Power Engineering and Engineering Thermophysics
https://www.acadlore.com/journals/PEET

Enhancing Sustainability in Hopedale, Newfoundland and Labrador, Through Hybrid Microgrid System Design

Afreen Maliat[1*], Siddhanth Kotian[1], Samaneh Shirinnezhad[2], Davoud Ghahremanlou[1]

[1] Faculty of Business Administration, Memorial University of Newfoundland, A1B 3Y1 St. John's, Canada
[2] Department of Electronic and Computer Engineering, Faculty of Computer Engineering, University of Jundishapur, 61357-1579 Ahvaz, Iran

[*] Correspondence: Afreen Maliat (amaliat@mun.ca)

Received: 02-05-2024 **Revised:** 03-20-2024 **Accepted:** 03-26-2024

Citation: A. Maliat, S. Kotian, S. Shirinnezhad, and D. Ghahremanlou, "Enhancing sustainability in Hopedale, Newfoundland and Labrador, through hybrid microgrid system design," *Power Eng. Eng. Thermophys.*, vol. 3, no. 1, pp. 58–76, 2024. https://doi.org/10.56578/peet030105.

Abstract: An evaluation of renewable energy system (RES) adoption in Hopedale, Newfoundland and Labrador, was conducted with the focus on developing a robust hybrid microgrid system. Situated in a remote area distinguished by its severe weather and rich cultural history, Hopedale primarily relies on diesel generators for energy, presenting unique challenges including high energy costs and significant environmental impacts. The current reliance on three diesel generators for electrical needs underscores the necessity for a shift towards sustainable energy. Hybrid Optimization of Multiple Energy Resources (HOMER) Pro simulations were employed in this study to analyze a proposed system integrating solar and wind power, battery storage, and an additional diesel generator. The system's design aims to reduce dependency on fossil fuels amidst increasing environmental concerns and fossil fuel limitations. The environmental performance and cost-effectiveness of combining solar and wind energy with battery storage and a diesel backup were assessed. The hybrid system's potential to decrease carbon emissions by over 50% compared to the existing diesel-only setup is demonstrated, suggesting a substantial reduction in greenhouse gas emissions. Although the economic Levelized Cost of Energy (LCOE) of \$0.182 per kWh is higher than the traditional diesel cost of \$0.16 per kWh, it represents a strategic commitment to environmental sustainability. A Net Present Cost (NPC) of \$14.6 million was predicted for the system, encompassing Capital Expenditure (CAPEX), Operational Expenditure (OPEX), and replacement cost over 25 years. Significant reductions in environmental impact and notable operational savings were anticipated. These findings contribute valuable insights into the benefits of hybrid microgrids for remote communities, offering a model for energy resilience, cost savings, and reduced carbon footprints. Thus, the study adds significant information to the ongoing discourse on sustainable energy solutions for isolated locations.

Keywords: HOMER Pro; Microgrid; Levelized cost of energy; Net present cost; Battery storage; Wind energy; Solar energy; Hopedale; Newfoundland and Labrador

1 Introduction

As the global energy landscape continues to evolve, two primary forces are propelling the transition towards RES: the environmental impact of traditional fossil-fueled power generation, and the pressing need to find sustainable alternatives in a world where fossil fuels are becoming increasingly scarce. These drivers highlight the need to shift to cleaner, renewable energy sources [1]. However, scaling up renewable energy sources comes with several challenges, including the higher cost of generating electricity from renewable energy sources compared to traditional methods and the variability of renewable energy sources [2, 3]. These challenges highlight the need to strategically transition to hybrid systems that combine renewable technologies with conventional energy generation methods to increase the proportion of renewable energy in the energy mix [4].

Renewable energy microgrids (REMGs), which are hybrid systems, have emerged as a promising solution, offering the flexibility to maintain consistent electricity supply. These systems can function independently of the main grid for extended periods, operating in both standalone and grid-connected modes [5, 6]. In remote communities, where electrical infrastructure can be erratic or nonexistent, this flexibility is of special significance. Despite living in locations abounding in renewable resources, these communities, dispersed throughout rural and remote regions of the world, are home to almost 1.5 billion people who do not have access to reliable energy [7, 8]. Hence, in these remote areas, the idea of a REMG serves as a means of bringing about social and economic change in addition to providing a technological answer. Utilizing nearby renewable energy sources like wind and sun, REMGs may significantly lessen reliance on diesel generators, which are known for having high fuel prices and a major adverse effect on the environment [9, 10].

Renewable resources account for a sizable share of the power generated in Canada. Conversely, however, disconnected from the national grid, isolated microgrids in the southern portion of the nation that supply electricity to isolated towns mostly rely on fossil fuels. Stringer and Joanis [11] explored the nation's gradual transition from fossil fuels towards renewable energy sources. This change in direction is crucial for promoting energy sovereignty and reducing the environmental impact of energy production. The increasing reliance of isolated populations on conventional energy sources, particularly fossil fuels, raises serious concerns as transitions to more sustainable energy frameworks are undertaken [12].

Located away in the untamed landscape of Newfoundland and Labrador, positioned at 55°27'N 60°13'W [13], Hopedale is a symbol of tenacity and cultural diversity in the face of isolation. More than its physical coordinates or the results of a population census, this Inuit community, the legislative hub of the Nunatsiavut Land Claims Area, represents a close relationship between its people and the natural world. Hopedale has 596 residents as of the census conducted in 2021 [14], which is evidence of the community's close-knit dynamics and the strength that comes from its Inuit ancestry and cultural customs. Hopedale's distant location and restricted access to centralized grid infrastructure make it extremely difficult to address energy security. The use of fossil fuel generators creates environmental sustainability issues in addition to financial hardships due to high energy expenses.

This study aims to incorporate RESs into the Hopedale community, bringing technological innovation and cultural values in tandem and creating a foundation for a sustainable energy future that aligns with the community's goals and the larger objectives of environmental stewardship. The transition to sustainability in Hopedale, Newfoundland and Labrador's pursuit of RESs goes beyond addressing the financial and ecological challenges associated with the province's dependence on fossil fuels. It also shows a strong accord with the firmly held beliefs and customs of society. This change is a step toward protecting Hopedale's land for future generations in line with Inuit customs and beliefs. It also advocates environmental stewardship, a concept that is firmly embedded in the community. This move is essential for helping isolated communities succeed socioeconomically since it provides a way to reduce energy expenses and lessen environmental effects. The socio-economic benefits of adopting hybrid energy systems are detailed [15]. By harnessing the region's renewable resources, the community not only reduces its carbon footprint but also ushers in a new era of social and economic advantages. To be more precise, the implementation of this kind of system is anticipated to promote job growth, especially in the areas of building, upkeep, and system management, which will help locals improve their skills and find work [16]. The development and continual management of the energy system will necessitate the involvement of a workforce competent in renewable energy technology, including both professional and semi-skilled positions. This requirement enables opportunities for both local employment and skill development, bolstering the community's economy. Additionally, Hopedale and other distant communities must progress toward energy independence, which is why switching to a REMG is significant. By reducing the unpredictable nature of fuel prices and supplies, this independence from outside fuel sources contributes to a more stable and secure energy future. Furthermore, the transition from diesel generators to renewable energy sources is expected to result in notable enhancements to air quality, since the lower levels of pollutants will promote a better atmosphere for the population [17, 18]. These changes are very much in line with Hopedale's community philosophy, which values wellness for residents and harmony with the environment. In addition, the projected REMG represents the community's dedication to environmentally conscious living, sustainable living, and the preservation of its cultural legacy. From this perspective, the project transcends the technical domain and represents a comprehensive energy strategy that supports Hopedale's cultural vitality, economic resilience, and ecological stewardship.

In this study, a hybrid energy system for Makkovik was proposed, which makes use of solar and wind energy in addition to battery storage options along with diesel generators. With HOMER Pro, the design and analysis process were carried out to offer the area a cost-effective, efficient, and sustainable energy solution.

This study is organized in the following way: The literature review is offered in Section 2, followed by an explanation of the methodology in Section 3, an examination of the load profile and local resources in Section 4, an explanation of the hybrid system design in Section 5, findings and discussion in Section 6, and a conclusion to the research in Section 7.

2 Literature Review

In an era of increasing environmental consciousness and depleting fossil fuel supplies, the shift to RESs is not an aberration, but an urgent necessity. With a special emphasis on hybrid systems, this literature review takes readers on an in-depth study of the state of renewable energy research today. These systems, which cleverly combine energy storage technologies with renewable energy sources like solar and wind, appear as rays of hope for remote populations facing energy-related problems. Studies conducted in many different areas have explored renewable energy technology in detail, with solar panels, wind turbines, and battery systems receiving the most attention. Recent research highlights the revolutionary potential of combining renewable energy sources like solar Photovoltaics (PV), wind turbines, hydroelectric systems, and biomass with modern storage technologies like batteries and hydrogen fuel cells. This convergence is highlighted in the context of isolated settlements, where hybrid energy systems offer a sustainable and resilient energy future free from traditional grid dependence, in addition to an alternative. Farahmand et al. [19] delved deeper into hydrogen as a key element of renewable solutions in Newfoundland and Labrador, extending the story of sustainable energy. The integration of hydrogen production, storage, and distribution within the province was highlighted by their thorough assessment, emphasizing its potential to improve energy sustainability and resilience. This viewpoint is consistent with worldwide tendencies toward lowering carbon footprints and utilizing regional resources to achieve energy independence. Sakthi et al. [20] offered a thorough analysis of sustainable hydrogen generation, storage, and delivery in Newfoundland and Labrador, contributing to the conversation on renewable energy. The analysis highlights the province's strategic advantages in producing renewable hydrogen, especially given its strategic location to service European energy markets and wealth of wind resources. This assessment describes how renewable energy technology may be directly used to meet global energy security and sustainability concerns, while particularly emphasizing Newfoundland and Labrador's potential involvement in alleviating Europe's energy crisis [21–26].

Numerous studies have demonstrated the effectiveness of hybrid RESs in ensuring a consistent power supply [27–29]. Nebey [30] investigated a hybrid system for a community load in Ethiopia that includes hydropower, wind, and solar PV. Khalil et al. [31] investigated a hybrid system that uses solar and wind power to cut costs for the Baluchistan Seashore. The study showed a 64% decrease in pollutant gas emissions and made use of the NPC minimization method. An evaluation of a grid-connected energy system comprising solar PV, wind energy, and battery storage components was conducted by Riayatsyah et al. [32] in Indonesia. The system can supply up to 82% of the university's power needs, according to its optimization criteria, which also prioritizes the minimization of NPC in conjunction with the LCOE. Jumare et al. [33] evaluated the feasibility of integrating solar PV, wind power, and biogas technologies in a grid-connected setting inside Nigeria as part of their search for decentralized energy solutions. Like other studies, HOMER software was used to prioritize configurations with the lowest NPC, which streamlined the selection process and showed a proactive approach to sustainable and financially feasible energy generation. The combination of solar PV, wind turbines, and energy storage systems has been the subject of a substantial amount of research. Ghaffari and Askarzadeh [34] sought to maximize the performance of a hybrid energy system made up of fuel cells, diesel generators, and solar PV panels, aiming to find the most economical arrangement by reducing the NPC. A hybrid renewable energy system combining solar, wind, and storage technologies were also examined and evaluated at Makkovik, Newfoundland and Labrador in study [35]. Through a considerable reduction in greenhouse gas emissions and operating costs, the study showed that the system might offer an environmentally benign and technically feasible alternative. Farahmand et al. [36] concentrated on developing a hybrid energy system for the Natuashish. This study emphasized the urgent need for cogent and sustainable energy solutions, with a focus on promoting renewable energy sources and reducing reliance on diesel generators in remote Inuit settlements.

Research on renewable energy technologies shows that integrating various energy sources is feasible and has benefits for the environment. In remote areas, for instance, several studies have implied that hybrid energy systems can remain technically and economically feasible while enhancing energy resilience, lowering greenhouse gas emissions, and enhancing access to energy [37–39]. Ahmadi et al. [40] thoroughly investigated the economic and environmental implications of hybrid energy systems, and highlighted the importance of sustainable design concepts in attaining energy self-sufficiency and reducing ecological footprints. To further this discussion, Cruz-Soto et al. [41] highlighted the vital role of Power to Gas to Power (P2G2P) technologies in improving microgrid sustainability. The research shows how P2G2P systems may help with seasonal energy storage and drastically reduce carbon dioxide emissions through a thorough techno-economic analysis of a hydrogen-based storage system within a microgrid situated in Baja California, Mexico. Chisale et al. [42] explored the implementation of a hybrid power system in Malawi to address the challenges of interrupted power supply and limited electricity access. Utilizing HOMER Pro and Criteria Importance Through Intercriteria Correlation-Preference Ranking Organization Method for Enrichment Evaluations (CRITIC-PROMETHEE) II methodologies, six scenarios were evaluated, which identified a combination of grid, solar PV, and biogas from human excreta as the most viable solution. This approach not only promises to enhance electricity reliability and reduce bills but also offers a sustainable reduction in greenhouse gas emissions, advocating for broader adoption by schools and government entities.

Table 1 provides an overview of several studies that were carried out utilizing various hybrid system combinations in numerous locations. Although several worldwide case studies have addressed the creation of hybrid systems, there is a specific lack of information in the literature about the planning and execution of these systems in Hopedale, Newfoundland and Labrador. A tailored hybrid energy system for Hopedale was proposed in this study, which utilizes battery storage alternatives together with solar and wind energy, to address this gap. The design and analysis process were completed using HOMER Pro to provide the community with an affordable, effective, and sustainable energy solution.

Table 1. Summary of literature review in remote communities

Reference	Type	System	Homer Tool	NPC	COE	CAPEX	O&M	Location
[21]	Hybrid	DG, PV, WT, BT.	Yes	Yes	Yes	Yes	Yes	Nain, NL
[22]	Hybrid	BDG, Grid, PV, WT, BT.	Yes	Yes	Yes	Yes	Yes	West China
[23]	Hybrid	DG, Hydro, PV, BT.	Yes	Yes	Yes	Yes	Yes	Sierra Leone, West Africa
[24]	Hybrid	DG, PV, WT, BT.	Yes	Yes	Yes	No	No	Monpura Island, Bangladesh
[25]	Hybrid	DG, PV, WT, BT, FC, HT, EL.	Yes	Yes	Yes	Yes	Yes	Isfahan, Iran
[26]	Hybrid	DG, PV, WT, BT.	Yes	No	No	No	No	Ramea Island, NL, Canada
	Hybrid	BDG, DG, PV, WT, BT.	Yes	Yes	Yes	Yes	Yes	Vancouver, Canada

Note: FC - fuel cell, HT - hydrogen tank, WT - wind turbine, PV - photovoltaic, DG - diesel generator, BT - battery, BDG - biogas generator, EL - electrolyzer, NL - Newfoundland and Labrador, O&M - operating and maintenance, COE - cost of energy.

3 Methodology

A methodical methodology was used in this study to create a hybrid energy system specifically for Hopedale. Based on thorough data collection and rigorous simulation methods, the methodological approach seeks to produce an optimal system configuration that is both ecologically friendly and commercially profitable. After doing an extensive literature review and collecting necessary data about the community, Homer Pro software was used to design the system. Figure 1 shows the flow chart for the overall methodology.

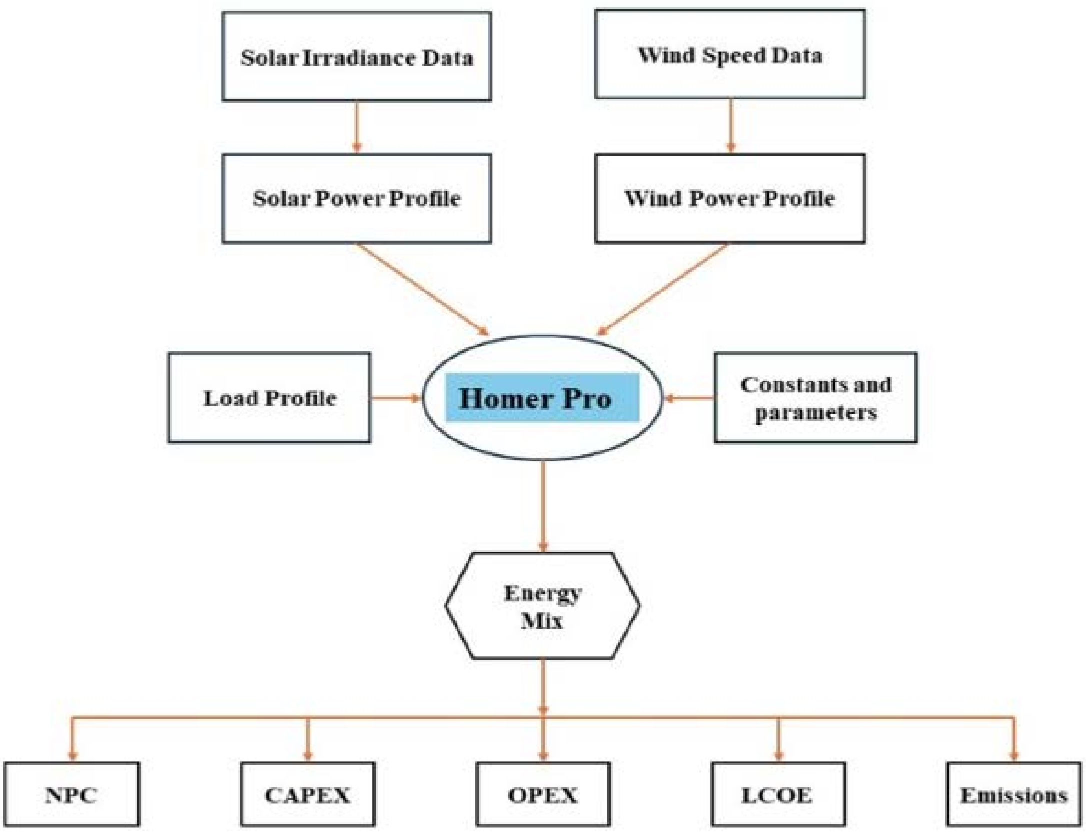


Figure 1. Flow chart of this study

The step-by-step process is given below:

Step 1: Data collection and analysis.

Key datasets were gathered and analyzed as part of this step:

a) **Meteorological data**: The surface meteorology and solar energy database of the National Aeronautics and Space Administration (NASA) was used to gather information on wind speed and solar irradiation. For evaluations of renewable energy, this database offers a thorough 22-year record of atmospheric conditions.

b) **Comparable community load data**: The load profile was generated by scaling the load profile of a comparable northern community with publicly available data, as Hopedale's power consumption data was not available to the general public. The number of residences in each neighborhood served as the basis for this scaling.

c) **Census data**: Hopedale's estimated 596 private households were determined using data from the most recent census. The development of a realistic load profile was aided by this estimation.

Step 2: Homer Pro system modelling.

The HOMER Pro software was utilized for modeling and simulation due to its sophisticated ability to optimize RESs. The simulation includes the following inputs:

a) **Normalization**: To ensure that the load data properly reflects usual usage patterns throughout the year, it was normalized to account for seasonal variances.

b) **Location**: The location in Homer Pro was defined as the first part of designing the hybrid system.

c) **Integration of renewable profiles**: In HOMER Pro, the available energy production from solar and wind resources is represented by generation profiles created from the data inputs.

d) **Electricity load profile**: The hourly data was compiled to determine daily, weekly, and monthly usage trends, and detailed load profiles were produced. Understanding Hopedale's base load requirements and peak demand periods was made easier by this technique.

e) **Constants and parameters**: To direct the simulation process, several system constants and operational parameters were specified.

f) **Iterative simulation**: To investigate a variety of system settings, simulations were conducted repeatedly. This stage identified the best system designs that balance load needs and cost minimization using HOMER Pro's powerful decision-making algorithms.

- **Analysis of configurations**: To comprehend how different system components, such as solar panels, wind turbines, and batteries, interact and affect the overall performance of the system, the size and arrangement of these components were modified for each simulation.

- **Optimization algorithms**: To determine the most promising system designs, optimization algorithms were employed in HOMER Pro to assess the simulations against predetermined goals, such as maximizing efficiency or lowering cost.

g) **Validation and analysis of the results**: Then the simulation results went through a stringent validation procedure.

- **Performance criteria**: These criteria include consistently meeting load demand, upholding dependability requirements, and staying below cost ceilings. Configurations that meet or exceed these benchmarks are advanced for further examination.

- **Impact assessment**: To comprehend the ramifications of the verified system designs, an analysis was conducted. This involves evaluating the effectiveness of each configuration in terms of emissions, reliance on non-renewable energy sources, and use of renewable energy as well as its financial viability.

Step 3: Financial evaluation.

The study's post-simulation research concentrates on the suggested energy mix's economics. The assessment measures include NPC, CAPEX, OPEX, LCOE, and emissions.

4 Location, Load Profiles and Local Resources

This section provides a detailed explanation of Hopedale's load profile, solar energy potential, and wind energy potential.

4.1 Location

The study's geographical focus is Hopedale, located at coordinates 55°27'0" N and 60°13'0" W, as depicted in Figure 2.

4.2 Electrical Load Profile of Makkovik

To ensure the system's dependability, effectiveness, and financial sustainability, Hopedale's hybrid energy system design requires a thorough study of the load profile. The intricate patterns of the island's energy usage were revealed by the data collected over 12 months. The average load of Hopedale is 16,967 kWh/day and the peak load is 1,900 kW.

Figure 2. Map of Hopedale, Newfoundland and Labrador

Figure 3 shows the monthly average load profile. A significant seasonal variation can be observed, with energy consumption highest in the winter. There is a notable seasonal difference, with a winter peak demand of 12,390.21 kWh/day in December and a reduced demand of 6,559.902 kWh/day in August. The management of energy distribution and the sizing of system components both greatly benefit from this knowledge. These intricate details of the load profile, which account for a peak demand of 3,659.05 kW and an average daily load usage of 4,944.20 kWh, were used by HOMER software to optimize the hybrid system. To satisfy Hopedale Island's particular energy needs, the system's scalability and adaptability were strategically designed based on the patterns found.

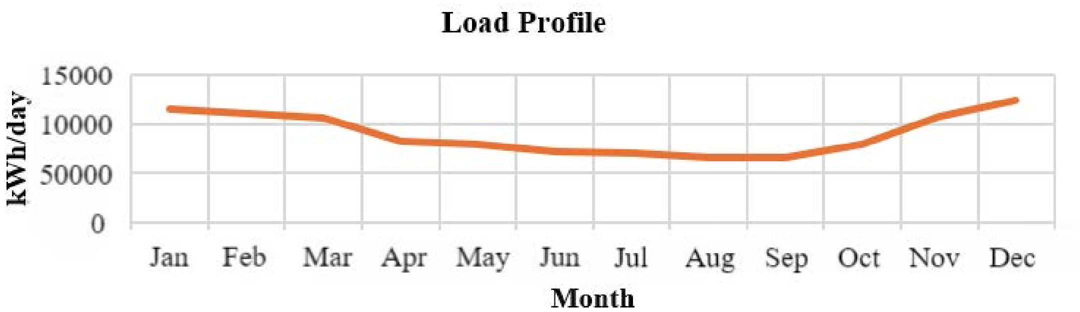


Figure 3. Electric load profile

4.3 Renewable Energy Resource Evaluation

NASA's extensive surface meteorology and solar energy data collection provides a detailed record of Hopedale's atmospheric conditions throughout a 22-year observing period. This dataset, in conjunction with wind speed measurements recorded over the past decade at a height of 10 meters, facilitates a detailed analysis of the area's wind profile. Table 2 illustrates the yearly mean daily solar irradiation, which is 2.83 kWh/m²/day, and the average wind speed, which is 7.94 m/s, with a temperature average of -4.69°C. These combined climatological insights demonstrate the depth and dependability of NASA's environmental databases and reaffirm Hopedale's readiness for solar and wind energy projects.

Table 2. Meteorological data for Hopedale

Month	Clearness Index	Daily Radiation $(\mathrm{kWh/m^2/day})$	Wind Speed $(\mathrm{m/s})$	Temperature ℃
January	0.481	0.76	9.67	-20.59
February	0.505	1.53	9.19	-20.33
March	0.491	2.67	8.88	-14.36
April	0.504	4.14	7.99	-6.46
May	0.499	5.22	7.03	-0.3
June	0.437	5.01	6.45	5.44
July	0.431	4.68	5.96	9.27
August	0.469	4.17	6.35	9.56
September	0.443	2.74	7.46	5.23
October	0.472	1.7	7.83	-0.61
November	0.488	0.9	8.88	-7.96
December	0.41	0.49	9.61	-15.14

5 System Design

This section provides the schematic design of the system along with the details of each selected component.

5.1 Analysis Tool – HOMER Pro

HOMER Pro software was used to design the system for Hopedale. The software is great for designing and analyzing the costs of hybrid energy systems. The selection of HOMER Pro stems from its all-encompassing simulation capabilities, which set the standard for simulating energy resources on a unified platform, ranging from conventional to renewable and storage technologies. It provides unmatched versatility in scenario analysis, allowing the evaluation of various technology combinations and operational approaches to determine the most practical hybrid system architecture. One of HOMER Pro's most notable features is its sensitivity analysis, which enables investigation into how changes in important factors, such as fuel pricing or resource availability, might impact system performance. This powerful tool is strengthened even further by its smooth interaction with international databases of renewable resources, guaranteeing that model inputs are accurate and representative of actual situations. Furthermore, HOMER Pro's intuitive interface significantly reduces the mystery surrounding system design, enabling a wide range of users from university researchers to industry experts to effectively utilize the tool.

However, HOMER Pro's drawbacks include its lack of consideration for real-time market dynamics and its reliance on past data for predictive modeling. Furthermore, the tool's cost models cannot accurately reflect the complexity of financial hazards throughout the system's lifetime because they are dependent on static inputs.

5.2 Design of the Proposed System

Figure 4 shows the system schematic for the proposed hybrid system. The design includes a diesel generator, wind turbine, PV panels, battery banks, a bidirectional converter, and an electric load.

The PV system and wind turbine, which were chosen for their energy output as well as their longevity and ability to withstand regional weather patterns, are two ways to harness renewable energy. The Fronius 20 solar PV array and the WES250 wind turbine were designed to endure strong winds and other extreme weather events prevalent in Hopedale, guaranteeing a steady flow of electricity.

The Hopedale microgrid was designed with a resolute emphasis on sustainability and dependability, considering the local climate and the necessity to survive extreme weather occurrences. The CAT-910 diesel generator is an integral part of its resilience. It is an efficient and reliable backup power supply that is essential when weather unpredictability undermines renewable energy sources.

The microgrid takes advantage of an Eaton 2000 inverter and a bank of SAGM 12 205 batteries to improve system resilience. The electrical components are protected from environmental extremes by weather-resistant housing. Furthermore, the battery bank functions as an energy buffer, accumulating excess power to supply continuous electricity during protracted bad weather.

To account for unforeseen circumstances, the microgrid design has redundant energy flow paths, guaranteeing that a malfunction in one pathway will not cause the system to shut down entirely. In anticipation of severe weather conditions, automated weather tracking systems were integrated to adjust system operations preemptively, reducing system load as necessary and prioritizing critical services. Additionally, to preserve optimal performance and speedy disaster recovery, regular maintenance plans were created, and important system components were raised and reinforced against potential flooding or storm surge impacts.

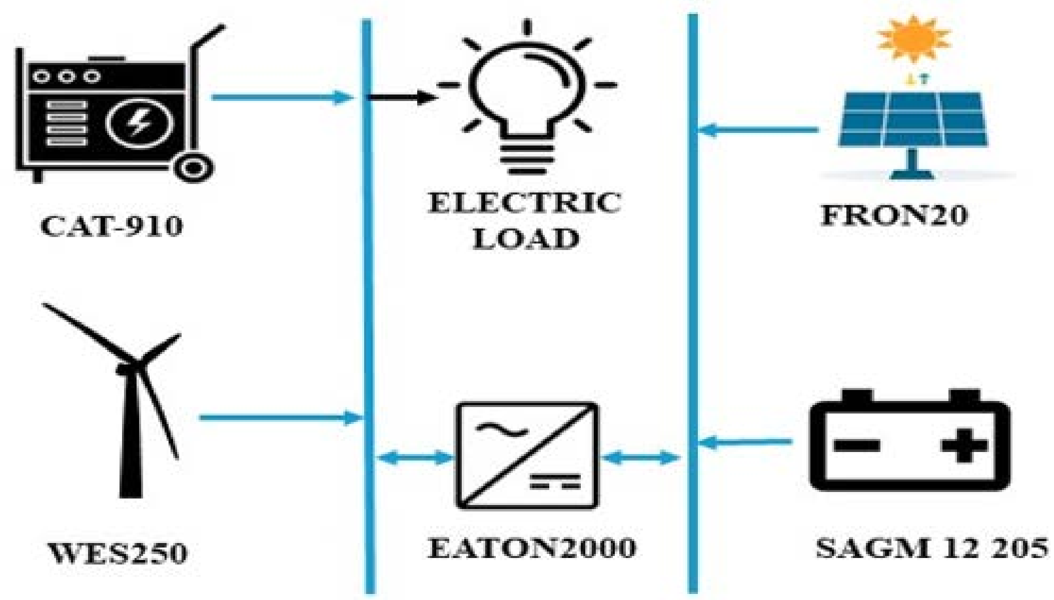


Figure 4. Schematic of the proposed system using HOMER Pro

Table 3. Component details

Input Parameters	PV Panels	Wind Turbine	Generator	Battery	Converter
Name	Fronius Symo 20.0-3-M Generic PV	WES 30 [250kW]	CAT-910kW-60 Hz – PP	Trojan SAGM 12205	Eaton Power Xpert 2000kW
Rated capacity	20 kW	250 kW	910 kW	-	-
CAPEX	\$3000, 000	\$550, 000	\$100, 000	\$600	\$6, 000
Replacement cost	\$3000, 000	\$500, 000	\$85, 000	\$500	\$4500
O&M	\$10 / year	\$40, 000/ year	\$55 / op. hour	\$50/ year	\$100 / year
Lifetime	25 years	20 years	90, 000hrs	-	15 years
Hub height	-	48	-	-	-
Fuel	-	-	Diesel	-	-
Fuel price	-	-	\$1.79/L	-	-
Minimum load ratio	-	-	25%	-	-
Nominal voltage	-	-	-	12 V	-
Nominal capacity	-	-	-	2.63kWh	-
String size	-	-	-	66	-
Voltage	-	-	-	792 V	-
Maximum capacity	-	-	-	219Ah	-
Initial state of charge	-	-	-	100%	-

The details of each component are given in Table 3. A focus on energy stability, environmental sustainability, and economic viability was placed throughout the design of the Hopedale microgrid system, especially considering the system's remote location and harsh weather.

5.2.1 PV panels

The efficiency and suitability of the Fronius Symo 20.0-3-M Generic PV panels for Hopedale's varied weather conditions contribute to their selection. With a 20 kW capacity, each panel is quite successful at converting solar radiation into electrical energy. The panels have a $3,000,000 CAPEX and a 25-year lifetime. The operating and maintenance (O&M) expenses are comparatively cheap, at $10 per panel year, and the replacement cost is equal to the initial CAPEX. Due to their adaptability to a variety of environmental circumstances, the Fronius Symo panels were selected to provide consistent energy production even during the severe weather events that are typical of the Hopedale region. Taking into account Hopedale's latitude and usual weather patterns, the panels were positioned at the ideal tilt angle to optimize sun exposure all year round.

5.2.2 Wind turbine

The wind turbines that were chosen are WES 30 [250 kW] types, each having a hub height of 48 meters and a capacity of 250 kW. With a $550,000 initial cost and a $500,000 replacement cost per turbine, these turbines have a 20-year lifetime. For every turbine, the yearly O&M expense comes to $40,000. The WES 30 turbines were made expressly to take advantage of Hopedale's strong wind energy potential, offering a reliable and steady supply of electricity. In order to sustain energy production under the region's regular high-wind conditions, the hub height was tailored to catch maximum wind energy. In order to optimize blade angles for optimal energy extraction and to guarantee safety during strong wind conditions, the turbines were fitted with advanced pitch control systems. These turbines were also equipped with a remote monitoring system for predictive maintenance, thereby reducing downtime and enabling real-time performance tracking.

5.2.3 Generator

A CAT-910kW-60Hz-PP diesel generator operates as the microgrid's backup power supply. With a minimum load ratio of 25% and a capacity of 910 kW, this generator was built to operate effectively even at lower loads. With a fuel cost of $1.79 per liter, the generator can run for 90,000 hours. The generator has an initial cost of $100,000 and a replacement cost of $85,000. Each operational hour costs $55 for O&M. The community's power demands are constantly satisfied by the CAT-910 diesel generator, which is essential for dependability at times when the output of renewable energy is insufficient. The generator has an automated start-stop mechanism that minimizes fuel consumption and lowers OPEX by turning on when battery levels are low or during times of heavy demand. The generator also satisfies the most recent Environmental Protection Agency (EPA) requirements for stationary diesel engines using cutting-edge emissions control technology to reduce its negative environmental effects.

5.2.4 Battery

Trojan SAGM 12 205 batteries were used as the microgrid's energy storage system. Each battery runs at a nominal voltage of 12V and has a capacity of 2.63 kWh. With a ten-year lifetime and a reputation for extensive cycling, these batteries are perfect for long-term energy storage. Each battery has a $600 initial cost and a $500 replacement cost. The battery's O&M expenses come out to $50 annually. Even in low-renewable generation situations, the extra power produced by solar panels and wind turbines is stored in these batteries to provide a steady supply of electricity. When renewable energy output is inadequate, the battery bank has enough capacity to sustain backup power for up to 24 hours. The batteries were integrated with a battery management system (BMS) that guarantees ideal charging and discharging cycles, thereby improving overall efficiency and safety. The batteries were placed in a climate-controlled environment to maximize performance and longevity.

5.2.5 Converter

The Eaton Power Xpert 2000kW converter plays an indispensable role in interfacing direct current (DC) and alternating current (AC) conversions within the microgrid. With a lifespan of 15 years, this converter can handle 2000 kW of power. The converter has an initial cost of $6,000, a replacement cost of $4,500, and an annual O&M cost of $100. To ensure effective energy distribution within the microgrid and to ensure that the generated power is used efficiently, the Eaton Power Xpert converter is necessary. Maximum power point tracking (MPPT) for solar inputs is one of the aspects of the converter system that improves the effectiveness of energy conversion from the solar panels. In order to guarantee dependability and safety, it also has built-in protection systems against overvoltage, overcurrent, and short-circuit situations.

5.3 Comparative Analysis

A comparison between the planned hybrid microgrid system and Hopedale's existing pure diesel power-generating system was made to demonstrate the benefits of the former, as shown in Table 4.

According to the table, compared to the currently installed diesel system, which costs $190,000, the proposed hybrid system has a greater initial CAPEX of $6.12 million. On the other hand, ongoing operating savings offset this large initial outlay. The diesel system has an OPEX of $7.21 million, while the hybrid system has a slightly higher OPEX of $7.23 million. However, the hybrid system offers considerable replacement cost savings, with $1.85 million compared to $40,409 for the diesel system. Due to the infrastructure and renewable technology investments made, the hybrid system has a higher LCOE of $0.182 per kWh than the diesel system's $0.0929 per kWh.

Table 4. Comparison between the existing and proposed systems

Parameter	Current Pure Diesel System	Proposed Hybrid System
Generators	Three diesel generators (910 kW, 500kW, 500 kW)	One diesel generator (910 kW)+ solar panels (20 kW each) + wind turbines (250 kW each) + battery storage
NPC	\$7.44 million	\$14.6 million
CAPEX	\$190,000	\$6.12 million
OPEX	\$7.21 million	\$7.23 million
Replacement cost	\$40,409	\$1.85 million
LCOE	\$0.0929 per kWh	\$0.182 per kWh
Annual diesel consumption	2,380 tons	1,053 tons (reduced by over 50%)
Annual CO_2 emissions	434 kg/ year	217 kg/ year (reduced by over 50%)
Total annual electricity production	6,193,065kWh/ year	7,036,402kWh/ year
Fuel efficiency	0.266 L/kWh (910 kW generator), 0.279 L/kWh (500 kW generators)	Improved due to the integration of renewable sources
Operational reliability	Relies solely on diesel generators	Solar, wind, battery storage with diesel backup
Environmental impact	High due to diesel dependency	Lower due to reduced diesel usage
Sustainability and resilience	Vulnerable to fuel supply disruptions	Enhanced by diverse energy sources and local renewable resources

The hybrid system has significant advantages in terms of the environment. In comparison to the 2,380 tons of fuel used by the diesel system, it achieves an annual reduction of nearly 50% to 1,053 tons of diesel use. By switching from a diesel system that produces 434 kg of carbon dioxide (CO_2) emissions per year to a hybrid system that produces 217 kg, the diesel system's yearly CO_2 emissions can be significantly reduced. This change emphasizes the system's potential for sustainability. The combination of solar, wind, and battery storage in a hybrid system enhances operational dependability by delivering a steady power supply even when renewable energy production is scarce. But the diesel system depends only on diesel generators, which are more likely to have problems with upkeep and operation.

By employing locally available renewable energy, reducing reliance on imported diesel fuel, and lowering the risk of fuel supply disruptions, the hybrid system also increases sustainability and resilience. Furthermore, it raises the total annual power generation from 6,193,065 kWh/year from the diesel system to 7,036,402 kWh/year.

Therefore, the suggested hybrid microgrid system provides a more economical, ecologically friendly, and sustainable substitute for the existing pure diesel power generation system. It not only caters to the specific energy requirements of the Hopedale community but also fosters sustainability and resilience in the long run.

6 Results and Discussion

The findings from the HOMER Pro simulation for the proposed hybrid system are presented in this section.

6.1 The System Selected by HOMER Pro

Using HOMER Pro software, a thorough simulation was conducted to design a reliable and effective hybrid energy system for the Hopedale community. A total of 17,024 system designs covering a range of diesel generator capacities and battery technologies were put to the test by HOMER Pro as part of the investigation, aiming to find the design that could result in the lowest NPC at the beginning of the project. Of all the scenarios that HOMER Pro examined, 9,255 were found to be feasible, meeting the predetermined goals and guaranteeing a steady supply of electricity. It was determined by HOMER that the other layouts were not possible, mostly because of deficiencies like inadequate power generation or missing necessary parts like converters. Table 5 shows the three best system architectures and their costs.

Table 5. Optimization results for different system architectures

Design	PV Array (kW)	Diesel Generator (kW)	Wind Turbine (ea.)	Battery (kW)	Converter (kW)	NPC (\$)	Diesel Fuel (tons/year)
1	40.9	910	4	1,122	504	14.6M	1,053
2	87.9	500	6	3,432	895	21.8M	683
3	-	500		3.498	886	21.6M	690

Based on the platform's insights into different configurations and their impacts, Table 6 shows the optimal system configuration for the community.

Table 6. System architecture selected by HOMER Pro

Component	Name	Size	Unit
Generator#1	CAT-910kW-60Hz-PP	910	kW
PV	Fronius Symo 20.0-3-M with Generic PV	40.9	kW
PV dedicated converter	Fron20 converter	20.0	kW
Storage	Trojan SAGM 12 205	17	strings
Wind turbine	WES 30 [250kW]	4	ea.
System converter	Eaton Power Xpert 2000kW	504	kW
Dispatch strategy	HOMER Cycle Charging		

6.2 Electrical Summary

Results showed a notable variation in the output of different components when the energy production and consumption for the given system were analyzed. By producing 42,852 kWh annually, the Fronius Symo 20.0-3-M with Generic PV contributed 0.609% of the total energy output for the production summary. 37.8% of the total production, or 2,661,747 kWh/yr, was produced by the CAT-910kW-60Hz-PP. With 4,331,803 kWh generated annually, or 61.6% of the overall production, the WES 30 [250kW] made the largest contribution. In all, 7,036,402 kWh of energy were produced annually by the system. The system's production summary is given in Figure 5.

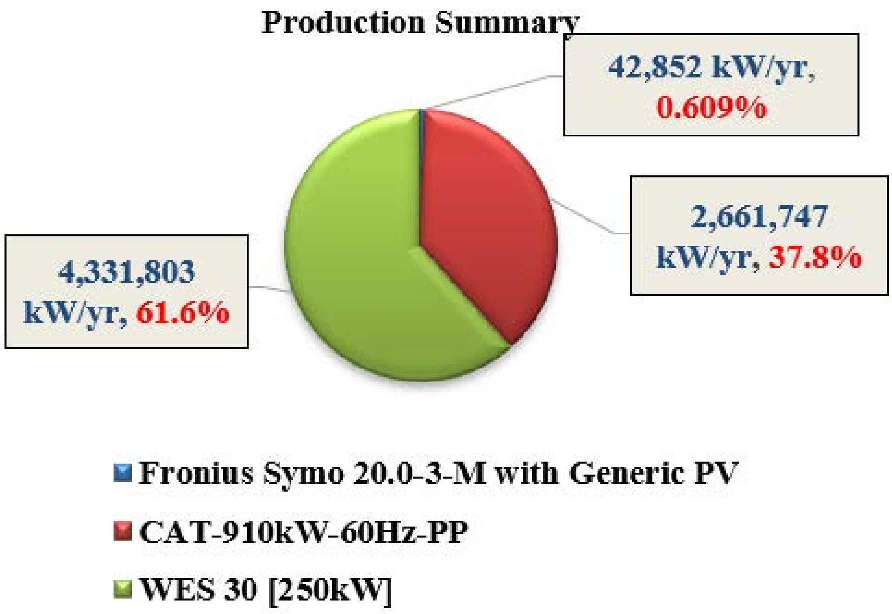


Figure 5. Annual production of each component

Table 7 shows the consumption summary of the proposed system. It can be observed from the table that a single item of the AC primary load represents 100% of the entire energy consumption reported for the time, with an annual usage of 6,191,416 kWh. Notably, neither DC primary load nor deferrable load consumptions were recorded, which accounts for 0% of the total.

Table 7. Consumption summary the proposed system

Component	Consumption (kWh/yr)	Percent
AC primary load	6, 191, 416	100
DC primary load	0	0
Deferrable load	0	0
Total	6, 191, 416	100

After the analysis of production and consumption, a detailed energy profile was displayed in the excess and deficit numbers, as shown in Table 8. The surplus power (excess electricity) generation of the system was 824,469 kWh annually. The unmet electric load, on the other hand, was significantly smaller at 1,539 kWh/year with a 6,161 kWh/year capacity shortfall. With periodic demand-side fluctuations, these measurements demonstrate a production capacity that is generally sufficient.

Table 8. Excess electricity, unmet electric load, and capacity storage of the system

Quantity	Value	Unit
Excess electricity	824,469	kWh/yr
Unmet electric load	1,539	kWh/yr
Capacity shortage	6,161	kWh/yr

Figure 6 shows the monthly electric production by each component of the hybrid system in graphical format. The production of the Fronius Symo solar panels remains steady, reaching a small peak of 4697 kWh in April, indicating the best sunlight gain throughout the spring. With an astounding 3082 kWh in February, the WES 30 wind turbine demonstrates its maximum output while harnessing the strong winter wind currents. The CAT-910 diesel generator is a vital component that guarantees energy dependability during times of reduced renewable output. It makes a significant contribution, especially in January when it generates over 455k kWh. This combination of energy sources, with their variable monthly outputs, serves as the foundation for a flexible and robust power system.

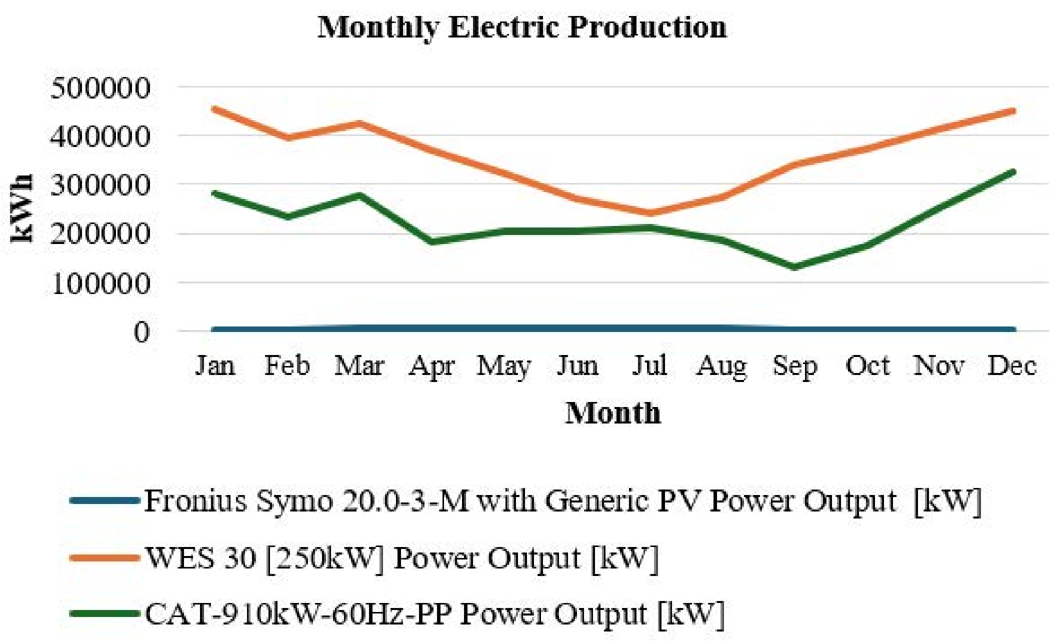


Figure 6. Monthly electrical production using HOMER Pro

6.3 Fuel Summary

As shown in Table 9, the fuel analysis outlines a total diesel consumption of 1,053 tons annually, with an average daily usage of 2.89 tons, breaking down to 0.120 tons per hour. The accompanying density plot shown in Figure 7 reveals temporal fluctuations in hourly diesel usage throughout the year, underscoring the operational dynamics.

Table 9. Fuel summary

Quantity	Value	Unit
Total feedstock consumed	1,053	tons
Avg feedstock per day	2.89	tons / day
Avg feedstock per hour	0.120	tons / hour

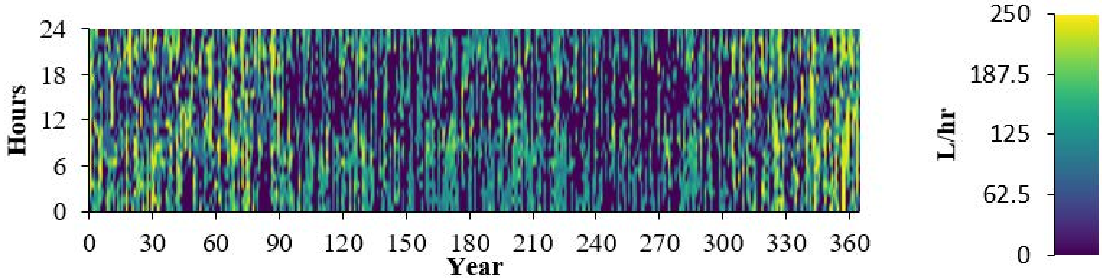


Figure 7. Graphical representation of fuel summary

6.4 Cost Summary

6.4.1 NPC and annualized cost of each component

Table 10 presents the financial analysis of the Hopedale hybrid energy system and breaks down the NPC of each component. Combining the values of CAPEX, OPEX, and replacement and salvage costs, the system's total NPC value is $14.6 million. The CAT-910kW-60Hz-PP generator represents a significant component of the CAPEX at $100,000. For its lifetime, OPEX will reach $3.78 million, making the total NPC value of $3.90 million after deducting the salvage value. Similarly, the Eaton Power Xpert 2000kW converter has a $4.46 million total NPC value due to its $3.03 million initial investment and high OPEX. At $122,847 and $2.20 million, respectively, the Fronius PV panels and WES wind turbine have high beginning expenses. However, over the long run, their OPEX is significantly less, resulting in a total NPC value of $28,141 for the PV and $4.55 million for the wind turbine.

Table 10. NPC of all the components

Name	**CAPEX** ($)	**OPEX** ($)	**Replacement Cost** ($)	**Salvage Cost** ($)	**Resource Cost** ($)	**Total Cost** ($)
CAT-910kW-60Hz-PP	100,000	3.78M	32,308	$-10,645$	0.00	3.90M
Eaton Power Xpert 2000kW	3.03M	652,109	963,083	$-181,262$	0.00	4.46M
Fronius Symo 20.0-3-M with Generic PV	122,847	5,294	0.00	0.00	0.00	$28,141
Trojan SAGM 12205	673,200	725,234	218,440	$-65,180$	0.00	1.55M
WES 30 [250kW]	2.20M	2.07M	637,615	$-359,337$	0.00	4.55M
System	6.12M	7.23M	1.85M	$-616,424$	0.00	14.6M

A breakdown of the annualized costs is given in Table 11, which separates the costs for each system component annually. Although the CAT-910kW-60Hz-PP generator has a lower yearly CAPEX, its high OPEX ($292,490) adds up to an annualized total of $301,901 when salvage and replacement are considered. The Eaton Power Xpert and WES wind turbines, with yearly totals of $345,042 and $351,706, respectively, demonstrate a balance between CAPEX and OPEX. When considering their replacement cycle, the Trojan SAGM 12 205 batteries exhibit a noticeable OPEX, resulting in a yearly cost of $120,030. It can be seen from the table that the system's overall yearly cost comes to $1.13 million.

Table 11. Annualized cost of all the components

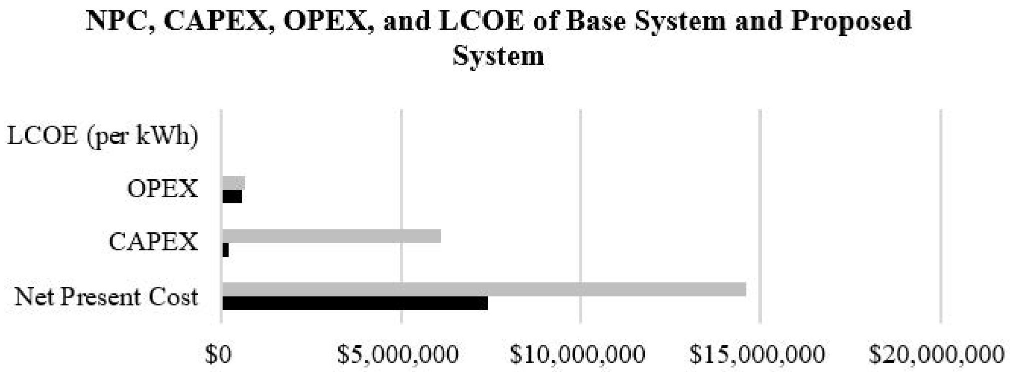
Name	**CAPEX**	**OPEX**	**Replacement** ($)	**Salvage** ($)	**Resource Cost** ($)	**Total Cost** ($)
CAT-910kW-60Hz-PP	7,735	292,490	2,499	-823.44	0.00	301,901
Eaton Power Xpert 2000kW	234,121	50,443	74,499	$-14,021$	0.00	345,042
Fronius Symo 20.0-3-M with Generic PV	9,503	409.49	0.00	0.00	0.00	9,912
Trojan SAGM 12 205	52,075	56,100	16,897	$-5,042$	0.00	120,030
WES 30 [250kW]	170,180	160,000	49,322	$-27,796$	0.00	351,706
System	473,614	559,443	143,217	$-47,683$	0.00	1.13M

The base system's NPC is \$3.36 million, which is less than that of the proposed system (\$5.25 million). The OPEX (Operational Expenditure) costs of the proposed system are also less than those of the base system. The suggested approach, however, shows a notable reduction in environmental impact, with fuel consumption falling from 797 liters a year to 360 liters annually and CO_2 emissions falling from 144 kg/yr to 64.4 kg/yr. The suggested system has a higher CAPEX of \$325,800 as opposed to the base system.

According to the comparison of LCOE figures, diesel-based generation costs \$0.131 per kWh, whereas the suggested hybrid system costs \$0.204. There are several explanations for this disparity. First, compared to diesel generator installations, the initial CAPEX for renewable energy infrastructure such as solar panels and wind turbines is often higher. In addition, even if fuel costs for renewable energy sources are low, the hybrid system's entire life cycle costs are greatly increased by regular battery replacements and continuous maintenance. Although the proposed system's LCOE is greater as opposed to that of the base system, the significant environmental benefits point to a potential trade-off that could be acceptable given the objectives of eco-friendly and sustainable energy generation.

6.4.2 Cost comparison between the base and proposed systems

Figure 8 shows the comparison between the base and proposed systems in terms of cost.



	Net Present Cost	CAPEX	OPEX	LCOE (per kWh)
Proposed System	\$14,600,000	6120000	\$654,977	\$0.18
Base System	\$7,440,000	\$190,000	\$560,484	\$0.09

Proposed System ■ Base System

Figure 8. NPC, CAPEX, OPEX, and LCOE of the base and proposed systems

(a) NPC

The proposed system's NPC of \$14.6 million is significantly higher than the base system's \$7.44 million. On the other hand, OPEX exhibits a distinct pattern, with the proposed system incurring slightly more costs. Despite the greater initial CAPEX, this is in line with the worldwide demand for greener energy alternatives.

(b) LCOE

The LCOE is critical financial data. The LCOE of the proposed hybrid system was calculated at \$0.182 per kWh, which is more expensive than typical diesel generation. This rise can be attributed to the upfront CAPEX required for the integration of renewable energy technology. While the operating fuel costs for renewables are lower, the overall lifespan prices are higher because of the ongoing maintenance and replacement battery costs. The costs of renewable energy components and batteries are expected to decrease due to technological advancements and increased production scale, improving the hybrid system's economic viability. While the base system's LCOE (\$0.09 per kWh) is lower than that of the proposed system (\$0.18 per kWh), the use of renewable energy sources lessens the reliance on fuel with unstable prices. The suggested system's dependence on wind and solar energy can result in significant savings over time, as fuel costs are predicted to grow owing to market swings and possible carbon taxes. The benefits to the environment also provide a strong case for the system's adoption. A dedication to environmentally responsible behavior and sustainable practices is embodied by the noticeable decrease in carbon emissions. A longer-term reduction in OPEX is expected to make the hybrid system more cost-effective than a diesel-only configuration, which is why the higher initial LCOE represents a strategic investment in a greener future.

(c) CAPEX

Compared to the current system, which costs $190,000, the proposed system will cost $6.12 million in CAPEX. The reason for this disparity is the upfront cost of advanced renewable energy technology, which is usually greater than that of traditional diesel generators when it comes to installation and commissioning.

(d) OPEX

When comparing OPEX, there is not much of a difference between the basic system's $560,484 and the proposed system's $654,977. Despite the intricate design of the proposed hybrid system, this suggests that the ongoing O&M expenses for both systems are similar.

The thorough cost assessment over a predicted lifespan of 20-25 years is the basis of the economic study of the suggested hybrid RES for Makkovik. The choice of this duration was made to account for the 20–25-year average operating lifecycle of main system components, such as wind turbines and solar panels. Costs during this time were broken down into four categories: replacement costs, possible salvage costs after the project, O&M expenses, and initial CAPEX. It is anticipated that throughout this time, market conditions and technological developments will have a substantial impact on the cost trajectory of renewable energy solutions. Historically, advances in materials science, manufacturing techniques, and economies of scale have caused a steady decrease in the cost of renewable energy components, most notably solar PV modules and wind turbines [43, 44]. A continuation of this cost drop can be foreseen, making renewable energy more competitive with conventional energy sources, based on industry estimates and historical trends. It is anticipated that over the next ten years, the cost of wind turbines and solar PV will drop by 20-30%, significantly improving the financial sustainability of renewable energy projects. Additionally, advances in battery storage technology might lead to more affordable and efficient energy storage systems, which are essential for controlling the erratic nature of renewable energy sources [45]. The estimated NPC and LCOE estimates are based on these predicted improvements in technology costs and performance, which are essential to the project's economic analysis. This study offers a more precise and realistic financial picture for the installation of the hybrid RES in Makkovik throughout its anticipated operational lifetime by taking these dynamic cost trends into account.

6.5 Emission Summary

As demonstrated by HOMER Pro results, a comparative analysis of emissions from the base and proposed energy systems for Hopedale, as shown in Figure 9, reveals significant differences in environmental impact. The proposed system shows a significant decrease in CO_2 emissions, with values falling from 434 kg per year on the base to 192 kg per year, which is an astonishing 55.8% reduction. Carbon monoxide (CO) emissions, which have more than halved from 1.33 kg per year to 0.632 kg per year, are also a reflection of this significant reduction. In addition, the proposed system shows that it has better performance at reducing these pollutants by 55.6% and 55.9% in terms of unburned hydrocarbons and particulate matter. The nitrogen oxides are the most significant difference, with the proposed system emitting 18.2 kg per year, a reduction of 56.8% compared to the base system's 42.1 kg per year.

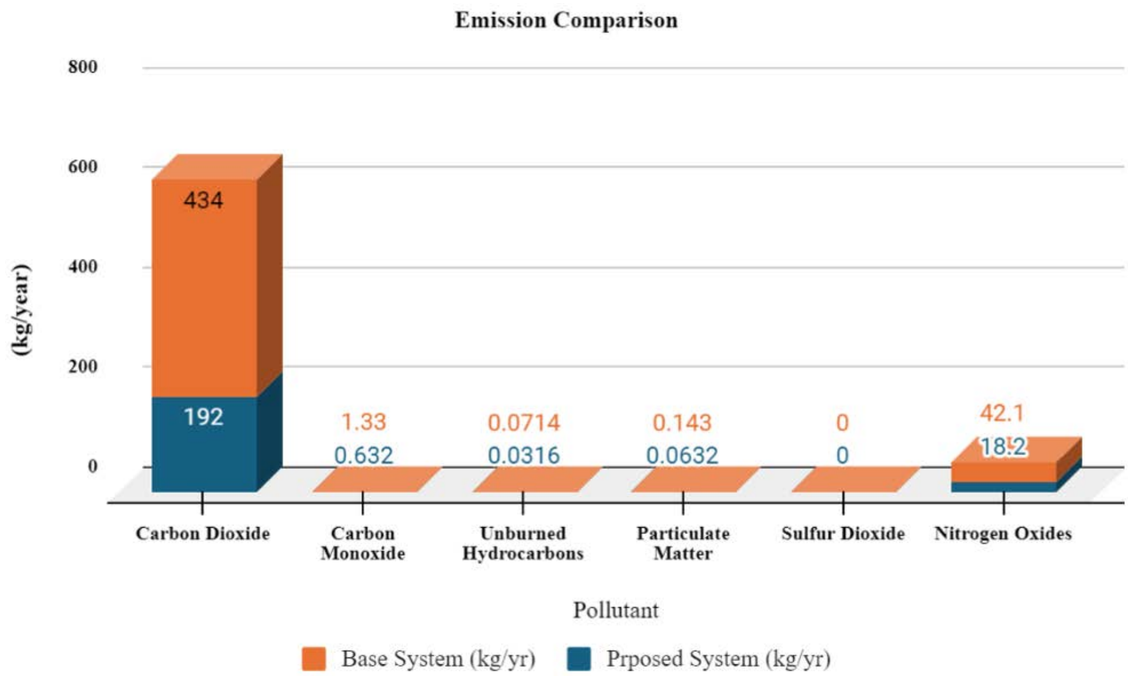


Figure 9. Emission comparison between the base and proposed systems

These findings are significant, as they not only emphasize the potential of the proposed framework in checking greenhouse gas emanations but also its viability in essentially reducing the discharge of pollutants that contribute to smog and respiratory issues. The absence of sulfur dioxide (SO_2) in both systems may be a positive commonality, indicating compliance with rigid emanation controls. This data supports the proposed system's advancements over the conventional setup, marking a significant step towards environmental sustainability and aligning with global efforts to reduce the carbon footprint of energy generation.

6.6 Applicability of the System

The existing energy consumption scenario was examined and future demand was anticipated to make sure that the proposed hybrid microgrid system is suitable for the Hopedale community's consumer demand. This thorough analysis considers the community's unique energy consumption practices, the availability of renewable energy resources, and the expected rise in demand.

6.6.1 Present scenario regarding energy use in Hopedale

Hopedale at this instant gets its power from three diesel generators, each with a capacity of 500 kW, 910 kW, and 500 kW. The total annual generation of power is around 6,193,065 kWh. All through the long, severe winters, when temperatures often dip below freezing, a large amount of this energy is used for heating. The reliance on diesel generators, which require 2,380 tons of diesel annually, results in a significant OPEX. Due to this usage, substantial CO_2 emissions are produced and calculated to be approximately 434 kg each year, which adds to pollution in the environment and the buildup of greenhouse gases.

6.6.2 Hopedale's renewable energy resources

There is a great deal of potential for producing renewable energy in the area. With an average yearly solar insolation of 2.83 $\mathrm{kWh/m^2/}$ day, the solar irradiance levels are sufficient for PV panels to operate well. Hopedale's coastline position makes it perfect for wind turbine construction because it consistently experiences high winds of 7.94 m/s. The community's reliance on diesel generators may be greatly decreased by utilizing these renewable energy sources.

6.6.3 Scalability and system design

The proposed hybrid system was designed to be simultaneously scalable to handle future expansion and capable of meeting present energy demands. PV panels, wind turbines, battery storage, and a diesel generator are all parts of the system that were selected for their dependability and effectiveness. If additional PV panels and wind turbines are required, the basic layout may be extended to ensure that the system can continue to satisfy the community's changing energy demands. Battery storage was integrated into systems to improve their dependability by supplying backup power and mitigating changes in energy supply and demand, ensuring a steady and consistent energy output.

7 Conclusions

By studying the development of a hybrid microgrid for Hopedale, this research highlighted the delicate balance between the integration of renewable energy sources and financial sustainability, therefore illuminating a route toward sustainable energy autonomy for isolated settlements. Through a careful assessment of the viability of integrating solar and wind power with cutting-edge energy storage systems and a standby diesel generator, the possibility of considerably diminishing dependency on fossil fuels was validated in this study, promoting ecological responsibility and augmenting regional energy resilience. The results show that although the suggested hybrid microgrid system initially has a higher LCOE than conventional diesel production, there are strong arguments in favor of its adoption due to the long-term environmental and financial advantages. The system has the potential to be a game-changing energy solution for Hopedale and other remote towns because of its ability to reduce greenhouse gas emissions by more than 50% and its estimated significant reduction in OPEX.

The proposed hybrid energy system for Hopedale was evaluated financially, accounting for expenses throughout the project's anticipated 20-25-year lifespan. Due to the higher CAPEX of renewable technologies, the system's LCOE, now $0.182 per kWh, is greater within this range than that of diesel production. However, as technology develops, these numbers might fluctuate and not be constant. Advances in material science, manufacturing techniques, and economies of scale are predicted to drive additional cost reductions in renewable energy technology over the next decades, with solar and wind turbines expected to benefit. Similar benefits from cost-cutting and lifespan-extending technological advancements are anticipated for battery storage systems. These expected advances point to a potential reduction in the hybrid system's LCOE, making it more financially appealing than generation based on fossil fuels. Furthermore, the system's environmental advantages, which play a major role in the decision to choose it, support a more sustainable energy strategy. Given the trend of technological prices, which are expected to decline, the project's higher LCOE is a calculated strategic investment that will eventually validate the original investment and confirm the project's viability as a long-term sustainable energy option.

Nevertheless, this study has several limitations. Although HOMER Pro's dependence on simulation data and assumptions offers insightful information, it is not possible to fully evaluate system performance and scalability without empirical validation through pilot projects or real-world deployments. To close these gaps, future research should focus on longitudinal studies that monitor the operational and financial performance of hybrid microgrids that have been put into service. The feasibility and appeal of such systems for isolated populations might be further improved by research into cutting-edge renewable technology and creative finance strategies. Furthermore, ensuring the effective adoption and sustainability of these energy solutions would require collaborating with community stakeholders to match the designs of the energy systems with local requirements and values.

Overall, the proposed hybrid microgrid is a viable and sustainable energy solution for Hopedale. It also provides a model for isolated communities around the world to deal with the difficulties associated with energy transition. This study makes a substantial contribution to the conversation about the adoption of renewable energy sources and lays the groundwork for further investigations targeted at attaining global energy sustainability and resilience.

Acknowledgment

The authors are grateful to Minister Andrew Parsons (Minister of Industry, Energy, and Technology in the Province of Newfoundland and Labrador, Canada) for his inspiration and assistance in promoting renewable energy for remote communities. We would also like to thank Deputy Minister John Cowan for his dedication and support through government resources. Additionally, we are especially appreciative of Mr. Daniel J. Villeneuve, CEO of Great Northern Port Inc., for generously sharing his extensive knowledge and providing exceptional support.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] "The global energy landscape is going through major shifts: What does this mean for value pools in energy?" McKinsey & Company, 2021. https://www.mckinsey.com/industries/oil-and-gas/our-insights/oil-and-gas-blog/the-global-energy-landscape-is-going-through-major-shifts-what-does-this-mean-for-energy-value-pools

[2] "Rising to the challenges of integrating solar and wind at scale," BCG, 2021. https://www.bcg.com/publications/2021/addressing-variable-renewable-energy-challenges

[3] "NREL study identifies the opportunities and challenges of achieving the U.S. transformational goal of 100% clean electricity by 2035," Office of Energy Efficiency & Renewable Energy, 2022. https://www.energy.gov/eere/articles/nrel-study-identifies-opportunities-and-challenges-achieving-us-transformational-goal

[4] Q. Hassan, S. Algburi, A. Z. Sameen, H. M. Salman, and M. Jaszczur, "A review of hybrid renewable energy systems: Solar and wind-powered solutions: Challenges, opportunities, and policy implications," *Results Eng.*, vol. 20, p. 101621, 2023. https://doi.org/10.1016/j.rineng.2023.101621

[5] R. Elazab, A. A. Dahab, M. A. Adma, and H. A. Hassan, "Reviewing the frontier: Modeling and energy management strategies for sustainable 100% renewable microgrids," *Discover Appl. Sci.*, vol. 6, p. 168, 2024. https://doi.org/10.1007/s42452-024-05820-6

[6] M. Uddin, H. Mo, D. Dong, S. Elsawah, J. Zhu, and J. M. Guerrero, "Microgrids: A review, outstanding issues and future trends," *Energy Strategy Rev.*, vol. 49, p. 101127, 2023. https://doi.org/10.1016/j.esr.2023.101127

[7] Editorial, "Clean energy can fuel the future — and make the world healthier," *Nature*, vol. 620, no. 7973, p. 245, 2023. https://doi.org/10.1038/d41586-023-02510-y

[8] J. Jiang, L. W. Zhang, X. Wen, E. Valipour, and S. Nojavan, "Risk-based performance of power-to-gas storage technology integrated with energy hub system regarding downside risk constrained approach," *Int. J. Hydrogen Energy*, vol. 47, no. 93, pp. 39 429–39 442, 2022. https://doi.org/10.1016/j.ijhydene.2022.09.115

[9] D. Gielen, F. Boshell, D. Saygin, M. D. Bazilian, N. Wagner, and R. Gorini, "The role of renewable energy in the global energy transformation," *Energy Strategy Rev.*, vol. 24, pp. 38–50, 2019. https://doi.org/10.1016/j.esr.2019.01.006

[10] B. M. Opeyemi, "Path to sustainable energy consumption: The possibility of substituting renewable energy for non-renewable energy," *Energy*, vol. 228, p. 120519, 2021. https://doi.org/10.1016/J.ENERGY.2021.120519

[11] T. Stringer and M. Joanis, "Decarbonizing Canada's remote microgrids," *Energy*, vol. 264, p. 126287, 2023. https://doi.org/10.1016/J.ENERGY.2022.126287

[12] M. J. B. Kabeyi and O. A. Olanrewaju, "Sustainable energy transition for renewable and low carbon grid electricity generation and supply," *Front. Energy Res.*, vol. 9, p. 743114, 2022. https://doi.org/10.3389/fenrg.2021.743114

[13] "Geographical names data base," Natural Resources Canada, 2024. https://geonames.nrcan.gc.ca/search-place-names/unique?id=AAKDE

[14] "Hopedale, Newfoundland and Labrador Canada," Come Explore Canada, 2024. https://www.comeexplorecanada.com/newfoundland-labrador/hopedale

[15] N. S. Vurur, "The nexus between urbanization, renewable energy, financial development, and economic growth: Evidence from Turkey," *J. Corp. Gov. Insur. Risk Manag.*, vol. 9, no. 2, pp. 316–326, 2022. https://doi.org/10.56578/JCGIRM090202

[16] R. A. Al Hasibi and A. Haris, "An analysis of the implementation of a hybrid renewable-energy system in a building by considering the reduction in electricity price subsidies and the reliability of the grid," *Clean Energy*, vol. 7, no. 5, pp. 1125–1135, 2023. https://doi.org/10.1093/ce/zkad053

[17] S. Ahmed, A. Ali, and A. D'Angola, "A review of renewable energy communities: Concepts, scope, progress, challenges, and recommendations," *Sustainability*, vol. 16, no. 5, p. 1749, 2024. https://doi.org/10.3390/su16051749

[18] K. K. Sharma, A. Gupta, R. Kumar *et al.*, "Economic evaluation of a hybrid renewable energy system (HRES) using hybrid optimization model for electric renewable (HOMER) software—A case study of rural India," *Int. J. Low-Carbon Technol.*, vol. 16, no. 3, pp. 814–821, 2021. https://doi.org/10.1093/ijlct/ctab012

[19] F. Farahmand, J. King, D. Ghahremanlou, P. Sakthi, and M. R. M. Jafari, "A comprehensive systematic overview of Canadian hydrogen supply chains downstream," *J. Sustain. Dev.*, vol. 17, no. 2, 2024. https://doi.org/10.5539/jsd.v17n2p1

[20] P. Sakthi, D. Ghahremanlou, and A. B. A. Q. Lardi, "Sustainable hydrogen production, storage, and distribution – a systematic review for Newfoundland and Labrador," *J. Sustain. Dev.*, vol. 17, no. 1, 2024. https://doi.org/10.5539/JSD.V17N1P1

[21] S. Kotian and D. Ghahremanlou, "Design for hybrid power system in Newfoundland and Labrador: A case study for Nain," *Eur. J. Electr. Eng. Comput. Sci.*, vol. 8, no. 1, pp. 1–5, 2023. https://doi.org/10.24018/ejece.2024.8.1.598

[22] J. Li, P. Liu, and Z. Li, "Optimal design of a hybrid renewable energy system with grid connection and comparison of techno-economic performances with an off-grid system: A case study of west China," *Comput. Chem. Eng.*, vol. 159, p. 107657, 2022. https://doi.org/10.1016/J.COMPCHEMENG.2022.107657

[23] K. V. Konneh, H. Masrur, M. L. Othman, and T. Senjyu, "Performance assessment of a hybrid complementary power system for sustainable electrification: A case study," *Sustain. Cities Soc.*, vol. 76, p. 103412, 2022. https://doi.org/10.1016/j.scs.2021.103412

[24] T. Chowdhury, S. Hasan, H. Chowdhury *et al.*, "Sizing of an island standalone hybrid system considering economic and environmental parameters: A case study," *Energies*, vol. 15, no. 16, p. 5940, 2022. https://doi.org/10.3390/en15165940

[25] S. S. H. Dehshiri, "A new application of multi criteria decision making in energy technology in traditional buildings: A case study of Isfahan," *Energy*, vol. 240, p. 122814, 2022. https://doi.org/10.1016/j.energy.2021.122814

[26] S. Kotian, A. Maliat, A. Azeez, and T. Iqbal, "Design and simulation of a hybrid energy system for Ramea Island, Newfoundland," in *2022 IEEE 13th Annual Information Technology, Electronics and Mobile Communication Conference, Vancouver, BC, Canada*, 2022, pp. 589–595. https://doi.org/10.1109/IEMCON56893.2022.9946552

[27] A. Osmani and J. Zhang, "Optimal grid design and logistic planning for wind and biomass based renewable electricity supply chains under uncertainties," *Energy*, vol. 70, pp. 514–528, 2014. https://doi.org/10.1016/J.ENERGY.2014.04.043

[28] S. M. Hakimi and S. M. Moghaddas-Tafreshi, "Optimal sizing of a stand-alone hybrid power system via particle swarm optimization for Kahnouj area in south-east of Iran," *Renew Energy*, vol. 34, no. 7, pp. 1855–1862, 2009.

[29] W. Y. Won, H. Kwon, J. H. Han, and J. Kim, "Design and operation of renewable energy sources based hydrogen supply system: Technology integration and optimization," *Renew. Energy*, vol. 103, pp. 226–238, 2017. https://doi.org/10.1016/J.RENENE.2016.11.038

[30] A. H. Nebey, "Design of optimal hybrid power system to provide reliable supply to rural areas of Ethiopia using MATLAB and Homer," *Renew. Wind Water Sol.*, vol. 8, no. 1, pp. 1–7, 2021. https://doi.org/10.1186/S40807-021-00067-W

[31] L. Khalil, K. L. Bhatti, M. A. I. Awan, M. Riaz, K. Khalil, and N. Alwaz, "Optimization and designing

of hybrid power system using HOMER Pro," *Mater. Today Proc.*, vol. 47, pp. S110–S115, 2021. https://doi.org/10.1016/J.MATPR.2020.06.054

[32] T. M. I. Riayatsyah, T. A. Geumpana, I. M. R. Fattah, S. Rizal, and T. M. I. Mahlia, "Techno-economic analysis and optimisation of campus grid-connected hybrid renewable energy system using HOMER grid," *Sustainability*, vol. 14, no. 13, p. 7735. https://doi.org/10.3390/SU14137735

[33] I. A. Jumare, R. Bhandari, and A. Zerga, "Assessment of a decentralized grid-connected photovoltaic (PV) / wind / biogas hybrid power system in northern Nigeria," *Energy, Sustain. Soc.*, vol. 10. https://doi.org/10.1186/s13705-020-00260-7

[34] A. Ghaffari and A. Askarzadeh, "Design optimization of a hybrid system subject to reliability level and renewable energy penetration," *Energy*, vol. 193, p. 116754, 2020. https://doi.org/10.1016/J.ENERGY.2019.116754

[35] A. Maliat, S. Kotian, and D. Ghahremanlou, "Assessment of a hybrid renewable energy system incorporating wind, solar, and storage technologies in Makkovik, Newfoundland and Labrador," *J. Sustain. Energy*, vol. 3, no. 2, pp. 87–104, 2024. https://doi.org/10.56578/jse030203

[36] F. Farahmand, S. Kotian, A. Maliat, and D. Ghahremanlou, "Hybrid energy system development for Natuashish," *Eur. J. Electr. Eng. Comput. Sci.*, vol. 8, no. 2, pp. 71–76, 2024. https://doi.org/10.24018/ejece.2024.8.2.613

[37] S. M. N. Hasan, S. Ahmad, A. F. Liaf *et al.*, "Techno-economic performance and sensitivity analysis of an off-grid renewable energy-based hybrid system: A case study of Kuakata, Bangladesh," *Energies*, vol. 17, no. 6, p. 1476, 2024. https://doi.org/10.3390/EN17061476

[38] I. Worighi, A. Maach, A. Hafid, O. Hegazy, and J. V. Mierlo, "Integrating renewable energy in smart grid system: Architecture, virtualization and analysis," *Sustain. Energy Grids Netw.*, vol. 18, p. 100226, 2019. https://doi.org/10.1016/J.SEGAN.2019.100226

[39] M. H. Jahangir, A. Shahsavari, and M. A. V. Rad, "Feasibility study of a zero emission PV/wind turbine/wave energy converter hybrid system for stand-alone power supply: A case study," *J. Clean. Prod.*, vol. 262, p. 121250, 2020. https://doi.org/10.1016/j.jclepro.2020.121250

[40] M. M. Ahmadi, H. Hosseinzadeh-Bandbafha, Q. D. Le *et al.*, "A multi-approach framework for developing feasible, viable, and sustainable hybrid energy systems in remote areas: The case of Con Dao Island in Vietnam," *J. Clean. Prod.*, vol. 426, p. 139072, 2023. https://doi.org/10.1016/J.JCLEPRO.2023.139072

[41] J. de la Cruz-Soto, I. Azkona-Bedia, N. Velazquez-Limon, and T. Romero-Castanon, "A techno-economic study for a hydrogen storage system in a microgrid located in Baja California, Mexico. Levelized cost of energy for power to gas to power scenarios," *Int. J. Hydrogen Energy*, vol. 47, no. 70, pp. 30 050–30 061, 2022. https://doi.org/10.1016/J.IJHYDENE.2022.03.026

[42] S. W. Chisale, S. Eliya, and J. Taulo, "Optimization and design of hybrid power system using HOMER Pro and integrated CRITIC-PROMETHEE II approaches," *Green Technol. Sustain.*, vol. 1, no. 1, p. 100005, 2023. https://doi.org/10.1016/j.grets.2022.100005

[43] A. AlHammadi, N. Al-Saif, A. S. Al-Sumaiti, M. Marzband, T. Alsumaiti, and E. Heydarian-Forushani, "Techno-economic analysis of hybrid renewable energy systems designed for electric vehicle charging: A case study from the United Arab Emirates," *Energies*, vol. 15, no. 18, p. 6621, 2022. https://doi.org/10.3390/en15186621

[44] M. Manas, S. Sharma, K. S. Reddy, and A. Srivastava, "A critical review on techno-economic analysis of hybrid renewable energy resources-based microgrids," *J. Eng. Appl. Sci.*, vol. 70, p. 148, 2023. https://doi.org/10.1186/s44147-023-00290-w

[45] T. F. Agajie, A. Ali, A. Fopah-Lele, I. Amoussou, B. Khan, C. L. R. Velasco, and E. Tanyi, "A comprehensive review on techno-economic analysis and optimal sizing of hybrid renewable energy sources with energy storage systems," *Energies*, vol. 16, no. 2, p. 642, 2023. https://doi.org/10.3390/en16020642