Islamic University of Technology

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Techno-economic feasibility study on Hybrid renewable energy for electricity and hydrogen production in Batukunku village, The Gambia

Thesis presented in consideration of partial fulfillment for the requirements of the degree of

BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONICS ENGINEERING/TECHNICAL EDUCATION

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DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for an academic qualification certificate/diploma or degree

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The thesis titled "Techno-economic feasibility study on hybrid renewable energy for electricity and hydrogen production in Batukunku village, The Gambia" submitted by Modou Lamin Ceesay (200032204), Haruna A. bah (180021348), Ebrima Badjie (200032202), and Abideen Hydara (200032201) has been recognized as having fulfilled the requirements for the Bachelor of Science in Electrical and Electronic Engineering/Technical Education in a satisfactory manner.

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We gratefully acknowledge the support by the Gambia bureau of statistics (GBoS), for providing us information regarding the number of households and population in Batukunku village, Kombo South of The Gambia.

Contents

List of tables

Abstract

Rural electrification issues are the main hurdle to achieving universal access to electricity in The Gambia. In this paper, a case study of the community of Batukunku village, which is situated in the Kombo south of The Gambia, is used to show the techno-economic viability of a stand-alone hybrid renewable energy system (HRES) to meet the electric and hydrogen load for isolated rural communities. The system design that is most economical is found through simulation and optimization, and the net present cost is calculated. A hybrid photovoltaics/wind turbine/a backup Diesel generator/renewable energy system is suggested and examined for an off grid scenario. The primary objective is to identify the design that can most effectively meet the need for electricity and hydrogen. While also being acceptable from a fiscal and environmental perspective. The outcome results indicated the net present cost (NPC), cost of electricity (COE), and cost of hydrogen (COH) which is \$4.27M, \$0.469/kWh, and \$18.7/kg, respectively. The carbon footprint with CO_2 emission avoidance of around 151,751 kg/year. The results proved that implementing a hybrid power system might be a stable and financially viable strategy for achieving social and environmental benefits in remote rural electrification.

CHAPTER 1

INTRODUCTION

Currently, 621 million Africans, or more than two thirds of the continent's population, are without electricity [1]. An average of 20% is linked to the primary grid, and this is exclusive to sub-Saharan Africa. Achieving development requires having access to energy, which has a big impact on things like enhanced healthcare, telecommunications, and water supplies. Energy availability will also boost the expansion of remote areas, the provision of new jobs, and the establishment of enterprises that generate value. Notably, the region with the most prospective for energy from renewable sources is Sub-Saharan Africa, which has a 10 TW solar resource, a 1300 GW wind resource, and a 15 GW geothermal resource. Utilizing clean energy to address the region's energy issues therefore appears reasonable. It's essential for consideration, however, due to the region's abundant fossil and biomass reserves, investment in the renewable energy industry is hesitant, which is made worse by factors like grant financing reliance, variable wind speed, and cloudiness that have a significant impact on its development [2]. Africa's power industry may increase its use of renewable energy by 50% in 2030, which would result in 310 million tons less CO_2, will be released into the atmosphere by 2030 than under the baseline scenario [3]. Due to considerations like low power usage per person and sparse population, a main grid solution will be highly expensive in remote areas [1]. It is more affordable to use a solar off-grid setup than constructing a main grid in the sub-Saharan African countries, due to its abundance of solar radiation and Gambia is part of them. It should be mentioned that integrating a solar power system with one of the diesel-powered micro-grids already in place can save energy costs by as much as 50%. This is because fewer batteries are used, which lowers the system's overall cost by 40% [1]. Africa has the lowest per capital energy consumption in the world as a result of underdeveloped transmission facilities at the national and regional levels. Nevertheless, most African countries have average electricity prices that are perhaps twice as cheap as those in other wealthy countries. The generation of electricity should increase exponentially in order to meet regional objectives such as lowering energy access costs and easing demand constraints. Despite this, less than 1% of power is produced by solar and wind power. This is due to factors such as high investment prices, the unpredictability of these sources, the difficulty of connecting them to the grid [4].

The Gambia has the ability to utilize renewable energy sources like wind, solar, hydro, biogas, biomass, and geothermal energy that are widely used in other nations. Even though the majority of these technologies appear to have reasonable potential based on the scant data currently available, more thorough research would be needed to conclusively identify the most affordable options.

The African Development Bank awarded the Gambia government a grant in 2004 to carry out research on renewable energy. For the first time, the study offered 30-meter-high wind speed readings for a period of more than a year. Before that, the Department of Water Resources measured the sun's rays and the wind, albeit from a lower vantage point. All around the country, especially in the hinterland, wind conditions are mild (below 4.0 m/s at 30 m height), primarily due to The Gambia's latitudinal proximity to the equator. Due to the open wind flow coming from the sea in the west, the wind condition is a little greater along the coast (for example, at Kanuma and Jambanjelly) than in the interior (3.4 m/s to 4.2m/s at 30m measurement height) [5]. From January through May, wind speeds tend to be higher, and from June through December, they tend to be lower. Even though the modest wind speeds aren't ideal for producing electricity from wind on an economically sound basis, using wind energy effectively along the shore may be feasible.

The Gambia has two wind turbines, one of which is a 1 kW unit located in Gunjur and the other of which is a 150 kW unit that powers the complete village of Batukunku and occasionally, produces surplus energy that is resold to the NAWEC (National Water and Electricity Co. Ltd) grid through a power purchase agreement.

Another option is solar radiation on a tiny scale. Currently, The Gambia has tiny solar photovoltaic (PV) and solar thermal systems installed, most frequently at rural hospitals, schools, and private homes. The Gambia has a great potential for energy production due to its average annual solar insolation of 4.5–5.3kWh/m^2–day. The cost of solar energy systems is still expensive; however recent usage of solar power technologies in many nations worldwide has had a favorable impact on lowering the installed prices of new solar PV systems. It is predicted that such a system will eventually provide Gap Analysis and Rapid Evaluation of Energy Efficiency for all - The Gambia has a financially viable option for the sustainable development of The Gambia.

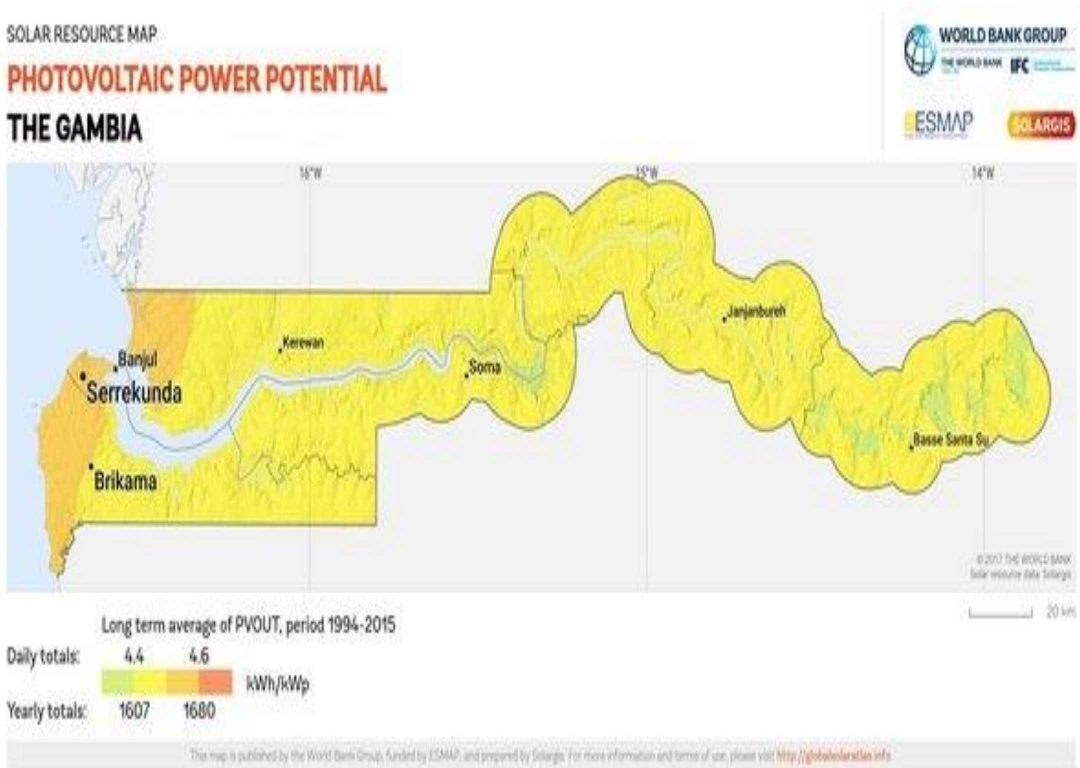


Figure 1.1 Photovoltaic power potential in The Gambia

Therefore, in this research, we looked at an HRES that included a wind turbine and solar panels, together with backup components, in the same village as Batukunku. In order to boost system dependability and condense the size of the system, Renewable energy devices use backup components. Diesel engines and batteries are frequently used as backup components, which has the benefit of collaborating with other energy resources and minimizing dependence on grids and other reliant on fossil fuels as a source of energy [6]. The HRES has evolved into a least expensive method to supply dependable energy for rural and isolated areas, due to improvements in utilizing renewable energy sources and the decrease in the price of related components [7].

The element that is most abundant in the universe is hydrogen, and accounts for more than 90% of all materials. Since it is so abundant and fossil fuels have negative environmental effects, hydrogen is the perfect fuel for the world's energy needs in the future. Although it cannot be produced from scratch, hydrogen can be produced in many ways from other materials. A range of energy sources, including sources of basic energy, such includes the supply of additional electricity and crude oil (those produced from main energy sources), and renewable energy sources comprising wind and solar, can be used to create hydrogen. A potential contender for clean energy, hydrogen is a gas that can be created by electrolysis of water or by the breakdown of hydrocarbon fuels. A long-lifetime energy storage device is needed to solve issues like seasonal or daily variations in solar and wind energy. Due to its tremendous efficiency, hydrogen, one of the cleanest, lightest, and most efficient fuels, is ideally suited for energy storage [8]. However, the expense of the start-up cost is the main problem with this technology. [9]. Findings indicate the possible energy generation and storage capability of hydrogen-based systems in nations with a great solar energy potential [8]. The majority of researchers advocate using hydrogen storage systems. Around 45–50 million tons of hydrogen are produced annually around the world for use in industry and commerce [10]. However, a large portion of energy is manufactured using fossil fuels, nuclear power plants, or electrolysis using electricity provided by coal, natural gas, and petroleum. The market for producing hydrogen is predicted to grow from $103.2 billion in 2017 to $ 207.48 billion in 2026.

CHAPTER 2

Literature review

2.1. Various methods of electrical and hydrogen production

Numerous studies have been done on renewable energy systems that generate hydrogen and electricity using various alternative energy source combinations. Many of them have concentrated on reducing initial and maintenance costs. A research carried to examined the processes for producing hydrogen with help from solar energy [11], Four techniques of producing hydrogen were studied in that article: Thermochemical process, solar energy, photo-biological production, focused solar and heat energy. According to a report, PV-based hydrogen production still has a lot of obstacles to overcome, such as expensive construction, maintenance, and repair costs, and that in order for it to be used more widely, it must reach increased energy economy, dependability, and safety. The findings also demonstrated the need for additional study into solar energy production techniques with a view to improving efficiency and reducing prices, designed software to assess the suggested system after supplying guidance on how to size a freestanding photovoltaic-wind power system. In this study, an algorithm created specifically for this purpose was used to examine all parameters affecting system performance. This article devised a technologically-based economic algorithm that aims to assess a standalone PV-Wind system, increasing efficiency and reducing expenses by determining the correct dimension of the battery storage and solar power system for a given load [12]. A research of a single-mode combined wind-photovoltaic fuel cell technology that will be utilized at the University of Zacatecas, Mexico with the objective of producing electricity and creating hydrogen that can be used to make fuel cells [13]. To improve system dimension, flexible modeling, and control of power through computational simulations in MATLAB software for a single-mode wind-solar-hydrogen combination has been demonstrated [14]. A proposed hybrid system of new energy for rural areas in the South East of Mexico that includes wind, photovoltaic, and hydrogen, and assessed its technical economic viability using artificial intelligence optimization methodologies [13]. Studied the techno-economic efficiency of Sharurah's heterogeneous renewable energy system (HRES), which utilized batteries, pumped hydro-based retention, and hydrogen-based storage devices [15]. The effectiveness of PV-based and solar-powered thermal hydrogen generation methods was assessed as well as other methods of energy production. The study's findings indicate that Photovoltaic systems are less energy-efficient than solar thermal systems. According to a report, in a solar thermal system, the effectiveness of the concentrating collector is one of the key performance indicators, while in a photovoltaic system; both the ambient and the system's energy efficiency are affected by temperature and solar radiation intensity [16]. An analysis of a solar PV system, researching how each element affects the entire process, and made recommendations for the manufacture of hydrogen [17]. An illustration of a wide range practical application for PV energy systems. They looked into a number of key concerns, including the most reliable simulation models. Grid connectivity difficulties and primary topologies for PV processing were also covered. [18].

2.2. Economic analysis

Performance of a thorough analysis of a hybrid system with a battery storage, solar, wind energy components, and the modeling, evaluation of financial viability, reliability, and various size optimization methods of this hybrid system, such as analytical, iterative, and artificial intelligence, were all investigated by these writers in order to accomplish this goal [19]. Investigate a systems for generating hybrid renewable energy by examining and sizing each component in light of efficiency, economic, and environmental standards [20].

Following the investigation and contrast of two case studies in Oman, it was discovered that the electricity costs for the hybrid systems in Halaniyar and Masirah were 0.222 and 0.182 dollars per kilowatt-hour, respectively. The findings of this study indicate that these areas have a significant capability of using solar-wind energy provided a study of the economics of a 100 MW hybrid energy plant. That produced electricity through a combination of gas turbines, photovoltaics, and hydrogen [21]. A financial evaluation of an innovative hybrid energy system in Ankara, Turkey that combines solar and hydrogen [22]. An economic analysis of hydrogen generation plant using chemical loop reforming. An Aspen plus model was employed in the analysis to gather the necessary thermodynamic information. The findings show that plant outputs and system efficiency are affected by reactor temperature [23].

CHAPTER 3

Methodology

An examination of a village in Kombo south, The Gambia has been examined to show the HRES's potential for producing hydrogen and delivering off-grid electricity in remote locations. The following is an explanation in detail of the methodology for the hybrid power system's optimal design and techno-economic analysis.

3.1 Modeling process of HRES

First, a remote community in The Gambia's Kombo South is located. Then, resources pertinent to the area renewable energy sector, load profiles, technological specifications of system components, pertinent economic inputs, as well as applicable limits, are inputs used in the design of the hybrid power system. After combining the aforementioned inputs, the best outcome is found through simulation and optimization utilizing Hybrid Optimization of Multiple Energy Resources (HOMER). Simulation is used to identify the practical configurations while taking the limitations into consideration for each strategy in the search space. The possible plans are compared to determine which configuration has the lowest NPC. Other outputs from the solutions, besides the system's NPC, include the components' capacities and the system's techno-economic performance, among others. Additionally, Sensitivity studies are performed to evaluate the impacts of changing a few factors on the setup and functionality of the system. The next sub-section of this study elaborates on the economic indicators taken into account.

3.2 The requirements for techno-economic analysis

To assess whether a project is feasible, finances are crucial. Cost of electricity at levelized prices (COE), the NPC, and the GDP are among the economic metrics taken into account in our research. The average cost of Hydrogen (COH) is displayed as follows. Economic output of this model is the total NPC, which is employed to rate every system configurations as a result of optimization. When all profits, such as grid sales income and salvage values, have been subtracted, the remaining costs, known as the total NPC, are what remain. Startup expenses, replacement prices, operating and maintenance (O&M) costs, and fuel costs, penalty charges for emissions, and costs associated with grid power purchases. By adding up all deducted cash flows annually for the project's lifetime, as shown in the study's equation (1), the total NPC of the system is determined [6]

$$C_{NPC} = \sum_{t=1}^{n} \frac{C_t}{(1+)^t} - C_0 \quad (1)$$

where n is the project lifespan in years, C_0 represent the initial capital cost, C_t indicates net cash outflow over the period i, and is interest rate in percent, which may be computed from the nominal interest rate (NIR), i and annual inflation rate (f) as equation (2).

$$i = \frac{i' - f}{1+f} \quad (2)$$

The system's average cost per kWh of electricity generated, or COE, is calculated as follows: equation (3). [6]

$$COE = \frac{C_{ann.tot}}{E_{served}} \quad (3)$$

E_{served} Is the sum of annualized electrical load served, and $C_{ann,tot}$ is the total annualized cost, which represents the annualized value of the C_{NPC}. The capital recovery factor (CRF) is multiplied by C_{NPC} to get the total, which is calculated using the following equations (4)-(5). [24]

$$C_{ann,tot} = C_{NPC} \times CRF(i,n) \quad (4)$$

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (5)$$

In this research, COH stands for the system's cost of supplying hydrogen, which is determined by the following equation (6)

$$COH(i,n) = \frac{C_{ann,tot} - C_{elec} \times E_{electrolyzer}}{M_{hydrogen}} \quad (6)$$

C_{elec} Is the system's electricity cost, and $E_{electrolyzer}$ is the annual electrical energy consumed by the electrolyzer, where $M_{hydrogen}$ denotes the total annual generation of hydrogen.

CHAPTER 4

Case study

4.1 Location description

The year and average temperature highs between 29°C and 34°C in this research, a village Batukunku (13° 19.8'N, 16°48.3'W) is considered, which is located in the southern part of the country called Kombo South, which is one of nine districts of the country's western division. Subtropical weather with lots of sunlight permeates the entire year. There are 262 households and 2945 people living in the community [34]. The major industries in this village are fishing and farming. Other commercial and community services include a community center, an elementary school, a health care facilities, and stores. Resources like solar and wind have a lot of promise for us here.

Figure 4.1 The map of Batukunku.

4.2 Regional resources

NASA's Surface Meteorology and Solar Energy information was utilized to determine the monthly averages for wind speed, temperature, and solar energy. The figures shown below represent the respective tables and graphs of the wind speed, temperature, and average monthly solar energy for the entire year. The region has a high potential for wind utilization, as shown by According to Figure 4.2

Figure 4.2 Wind data.

Figure 4.3 shows the average highest daily solar radiation, which is approximately 7.070 kWh/m^2/day, which happens in April. The average clearness index for the year was estimated to be 0.600, and the yearly average solar radiation was roughly 5.75 kW h/m^2/day.

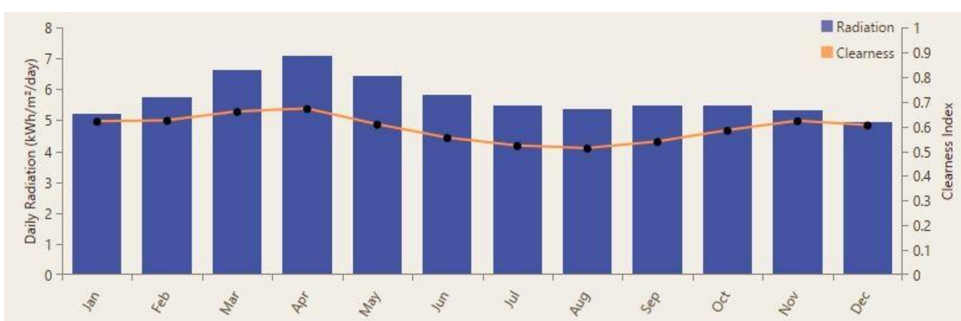


Figure 4.3 Solar GHI resources.

October has the highest average temperature of 27.470°C, which could negatively impact the amount of electricity generated by solar panels.

Table 4.1 Monthly average wind speed data

Month	**Average (m/s)**
January	5.360
Feb	5.400
Mar	5.330
Apr	5.280
May	4.820
Jun	4.420
Jul	4.340
Aug	4.220
Sep	3.440
Oct	3.080
Nov	3.570
Dec	4.650

Table 4.2 Monthly solar radiation data

Month	**Clearness index**	**Daily radiation ($kWh/m^2/day$)**
Jan	0.618	5.220
Feb	0.622	5.740
Mar	0.658	6.620
Apr	0.670	**7.070**
May	0.607	6.440
Jun	0.552	5.820
Jul	0.520	5.480
Aug	0.510	5.360
Sep	0.536	5.460
Oct	0.582	5.490
Nov	0.620	5.330
Dec	0.603	4.920

4.3 Load profile

The village's hydrogen and electrical load demand is evaluated depending on the type of component, amount, and anticipated operating hours, with accessible load chart of comparable rural locations documented in county government serving as a guide. While considering the residents' subjective opinions, each facility's expected electrical loads are predicted. We divide the village's load into two categories, main load and deferrable load, taking into consideration the function of electricity and its usage in order to more effectively Design the system's component capacities. The main load is the immediate electrical demand that the system must meet to avoid unmet demand. A deferrable load, on the other hand, is an electrical load that needs a predetermined amount of energy in a predetermined period of time, but the exact timing is not essential. The primary load is evaluated in this study for two important seasons throughout the year by taking into account the electricity use in residential, community, and industrial services. More information on these applications is provided in Table 4.3. Peak demand for primary load is 222.11 kW, with an average yearly primary load demand of 1625.35kW h/day.

Table 4.3 Demand projections regarding the village of Batukunku (262 households, 2945 inhabitants)

	Summer Season		Winter Season	
Residential	**Appliances**	**Kwh/day**	**Appliances**	**Kwh/day**
	LIGHTS	150	LIGHTS	150
	Fan (B)	215.87	Fan (B)	115.87
	Tv	247.16	Tv	247.16
	Stereo	72	Stereo	72
	Tv Decoder	80	Tv Decoder	80
	Mobile Phone	10.97	Mobile Phone	10.97
	Laptop	75	Laptop	75
	Fridge	536.78	Fridge	336.78
	Total KW	**1416**	Total KW	**1116.02**
Community	Schools	8	Schools	6
	local market	20	local market	15
	Mosque	2.03	Mosque	1.5
	community center	11	community center	8
	Total KW	**41.03**	**Total KW**	**32.5**
Industries	Hotels/guest house for Tourist	300	Hotels/guest house for Tourist	150
	Ice making for Fishing	200	Ice plant for Fishing	150
	Total KW	**500**	**Total KW**	**300**
	Overall TOTAL KW	**1929.52**	**Overall Total**	**1420.52**

The village's annual primary load profile is shown in figure 4.4. Due to more people staying at home in the evenings for the daily load pattern, this is consistent throughout the year. A higher level extends from midday to the start of the night due to more productive and communal activities, using the baseline electric consumption profile being minimal during morning and late-night hours. In terms of seasonal load patterns, load demand varies according to the time of year that various equipment items are used and for how long. When the power supply is inadequate, the deferrable load has a lower priority than the primary load and can wait until power is available. Water pumping is used in this study as an example of a deferrable load that allows flexibility in when the pump truly operates. Assuming the water reservoir doesn't run out. Another illustration of a deferrable load is storage charging and ice making. It is assumed that the deferrable load would remain constant each month. A modest ice storage facility for the Tanji fishing community is connected to the deferrable load in this scenario. With a specified storage capacity of 200 kW h and a peak load of 120 kW, the annual average deferrable load can be satisfied at any moment within a predetermined time period. On the AC side, there are connections for both the main load and the deferrable load. The need for hydrogen is to export it to the neighboring countries like Senegal and Morocco etc. This shipment can be done by liquefied hydrogen or it can also be transported as ammonia or in LOHs. It can also be use as energy storage, which can be an alternative to battery storage.

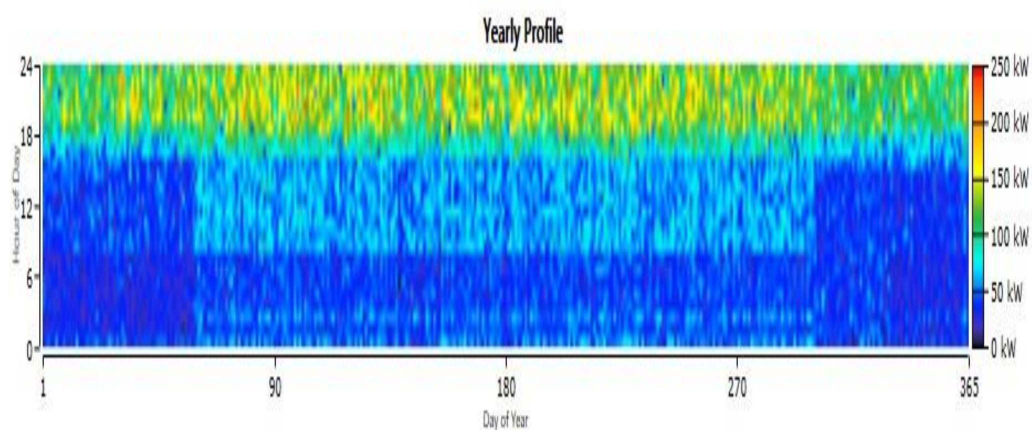


Figure 4.4 Yearly load profile

Figure 4.5 shows how much electricity is used throughout the day. Because individuals spend more time at home during the evening, it shows that this is when consumption is highest. As a result, evenings are when there is a significant demand for electricity.

Figure 4.5 Daily load profile.

Figure 4.6 displays the average monthly hydrogen load, with daily random variability set to 10% and time step random variability set to 20%, respectively. With a peak load of 5.35 kg/h, the average hydrogen load per year is 45 kg/day. The maximum daily hydrogen load per month is 55kg in January, and the minimum daily hydrogen load per month is 42kg in September.

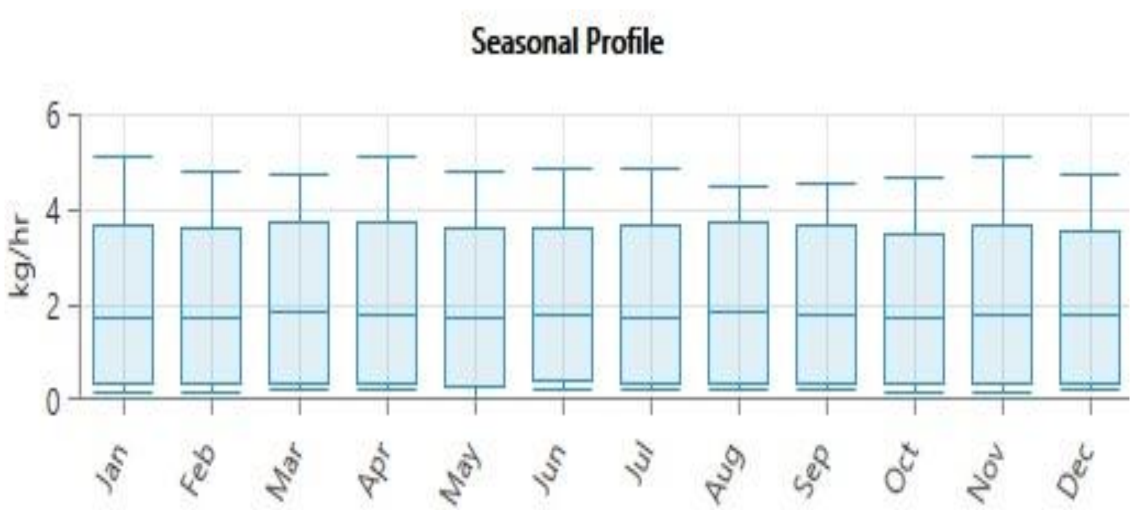


Figure 4.6 Average monthly hydrogen load profile.

4.4 Specifications for design

In this paper, the off-grid HRES design is displayed below as Figure 4.7. Solar energy systems (PV), wind turbines (WT), and diesel generators (DG) are all components of power production (DG). In order to keep a steady voltage, batteries serve as the storage unit, and a converter is utilized to convert current between AC and DC modes.

In order to meet the need for hydrogen, the method for generating and storing hydrogen consists of an electrolyzer and a hydrogen storage tank. Grid module is also imported into the simulation in order to determine the off-grid HRES development's breakeven economical distance. The following subsections include explanations and techno-economic information about the HRES and connected parts.

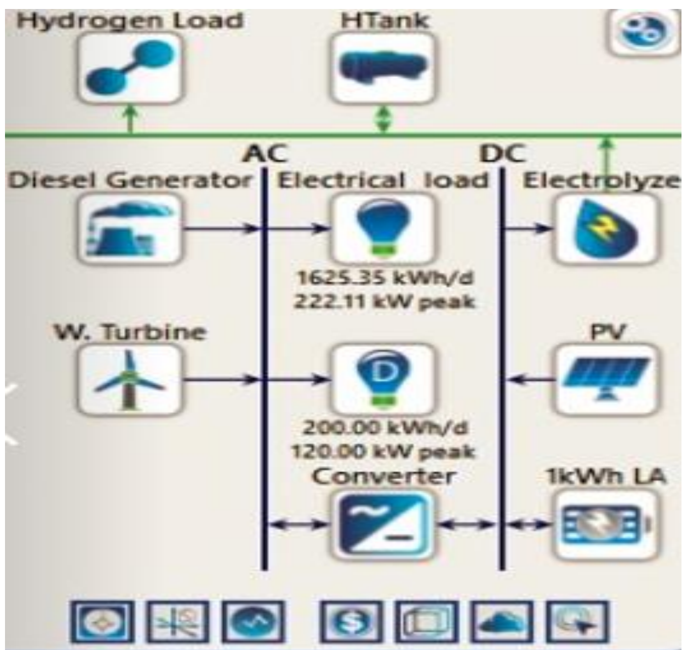


Figure 4.7 Schematic of the HRES.

4.4.1 Solar panels

PV panels, which are linked to the DC side, produce energy through the photovoltaic effect to power the system. Considering the temperature and solar radiation readings, PV panels' hourly energy output is computed. The following equation (7) determines the output of a PV array 24- [26] .

$$P_{PV} = P_{PV,STCFPV}\left(\frac{G_T}{G_{T,STC}}\right)[1 + \alpha_P(T_C - 25)] \qquad (7)$$

The current time step's incoming solar Radiation entering STC and radiation striking the PV array are each represented by the letters GT, STC [1 kW/m^2], and GT [kW/m^2], respectively. Current time step's PV cell temperature is Tc [C], and αP [%/C] is the temperature coefficient of power. The array's PV panels are modeled in this model at a 40-degree slope without the use of a tracking device, with 20% and 80%, respectively, being thought to be the ground reflectance and the derating component.

Figure 4.8 Solar PV Array.

4.4.2 Wind turbine

This research takes into account a wind turbine with a horizontal axis of 10 kW. In this case, for each time step, the wind turbine's power output is determined using a three-step process. First, as shown in equation (8) below, The logarithmic rule is used to calculate the wind velocity at the hub height [27].

The model then determines the power output of the wind turbine at the preferred wind speed and normal air density, which is referred to as a power curves for a wind turbine. Finally, the power generated at real air density is changed. using the equation (9) [28].

$$V_{hub} = V_{anem} \frac{ln(z_{hub}/z_0)}{ln(z_{anem}/z_0)} \qquad (8)$$

Where the hub height (24 m) and anemometer height are represented by zhub [m], zanem [m], z0 [m], and Vanem [m/s] (50 m), length of the surface roughness and wind velocity at anemometer height, correspondingly. The natural logarithm is represented by equation (9) .

$$P_{WT} = \left(\frac{\rho}{\rho_0}\right) P_{WT,STP} \qquad (9)$$

STP, PWT [kW] and z0 [1.225 kg/m^3] are, respectively, the air density at standard temperature and pressure (STP) as well as the wind turbine's power production. The air's real density is [kg/m^3].

Figure 4.9 Wind Turbines.

4.4.3 Diesel fueled generator

A diesel engine that also has an electric generator produces electricity. Liquid fuels or natural gas are frequently the main fuel sources for a diesel engine. The fuel and air compression are essential to a diesel generator's overall functioning. Diesel can produce energy at a higher rate per volume than petroleum because it has a greater energy density. Vehicles with diesel engines get superior gas mileage., they are a natural option for heavy-duty vehicles and machinery. Due to their increased efficiency and cost-effectiveness, diesel engines are receiving more focus. The AC output is linked to the diesel engine.

Figure 4.10 Diesel Generator

4.4.4 Battery and Converter

From the schematic design, we have seen the representation of a battery and a converter, through rectification, the converter transforms DC to AC, and the rectifier has a 100% capacity. The storage strategy is idealized. To simulate high-performance lithium-ion batteries since it allows for accurate battery modeling. The efficiency of the inverter input in the converter's case, it changes from alternating current (AC) to direct current (DC), is 95%. When the other components are unavailable, Battery backup and storage functions help to maintain a steady flow of electricity.

Figure 4.11 DC Battery

4.4.5 Electrolyzer and hydrogen tank

Due to its excellent energy efficiency, electrolysis is a well-known technique for producing hydrogen. The electrolyzer, which is powered by a hybrid system for generating renewable energy, is utilized to manufacture hydrogen in order to meet the hydrogen demand. In this study, the minimum load ratio of the generic electrolyzer is fixed at 0%, and its efficiency is assumed to be 85%. Hydrogen is stored in a generic hydrogen tank, with 10% of the tank's capacity as the initial level.

Figure 4.12 Hydrogen Tank

Figure 4.13 Electrolyzer

4.4.6 Other instructions on system operation

To guarantee a steady flow of electricity, the capacity deficit fraction is fixed at 0%. Additionally, per guideline, 10% of the hourly load is used as the operation reserve in order to guarantee dependable system functioning during load demand fluctuations [15]. This research examines both the load following (LF) and cycle charging (CC) dispatch techniques to enhance system operational control. [29]

4.4.7 Economical inputs

This subsection provides the economic inputs used in the modeling procedure. It is estimated that the project will last 20 years, which is the same amount of time as the primary renewable components would last. The discount rate is taken to be 6% and the inflation rate to be 2%.

According to information gathered from previously published literature, information from Batukunku's personal sources, as well as hypotheses based on the village's specific circumstances, is enumerated in Table 4.4 For each system component, their relevant economic parameters were computed.

Table 4.4 Economic information about the system's components

Component	Capacity	Lifetime	Capital ($/capacity)	Replacement ($/capacity)	Maintenance ($)	References
PV panel	1 KW	20 years	900	850	10/year	[30]
Wind turbine	10 KW	20 years	9500	9000	30/year	[30]
Diesel Generator	1 KW	15,000 h	550	500	0.05/h	[31]
Battery	1 KWh	15 years	500	500	5/year	[32]
Converter	1 KW	15 years	300	300	3/year	[32]
Electrolyzer	1 KW	15 years	1500	1000	20/year	[28]
Hydrogen Tank	1 Kg	20 years	600	450	10/year	[33]

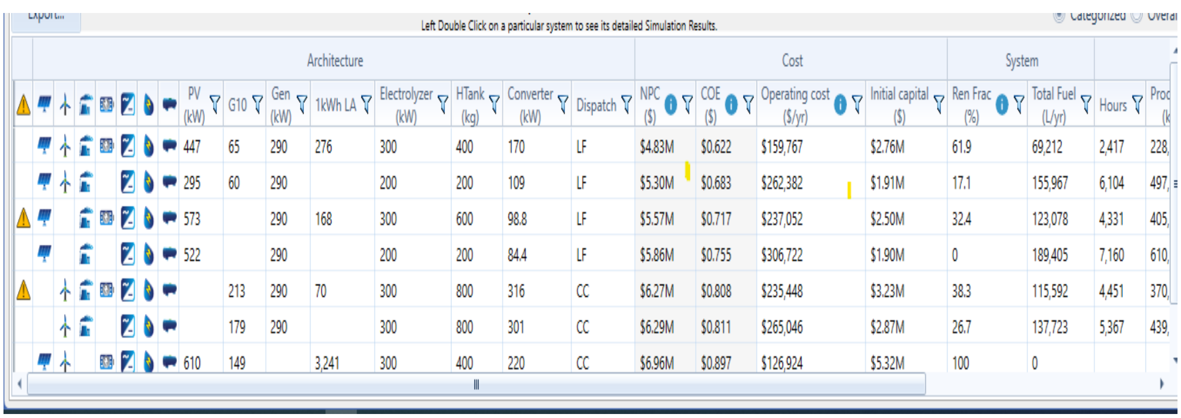
CHAPTER 5

Results and discussion

HOMER employs a list of system configurations in the simulation process and the capacities are ordered based on lowest COE and NPC. To estimate costs, at the same time determine the viability of a hybridized energy system throughout the years. Also shown are the results of the sensitivity analysis, and a few general observations on the system's social and environmental benefits are made.

5.1 System optimization results

The basic scenario for this study is as follows. The obtained yearly averages of the sun's radiation and the wind's velocity for the local primary energy resources are 5.79 kW h/m^2/day and 4.49 m/s, respectively. The daily average electric load is 1625.35 kW hours/day, and the daily average hydrogen load is 43.2 kg. For a 20-year project, the Discount rate is 6% and the inflation rate is 2%. Three ideal system architectures are thoroughly examined out of all the possible configurations. The hybrid energy system needed for the generation of hydrogen and reliable supply in any system architecture includes an electrolyzer and a hydrogen tank.


Left Double Click on a particular system to see its detailed Simulation Results.

Architecture								Cost				System			
PV (kW)	G10	Gen (kW)	1kWh LA	Electrolyzer (kW)	HTank (kg)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Proc (k
447	65	290	276	300	400	170	LF	$4.83M	$0.622	$159,767	$2.76M	61.9	69,212	2,417	228,
295	60	290		200	200	109	LF	$5.30M	$0.683	$262,382	$1.91M	17.1	155,967	6,104	497,
573		290	168	300	600	98.8	LF	$5.57M	$0.717	$237,052	$2.50M	32.4	123,078	4,331	405,
522		290		200	200	84.4	LF	$5.86M	$0.755	$306,722	$1.90M	0	189,405	7,160	610,
	213	290	70	300	800	316	CC	$6.27M	$0.808	$235,448	$3.23M	38.3	115,592	4,451	370,
	179	290		300	800	301	CC	$6.29M	$0.811	$265,046	$2.87M	26.7	137,723	5,367	439,
610	149		3,241	300	400	220	CC	$6.96M	$0.897	$126,924	$5.32M	100	0		

Figure 5.1 Optimization results

The techno economic success of each architectures lowest NPC representative is shown in Table 5.1. Shows that combination, (a) which features the PV-WT-diesel generator-Battery with Electrolyzer/HTank, is the ideal system with the least NPC. The ideal system has 719 kW of solar panels, 54 wind turbine of 10 kW, 250 kW of diesel power, 514 kW of lithium batteries, 300 kW of electrolyzers, 400 kg of hydrogen tank, and 144 kW of converters. The system's NPC, COE, and COH are $4.27M, $0.469/kWh, and $18.7/kg, respectively. Technically, combination (a) has a 29.3% excess of electricity. In addition, combination (b) and (c) refer to the PV-DieselGenerator-Battery and the WT-Diesel Generator-Battery with Electrolyzer/HTank, respectively, with each of these batteries specific combinations listed . In contrast to combination (a), simulation results of the ideal system are shown in this subsection. The standalone HRES produces 2,085,357 kWh of electricity annually, of which solar panels, wind turbines, and diesel generators account for 59.3%, 31.3%, and 9.37%, respectively. The power produced by the ideal system satisfied both the Electric load and the requirement for electricity for hydrogen generation, with a surplus of 224,676 kWh per year.

Table 5.1 Results of the combined power system's optimization with the electrolyzer and hydrogen tank

System	PV (kW)	Wind turbine quantity (10kw)	Diesel Generator (kw)	Battery (kwhLi)	Electrolyzer (kW)	Hydrogen tank (kg)	Converter (kW)	NPC ($)	COE ($/Kg)	COH ($/kg)	Excess Electricity (%)
PV-WT-DG-Battery	719	54	250	514	300	400	144	4.27 M	0.469	18.7	29.3
PV-DG-Battery	1081		250	147	300	200	149	5.04 M	0.522	22.2	36.2
WT--DG-Battery		455	250	7	300	400	250	7.85 M	0.861	34.2	74.4

Figure 5.2 below displays the average monthly electricity generation of the ideal HRES. Solar panels produce 1,237,247 kWh of power annually, with 4370 hours of operation per year at a levelized cost of $0.0441 per kWh. The annual electricity generated from wind turbines is

652,699 kWh with 6609 hours of operation and a levelized cost of 0.0599 kWh/year. Additionally, a diesel generator is added for energy generation as part of the system to boost cost effectiveness. This generator makes up for the inconsistent and unpredictable power output of solar panels and wind turbines. The diesel generator ran for 2024 hours per year and produced 195,412 kWh with 664 starters per year. With regard to hydrogen production, the levelized COH is 18.7 kg/year, and the electrolyzer's annual output of 7366 kg/year satisfied the load of 16,733 kg/year for hydrogen with no unmet demand.

Production	kWh/yr	%
Generic flat plate PV	1,237,247	59.3
Autosize Genset	195,412	9.37
Wind Turbine	652,699	31.3
Total	2,085,357	100

Consumption	kWh/yr	%
AC Primary Load	593,253	41.1
DC Primary Load	0	0
Deferrable Load	72,983	5.06
Total	1,442,732	100

Quantity	kWh/yr	%
Excess Electricity	611,580	29.3
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	70.7	%
Max. Renew. Penetration	1,105	%

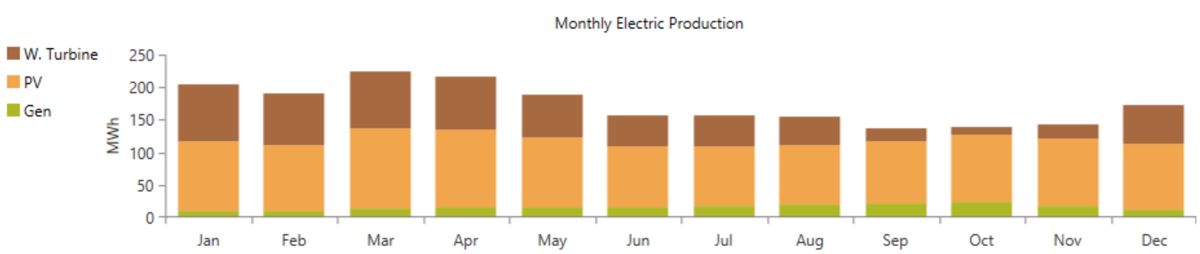


Figure 5.2 Production of energy by the ideal HRES on a monthly average

5.2 Emission Output

Output of emissions Fuels used by electricity generators result in emissions as a byproduct. The emission factor of each pollutant is used in this study to calculate the quantity of pollutant gas released by diesel generators. By dividing the emissions factor by the total yearly fuel used by a generator and the net power purchases from the grid, HOMER calculates the annual emissions of a pollutant. Equation shows how to do this

$$E_{i=EP_i^{fuel}F+EF_i^{grid}Enet,ann} \quad (10)$$

where, i is the type of pollutant EP_i^{fuel} is the emission factor of the ith pollutant for a fuel (biogas or diesel) in kg per unit of fuel consumed, F is fuel consumption as defined by equations below $F + EF_i^{grid}$ is the emission factor of the ith pollutant for the grid in g/kWh and Enet,ann is the net annual energy purchased from the grid.

Figure 5.3 shows the various sorts of emissions that the system can emit. The system's most commonly released substances is carbon dioxide

Quantity	Value	Units
Carbon Dioxide	151,751	kg/yr
Carbon Monoxide	957	kg/yr
Unburned Hydrocarbons	41.7	kg/yr
Particulate Matter	5.80	kg/yr
Sulfur Dioxide	372	kg/yr
Nitrogen Oxides	899	kg/yr

Figure 5.3 Emissions of the system

5.3 Hydrogen Production

Figure 5.4 displays the electrolyzer's input power over the course of the year. The mean input and maximum input energies are 88.6 kW and 300 kW, respectively, while the total input energy is 776,496 kW h/year. According to Figure 13, from around 8:00 am to 9:00 pm, in every single day of the year, is when hydrogen is produced in large quantities, using electricity from the system's power generation component to satisfy the hydrogen demand. The electrolyzer operates for 4122 hours per year, and its mean and highest hydrogen output rates are 1.91 kg/h and 6.46 kg/h, respectively.

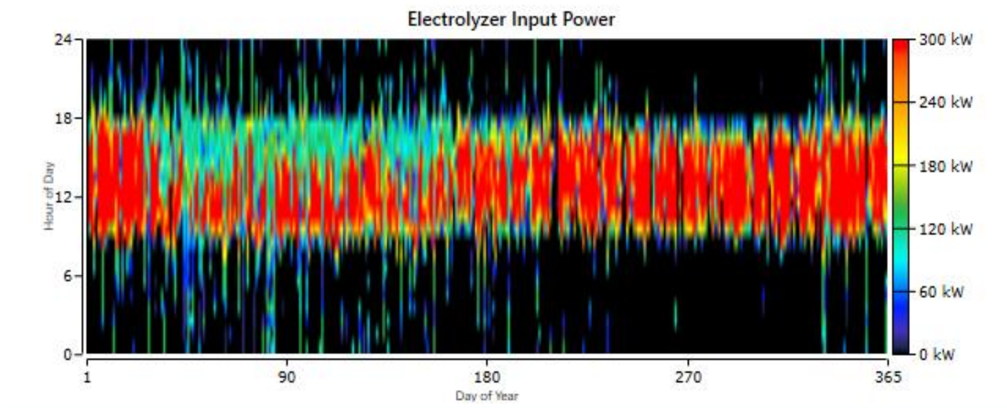


Figure 5.4 Input power of electrolyze throughout the year.

In this scenario, optimization yields a 400 kg hydrogen storage capacity. Due to the starting tank level being set at 10% of the hydrogen that is stored, the hydrogen tank has 40 kg of content at the start of the year, and 363 kg at the conclusion.

5.4 Financial Summary of system

The hybrid system is made up of seven (7) components: a diesel generator, a wind turbine, a battery, a converter, a tank for hydrogen, an electrolyzer, and solar panels. Each component carries a capital expense, a replacement expense, an operation and maintenance expense (O&M), a salvage expense, and a fuel expense for the generator.

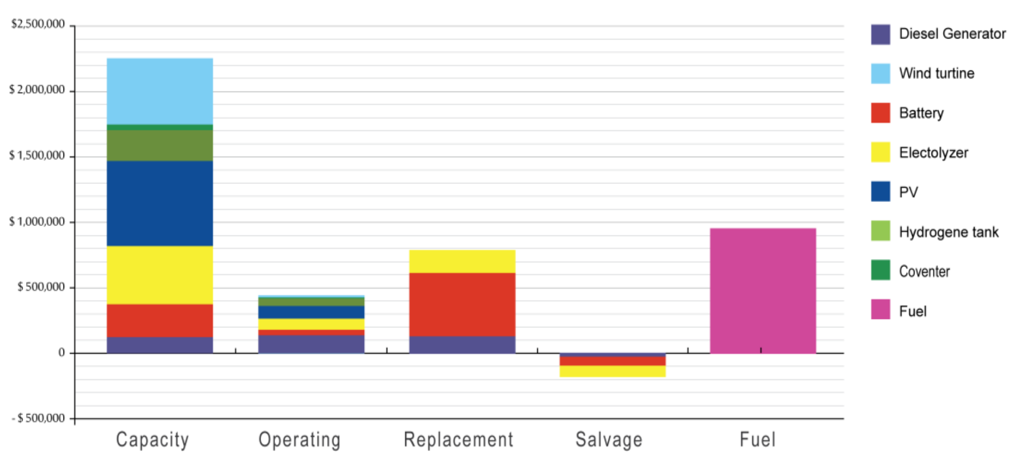


Figure 5.5 Cost of the HRES's optimum component breakdown.

Figure 5.5 and table 5.2 shows the ideal hybrid system's cost breakdown by category, with a capital of $647532, solar panels are the most expensive, followed by wind turbines, electrolyzers, Li-ion batteries, hydrogen tanks, diesel generators, and system converters. The most expensive operating costs are for diesel generators, the most expensive replacement costs are for lithium batteries, and the most expensive salvage value is for electrolyzers.

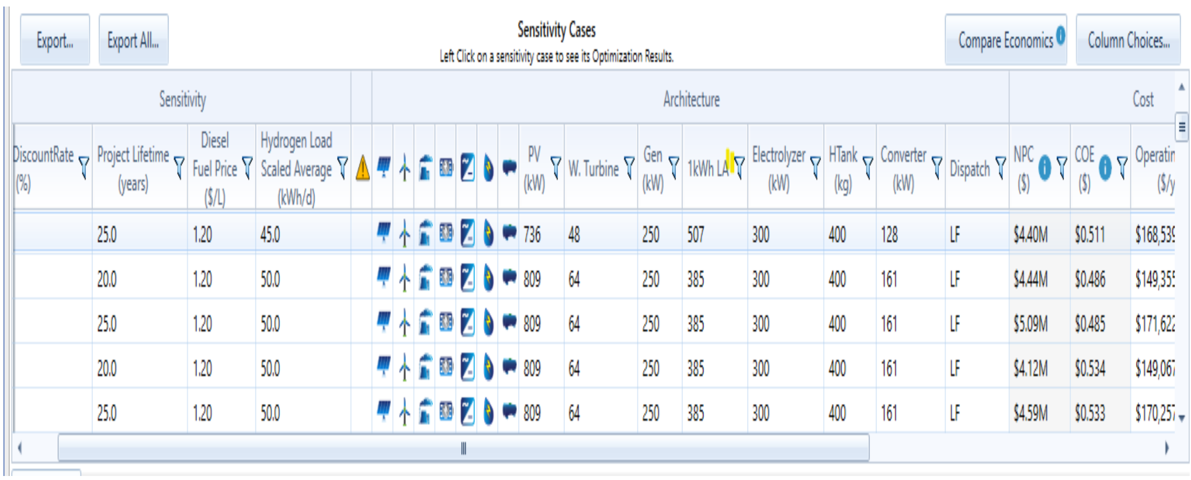
The PV component has the most expensive capital cost, the diesel generator has the highest operating and maintenance cost, the lithium-ion battery has the highest replacement cost, and the electrolyzer has the highest salvage cost as shown below.

Table 5.2 Cost summary of HRES

Components (US$)	**Capital (US$)**	**Replacement (US$)**	**O&M (US$)**	**Fuel (US$)**	**Salvage (US$)**	**Total**
Diesel Generator	125,000	131,739	131,494	952,044	13,961	1,333,317
Li-on Battery	257,000	494,187	35,170	0.00	80,178	706,179
Electrolyzer	450,000	168,475	82,111	0.00	92,665	607,921
PV	647,532	0.00	98,462	0.00	0.00	745,994
Hydrogen Tank	240,000	0.00	54,740	0.00	0.00	294,740
Converter	43,340	0.00	5,931	0.00	0.00	49,271
W Turbine	513,000	0.00	22,170	0.00	0.00	535,170
System	2,275,872	794,402	437,080	952,044	186,805	4,272,594

5.5 Sensitivity analysis

Sensitivity analysis has been done based on the basic scenario to assess the impact of various variables on the performance and economics of the suggested ideal PV-WT-DG-Battery with electrolyzer/HTank system. Annual average hydrogen load is taken into account as a sensitivity variable in this study that takes future hydrogen exports into account. In many parts of the world, traditional fossil fuels are replaced with hydrogen to a greater extent due to stricter carbon reduction requirement. The average yearly hydrogen load is anticipated to increase given the current global trend toward hydrogen technology as a source of energy.



Sensitivity Cases

Left Click on a sensitivity case to see its Optimization Results.

DiscountRate (%)	Project Lifetime (years)	Diesel Fuel Price ($/L)	Hydrogen Load Scaled Average (kWh/d)	PV (kW)	W. Turbine	Gen (kW)	1kWh LA	Electrolyzer (kW)	HTank (kg)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operatin ($/y
	25.0	1.20	45.0	736	48	250	507	300	400	128	LF	$4.40M	$0.511	$168,53
	20.0	1.20	50.0	809	64	250	385	300	400	161	LF	$4.44M	$0.486	$149,35
	25.0	1.20	50.0	809	64	250	385	300	400	161	LF	$5.09M	$0.485	$171,62
	20.0	1.20	50.0	809	64	250	385	300	400	161	LF	$4.12M	$0.534	$149,06
	25.0	1.20	50.0	809	64	250	385	300	400	161	LF	$4.59M	$0.533	$170,25

Figure 5.6 Sensitivity Cases

In the system base case, the annual hydrogen load is estimated to be 45 kg/day. The numbers entered for the hydrogen load for the sensitivity analysis are 50, 60, 70, and 80 kg/day, while the electricity demand is maintained at 1625.35 kW h/day.

Table 5.3 shows the effects of hydrogen load change on the system's techno-economic performance. The system's NPC rises as the hydrogen load rises because system components must be able to handle the rising demand for electricity for hydrogen production. The project life span has also been the subject of sensitivity analysis. The system's baseline scenario is 20 years, and a sensitivity analysis was performed for a period of 25 years. The conclusions reached in each situation are as follows. The system's NPC cost for the base scenario is $4.27M, its COE cost is $0.467, and its COH cost is 18.7 kg/$, respectively. For a life period of 25 years, the NPC is $5.02M, the COE is $0.512, and the COH is 20.4 kg/$. According to the results, the cost of the system rises proportionately to the project's lifespan because of some inevitable factors, such as O&M expenses.

Analysis of the effects of increasing hydrogen load on the COE and COH of the entire system is shown in table 5.3. The COE increases from $0.469/kWh to $0.772/kWh when the hydrogen load grows from 45 kg/day to 80 kg/day due to an increase in NPC, which is brought on by an increase in system size. Additionally, the COH falls from $18.7/kg to $16.2/kg as a result of the impact of hydrogen production on scale, in this investigation. The goal of the proposed stand-alone HRES in this project is to offer the community a dependable power supply.

Table 5.3 Impacts of hydrogen load variation on the system

System Architecture	**Annual average Hydrogen**	**PV (KW)**	**Wind**	**Diesel Generator**	**Battery 1 KWh Li**	**Electrolyzer (KW)**	**Hydrogen Tank (Kg)**	**Converter (KW)**	**NPC ($)**
PV - WT- Battery With Electrolyzer/ Hydrogen Tank	45	719	54	250	514	300	400	144	$4.27M
	50	809	64	250	385	300	400	124	$4.44M
	60	980	74	250	126	300	300	133	$4.91M
	70	1236	86	250	-	300	400	223	$5.77M
	80	1736	209	250	-	300	400	293	$7.04M

CHAPTER 6

Conclusion

This research uses a case study of a remote village in Kombo South, The Gambia, to show the techno-economic viability of an HRES for off-grid power supply and hydrogen production. We find the most economical system that satisfied the necessary electric and hydrogen load by simulating and optimizing. Data on wind speed, daily radiation, and information about the hydrogen system were initially gathered for the region under study. The study area has a significant potential for renewable energy, particularly solar energy for producing hydrogen, according to the findings of software processing. The HOMER program was then used with the data that had been gathered. Data were subjected to modeling and sensitivity analysis processes. The proposed stand-alone ideal system includes 719 kW of solar panels, 54 no. of 10 kW wind turbines, a 250 kW diesel generator, 514 kW of lithium batteries, a 300 kW electrolyzer, a 400 kg hydrogen tank, and a 144 kW converter. The system's NPC, COE, and COH are $4.27M, $0.469/kWh, and $18.7/kg, respectively. The impact of the growth in the annual average hydrogen load has been taken into account for sensitivity analysis. The results demonstrated that as the hydrogen load increases, the system's NPC and COE also increase in accordance, whereas COH falls due to the scale impact for hydrogen production. According to the HOMER software the amount of power output of the power plan for the HRES is 2,085,357 kWh/year and an electrical consumption of 1,442,731 kWh/year with excess electricity of 611,580 kWh/year. A yearly output of 16,733 kg of hydrogen was achieved. The cost of the hybrid system is 2.275.872.33 dollars, and its annual income is equivalent to 630,752 dollars, according to technical and economic analysis that was performed. Thus, it was determined that the hybrid PV-wind power plant in Batukunku village is fiscally viable for producing electricity and hydrogen.

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