of Pukur para, this work scrutinized all the possible outcomes, and achived quite a good LCOE in all the cases considered. This also highlights that, Pukur Para is practically suitable for integrating a Hydrogen fuel cell along with a floting PV structure which will result in downsizing the costs massively. As the user end supply will be given using DC connection, there will be no conversion losses involved and the overall system efficiency and durability will remain intact.

References

[1] Desa,U. N. “Transforming our world: The 2030 agenda for sustainable development,” 2016.

[2] Md Nuruzzaman, Raju Ahamed, Anan Ashrabi Ananno & A. N. M. Amanullah Tomal Mahadi Hasan Masud, “Renewable energy in Bangladesh: current situation and future prospect,” International Journal of Sustainable Energy, pp. 3-6, 2019.

[3] Toshihiko Nakata Makoto Kanagawa, “Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries,” The International Journal of the Political, Economic, Planning, Environmental and Social Aspects of Energy, p. 2-4, April 2008.

[4] Meenakumari.R., Prasanna. P, Saravana Kumar. E, Sarvesh. P Suresh.M, “Design and Development of Optimal Sizing of Integrated Renewable Energy Systems for electrifying the rural areas in Nilgiris District,” International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering, vol. 5, no. 3, March 2017.

[5] Md Fatin, Sk A. Shezan, Jannati Nabiha Nur, and Md Shafiul Islam Ishraque, “Optimal Sizing and Assessment of an Islanded Photovoltaic-Battery-Diesel Generator Microgrid Applicable to a Remote School of Bangladesh,” Engineering Reports, 2021.

[6] Yanuar Z., Nur Anisah Aziera Abdul Halim, and Mohd Hafiez Izzwan Saad Arief, “Optimization of hybrid renewable energy in Sarawak remote rural area using HOMER software,” in International UNIMAS STEM 12th Engineering Conference (EnCon), 2019.

[7] Energy, H. O. M. E. R. “Homer pro version 3.7 user manual,” HOMER Energy: Boulder, CO, USA, pp. 10-117 2016.

[8] Temiz, Mert, and Nader Javani. "Design and analysis of a combined floating photovoltaic system for electricity and hydrogen production." International Journal of Hydrogen Energy 45.5 (2020)

[9] Aziz, Shakila, and Shahriar Ahmed Chowdhury. "Performance evaluation of solar mini-grids in Bangladesh: A two-stage Data Envelopment Analysis." Cleaner Environmental Systems 2 (2021).

[10] Posso, F., A. Contreras, and A. Veziroglu. "The use of hydrogen in the rural sector in Venezuela: Technical and financial study of the storage phase." Renewable Energy 34.5 (2009)

[11] Masud, Mahadi Hasan, et al. "Renewable energy in Bangladesh: current situation and future prospect." International Journal of Sustainable Energy 39.2 (2020)

[12] Choi, Y. J., Oh, B. C., Acquah, M. A., Kim, D. M., & Kim, S. Y. (2021). “Optimal Operation of a Hybrid Power System as an Island Microgrid in South-Korea.” Sustainability, 13(9), (2021)

[13] Sharif, Shariful Islam, et al. "The prospect of renewable energy resources in Bangladesh: A study to achieve the national power demand." Energy and Power 8.1 (2018)

[14] Midilli, Adnan, et al. "On hydrogen and hydrogen energy strategies: I: current status and needs." Renewable and sustainable energy reviews 9.3 (2005)

[15] Grujicic, M., and K. M. Chittajallu. "Design and optimization of polymer electrolyte membrane (PEM) fuel cells." Applied surface science 227.1-4 (2004)

[16] Siegel, C. "Review of computational heat and mass transfer modeling in polymer-electrolyte-membrane (PEM) fuel cells." Energy 33.9 (2008)

[17] Hwang, Jenn-Jiang. "Effect of hydrogen delivery schemes on fuel cell efficiency." Journal of Power Sources 239 (2013): 54-63.

[18] Larminie, James, Andrew Dicks, and Maurice S. McDonald. “Fuel cell systems explained”. Vol. 2. Chichester, UK: J. Wiley, 2003

[19] Blomen, Leo JMJ, and Michael N. Mugerwa, eds. Fuel cell systems. Springer Science & Business Media, (2013)

[20] Cazzaniga, Raniero, and Marco Rosa-Clot. "The booming of floating PV." Solar Energy 219 (2021): 3-10.

[21] Hossain, Muhit, Abdullah Al Kayes, and Rayhan Suny. "Prospects and Design Assessment of a Hybrid Renewable Energy Microgrid for the Thuisa Para Indigenous Community in Bangladesh." 2021 IEEE 9th Region 10 Humanitarian Technology Conference (R10-HTC). IEEE.

[22] Ohkusu, M., and Y. Namba. "Hydroelastic analysis of a large floating structure." Journal of Fluids and Structures 19.4 (2004)

[23] Fauzan, N., et al. "Development of coconut-based floating structure for stand-alone solar PV system in the tropics." III International Conference on Agricultural and Food Engineering 1152. (2016)