Grid-Connected Solar-Biogas Power System for Cost Mitigation and Sustainability in a Bangladeshi University: A HOMER Pro Approach

Md. Feroz Ali[1], Md. Abdul Halim[2]

[1]Assistant Professor, Department of Electrical and Electronic Engineering, Pabna University of Science and Technology (PUST), Pabna-6600, Bangladesh
[2]M.Sc. Engineering Student, Department of Electrical and Electronic Engineering, Pabna University of Science and Technology (PUST), Pabna-6600, Bangladesh

Abstract

This study examines the feasibility and impact of a solar-biogas power system integration at Pabna University of Science and Technology (PUST) in Bangladesh, optimized using HOMER Pro software. The main goal is to reduce energy costs and carbon emissions within the university. The proposed system combines solar and biogas with the existing grid, using net metering for enhanced efficiency and sustainability. The financial analysis shows a Total Net Present Cost (NPC) of BDT 231,587,200.00 with a competitive Levelized Cost of Energy (COE) at BDT 1.49 per kWh. The Internal Rate of Return (IRR) is 18.4%, with a payback period of 4.89 years, emphasizing the system's economic viability. Environmentally, it significantly reduces CO_2 emissions from 1,960,780 kg to 840,268 kg annually, aligning with the university's sustainability goals. This study highlights the potential of renewable energy integration in Bangladeshi academic institutions, offering valuable insights for similar initiatives.

Keywords: Grid-Connected Solar-Biogas Power System, Net Metering, Levelized Cost of Energy (COE), Carbon Emissions Reduction and Sustainability Initiatives

Nomenclature:

1 USD = 109.82 Bangladeshi Taka (BDT) or ৳
BioGen = Biogas Generator
COE = Cost of Energy
ICE = internal combustion engine
IRR = Internal Rate of Return
LCOE = Levelized Cost of Energy
NPC = Net Present Cost
PUST = Pabna University of Science and Technology

1. Introduction

The need for workable and environmentally friendly energy solutions has never been greater in a time of growing concern over environmental sustainability and the rising expense of conventional energy sources. Bangladesh is leading this global energy transformation as a highly populated nation dealing with energy constraint and carbon emissions [1], [2]. This country is currently grappling with a power crisis, characterized by frequent electricity shortages and a growing demand-supply gap [3]. However, fossil fuels have several disadvantages. First, their continued use poses threats to the environment through the emission of pollutants and greenhouse gases, leading to environmental damage and changes in the atmosphere composition [4], [5]. Second, the extraction and combustion of fossil fuels can result in land damage, smog, acid rain, and adverse impacts on weather and climate patterns [6]. Additionally, the combustion of fossil fuels releases copious quantities of pollutants into the air, impacting air quality and posing risks to human health and the ecology [7]. Furthermore, the combustion of fossil fuels is a major contributor to global warming, with reducing carbon dioxide emissions presenting significant technological, economic, societal, and political challenges. Finally, the dominance of fossil fuels is incompatible with the goals of the UN Paris Agreement on Climate Change, and their decline needs to be managed to facilitate a low-carbon energy transition. The Ministry of Finance reports that in 2022, 50.32% of Bangladesh's grid-based power generation came from gas, 9.87% from coal, 28.11% from liquid fuels, 10.02% from imported electricity, and 1.69% from renewable sources which is shown in Figure 1 [8].

Renewable energy stands as the sustainable alternative to fossil fuels, offering a cleaner and environmentally responsible source of power [9]. Bangladesh's renewable energy policy aimed for 10% electricity generation from renewables by 2020, but by 2022, only 3% was achieved [10]. The Table 1 shows the present scenario of installed renewable energy in Bangladesh.

Table 1. Present status of installed renewable energy in Bangladesh [10]

Technology	Off-grid (MW)	On-grid (MW)	Total (MW)
Solar	366.79	601.69	968.48
Wind	2	0.9	2.9
Hydro	0	230	230
Biogas to Electricity	0.69	0	0.69
Biomass to Electricity	0.4	0	0.4
Total	**369.88**	**832.59**	**1202.47**

Solar energy is the leading renewable sector in Bangladesh, accounting for 39.5% of the country's 3% renewable energy consumption [8]. Bangladesh's installed solar PV capacity increased from 480 MW in 2021 to around 537 MW in 2022, according to the International Renewable Energy Agency [11]. However, to meet its basic energy needs, the nation uses a mere 0.11% of its solar energy [12].

The paper [13] presents a method for optimizing the cost-effectiveness and sourcing reliability of renewable energy in microgrids, with a focus on an urban university campus. However, it addresses challenges related to the inconsistent availability of renewable energy sources and the high capital costs involved. This study [14] explores a hybrid renewable energy system (HRES) combining biomass and solar energy at Mehmet Akif Ersoy University Istiklal Campus in Burdur, Türkiye, utilizing manure from the campus's animal farm for biomass generation. Using HOMER software for simulation, the optimal grid-connected system includes 5000 kW PV solar panels and a 1500 kW biomass generator, with an estimated net present cost (NPC) of USD 18.8 million and a cost of energy (COE) at USD 0.107/kWh, contributing to reduced emissions and global warming mitigation. With an emphasis on energy efficiency, system sizing, and economic factors, the article in [15] evaluates a hybrid grid-connected system that combines photovoltaic and biogas generator technology. The findings indicate that this hybrid system is economically favorable, contributing 64.3% renewable energy with a peak renewable penetration of 497. Using HOMER software, the study in [16] assesses the combined wind, solar photovoltaic, and biomass energy system's potential from a technical, financial, and environmental standpoint for Istanbul's Marmara University Goztepe Campus. The goal of this project is to evaluate a hybrid renewable energy system that combines solar, wind, and biomass energy sources to manage energy on university campuses in a way that is both sustainable and efficient.

However, the main problem is higher cost of energy (COE), longer payback period of the above-mentioned research article. To mitigate these issues, we propose a novel solar-biogas model, demonstrating its potential to reduce costs, shorten the payback period, and less CO_2 emissions thus offering a more economically viable and sustainable energy solution.

This research examines the implementation of a grid-connected solar-biogas power system at Pabna University of Science and Technology (PUST) in Bangladesh, where energy scarcity and carbon emissions are critical issues. The study focuses on the potential of PUST, a center of academic excellence, to adopt innovative renewable energy technologies. Utilizing the HOMER Pro software for optimization and analysis, the project assesses the sustainability, economic viability, and environmental impact of this hybrid system. This investigation highlights the significant role of renewable energy in reducing energy costs, lowering carbon footprints, and contributing to global sustainability efforts, showcasing the transformative potential of such systems in academic settings.

2. Methodology

The research methodology employed in this study focuses on the design and optimization of a grid-connected solar-biogas power system for Pabna University of Science and Technology (PUST) campus. HOMER (Hybrid Optimization of Multiple Energy Resources) Pro software [17] is utilized as the primary tool for system modeling and analysis. The methodology involves data collection, system configuration, sensitivity analysis, and cost-benefit assessment to determine the feasibility and sustainability of the proposed renewable energy solution for PUST campus.

2.1 Architecture of HOMER Pro software

HOMER Pro software features a modular architecture comprising data input, simulation, optimization, and result analysis modules. It integrates renewable energy and system components to optimize microgrid and distributed energy systems. The following **Error! Reference source not found.** shows t he architecture of HOMER Pro software.

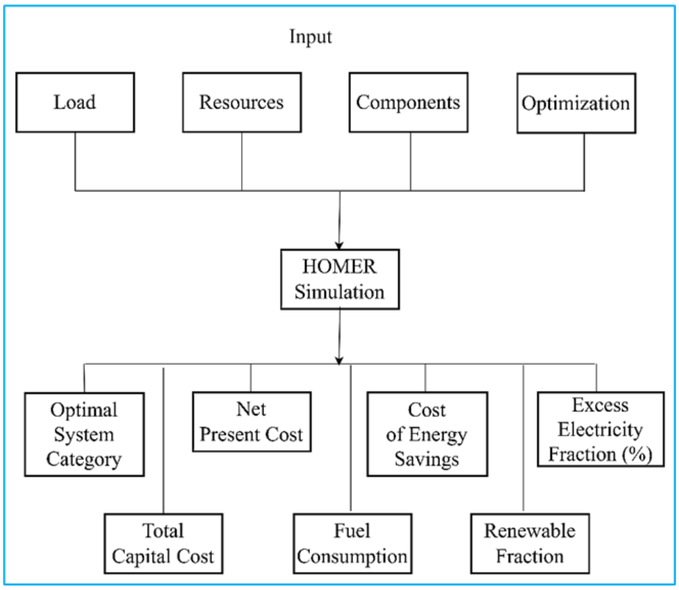

Figure 1 Architecture of HOMER Pro software [18]

HOMER Pro's optimization process starts with inputting data on resources, components, and constraints. It simulates configurations, analyzing cost and performance. The software identifies optimal solutions based on efficiency, reliability, and cost-effectiveness, outputting a detailed report of the best renewable energy system design from input to final recommendation.

2.3 Components

Figure 2. illustrates the proposed grid-connected model, featuring key components: solar PV panels, a biogas generator, energy storage batteries, a system converter, and the load. This setup combines renewable energy sources for optimal electricity generation and usage.

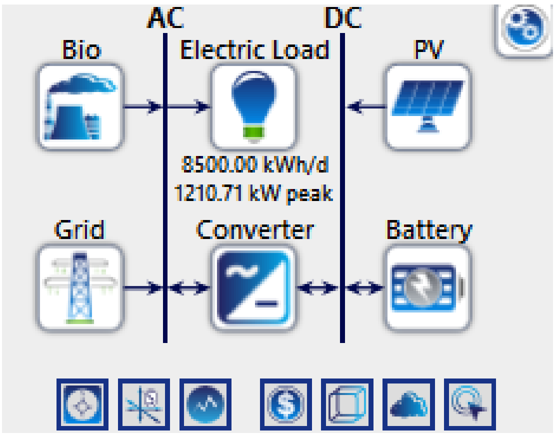

Figure 2 Schematic diagram of the proposed model.

2.3.1 PV Panels

Electricity from PV panels, once converted from DC to AC via an inverter, varies in installation cost based on project scale, PV type, and manufacturer. A study of six large-scale projects shows costs ranging from 40 to 50 BDT/kW, excluding the inverter. This study assumes a middle estimate of 45 BDT/kW for PV panel installation and an annual maintenance cost of 2 BDT per kW. In this simulation, 1800 kW solar panel system was chosen due to space limitations within the Pabna University of Science and Technology (PUST) campus. This decision reflects the practical constraints of available installation space for solar panels at the university.

2.3.2 Battery

In a grid-connected solar biogas system, a battery can play a crucial role. It serves as a means of energy storage, allowing excess electricity generated by solar panels and biogas systems to be stored for later use. This ensures a stable and reliable power supply, even when solar and biogas generation is insufficient or during grid outages. Batteries help balance energy supply and demand, improving system efficiency and reducing dependence on the grid. In the grid-connected solar biogas system, Lead acid batteries are employed for energy storage. Each battery unit has a capital cost of BDT 22,000, a replacement cost of BDT 14,000, and an annual maintenance cost of BDT 300. These batteries adhere to the Kinetic Battery Model with a nominal voltage of 12V, a nominal capacity of 1 kWh, and a maximum capacity of 83.4 Ah. They exhibit a capacity ratio of 0.403, a rate constant of 0.827 (1/hr), and a roundtrip efficiency of 80%. The maximum charge current is 16.7 A, the maximum discharge current is 24.3 A, and the maximum charge rate is 1 A/Ah with 10 years lifespan. These batteries play a vital role in ensuring a reliable and stable energy supply within the system.

2.3.3 Biogas Generator

The biogas generator in a grid-connected solar biogas system complements solar energy by producing electricity from organic waste, providing continuous power generation, and contributing to grid stability through sustainable biogas production. The biogas generated during this conversion process is ultimately fed into the internal combustion engine (ICE) to produce power. Compared to standard gas turbine and steam turbine systems, ICE has a greater power generation efficiency, typically ranging from 30% to 45% [15]. Low gas pressure and low caloric gaseous fuels are compatible with biogas engines. A single machine ICE can have a power supply ranging from 1 kW to 4 MW. As a result, the ICEs may run at high efficiency at either full or partial load [19].

2.3.3 Converter

In HOMER software, a converter's function is to manage and convert energy between different forms. It efficiently transforms DC electricity from sources like photovoltaic panels or batteries into AC electricity for grid compatibility, or vice versa. This ensures optimal integration and utilization of various renewable and conventional energy sources in a microgrid. In this study we consider a converter from ABB company with 40000 BDT per KW of capital and replacement cost. Both for converter and inverter, 96% of efficiency and 20 years lifespan is considered.

3. Case study on PUST campus

Pabna University of Science and Technology (PUST), established in 2008 in Pabna, Bangladesh, spans 30 acres and excels in science and technology education and research. Its campus harmoniously blends educational infrastructure with natural beauty, encompassing academic, administrative buildings, and student-teachers’ residences, significantly contributing to knowledge and innovation. The geographic coordinates for PUST are latitude 24.013050 and longitude 89.279446. The PUST campus is situated in Rajapur, approximately 5 kilometers northeast of central Pabna.

Figure **3** shows the PUST campus location.

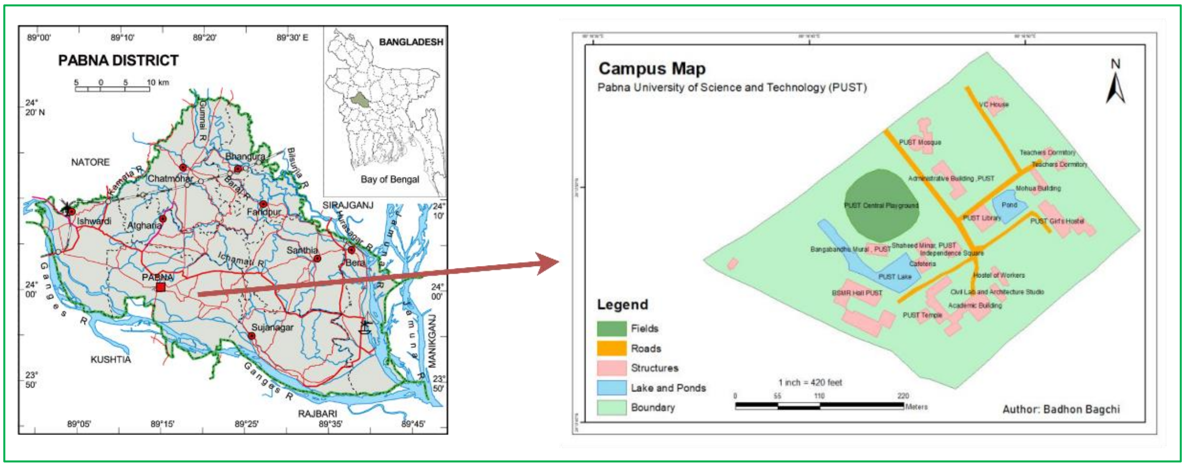

Figure 3 PUST campus location

For Pabna University of Science and Technology (PUST), utilizing renewable resources such as solar energy and biomass presents a sustainable and eco-friendly strategy. Solar panels can harness abundant sunlight, significantly reducing electricity costs and carbon footprint. Biomass, derived from organic materials, offers a renewable alternative for energy production, aligning with environmental goals. Together, these resources can propel PUST towards a greener future, emphasizing renewable energy in academic and operational practices.

3.1 Solar Radiation

Climate data, such as solar radiation and temperature, can be obtained from a number of reliable sources. For this study, monthly averaged global horizontal irradiance (GHI) values were obtained from NASA's surface meteorology and solar energy database, which was based on records spanning the previous 22 years [20].

Figure **4** shows the Solar Irradiance and clearness index for Pabna, Bangladesh

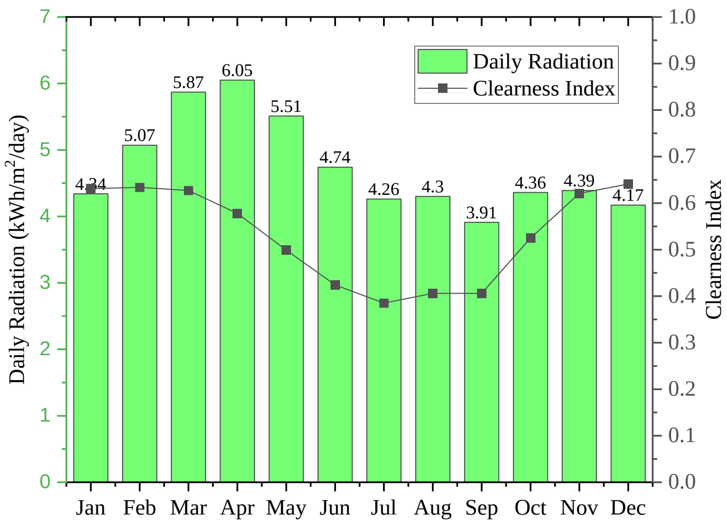

Figure 4 Solar Irradiance and clearness index for Pabna, Bangladesh

3.2 Temperature

Figure 5 depicts the daily average temperature for Pabna, Bangladesh, providing a visual representation of temperature fluctuations throughout the year in the context of solar energy [20]. This graphical representation serves to illustrate the monthly variations and helps in understanding the impact of temperature changes on solar technologies over the course of the year.

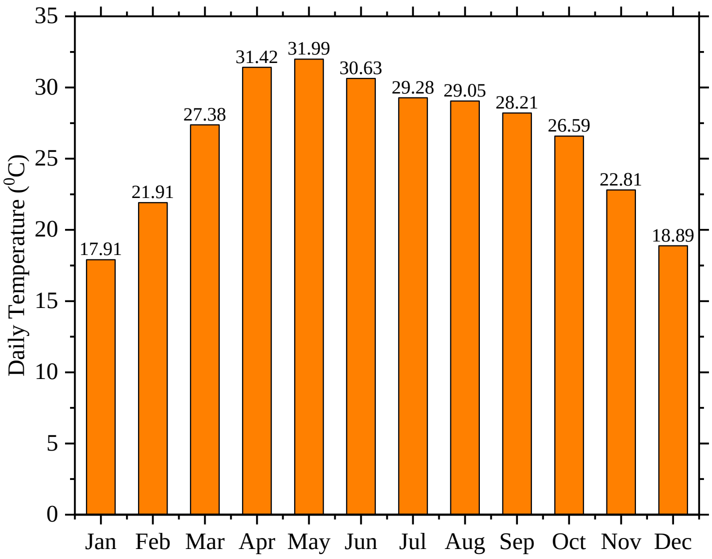

Figure 5 Daily Average Temperature

3.3 Biomass Resources

The Table 2 displays data regarding the Accommodation, population, and biomass information for the PUST campus. Municipalities generate a significant amount of biomass wastes as a result of the fast urbanization. It has a negative impact on public health and the environment. In Bangladesh, garbage produced by the rural population is just 0.15 kg per person per day, whereas waste produced by the urban population is between 0.4 and 0.5 kilogram per person per day [21]. For this study 0.5 kg per capita waste has been considered.

Table 2 Accommodation, population and biomass information for PUST campus

SL NO.	Types of Accommodation	Capacity of Population	Type of Biomass Waste	Average Human Waste /day (Kg)	Total Waste /day (Kg)	Total Waste /day (Kg)
1.	Student Hall (Male)-1	500	Human/ Kitchen	0.50	250	0.25
2.	Student Hall (Male)-2	1000	Human/ Kitchen	0.50	500	0.5
3.	Student Hall (Female)-3	500	Human/ Kitchen	0.50	250	0.25
4.	Student Hall (Female)-4	1000	Human/ Kitchen	0.50	500	0.5

5.	Teachers and staff Dormitory	300	Human/ Kitchen	0.50	150	0.15
6.	Teachers and staff Dormitory and Canteen	1000	Human/ Kitchen	0.50	500	0.50
Total					**2150 kg**	**2.15 Ton**

The following Figure 6 shows the Daily available biomass resources at PUST campus. In December, the biomass availability is limited as the PUST campus remains closed during the last week of the month for winter vacation.

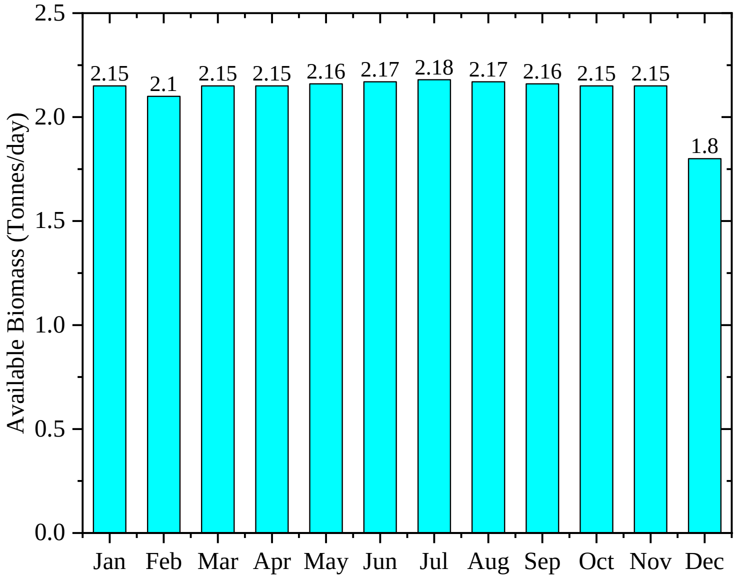

Figure 6 Daily available biomass resources at PUST campus

3.4 Load Profile

This study analyzed the load profile for PUST equipment, including lamps, TV, fan, fridge, computer, AC, and sockets. The Table 3 shows the equipment wise total load distribution of PUST campus.

Table 3 Equipment wise total load distribution of PUST campus

SL No.	Equipment	Load (kW)	Quantity	Total load (kW)
1.	Lamps	0.03	11,988	359.64
2.	TV	0.125	288	36
3.	Fan	0.08	6660	532.8
4.	Fridge	0.15	348	52.2
5.	Computer	0.18	1996	359.28
6.	AC	3.5	804	2814
7.	Socket	0.75	2350	1762.5
Total				**5916.42 kW /5.91642MW**

In our simulation using HOMER Pro for Pabna University of Science and Technology (PUST) campus, we focused on optimizing energy consumption and meeting the campus's power requirements. The average daily electricity consumption was determined to be 8500 kWh, reflecting the university's regular power needs. Additionally, a peak demand of 1210.71 kW was identified, signifying the maximum power demand during specific periods. Through this analysis, we aimed to design an efficient and sustainable energy system, potentially incorporating renewable sources to satisfy these energy demands while minimizing costs and environmental impact.

3.5 Purchasing and sell back tariff

The implementation of a grid-connected solar-biogas system at PUST campus, coupled with net metering, offers a promising avenue for sustainable energy generation. The government-regulated purchasing tariff of 10 BDT/kWh and a favorable sell price of 12 BDT/kWh create a financially attractive proposition. This tariff structure not only promotes renewable energy adoption but also significantly reduces the Cost of Energy (COE). The combination of reduced operational costs and a lucrative feed-in tariff results in a short payback period, making this integrated system a compelling choice for PUST campus, aligning both economic and environmental objectives.

4. Result and Discussion

The operational and financial components of the planned microgrid were assessed using HOMER Pro. HOMER Pro's non-derivative, streamlined optimizer allows it to run a lot of simulations in a short amount of time. HOMER Pro ranks viable solutions according to total NPC and removes any unfeasible options, such as those involving inverters, power supplies, or other problems [22]. An hourly time-series simulation is investigated for each possible system microgrid configuration over a 25-year planning horizon. The Table 4 summarizes the various case configurations of components, including the base case, considered case, Case-I, and Case-II, in relation to PV, BioGen, Battery, and Grid interactions.

Table 4 Summary of the cases

Components	Configuration
Grid	Base case
PV-BioGen-Grid-Converter	Considered case
PV-BioGen-Battery-Grid-Converter	Case-I
PV-Grid-Converter	Case-II

4.1 Techno-economic assessment of the microgrid

The techno-economic assessment of the microgrid involves analyzing different configurations, including the base case and various considered cases, by evaluating their capital costs, net present values, cost of electricity (COE), renewable energy fraction, unmet load percentage, and payback period in years are shown in

Table 5. This assessment helps in understanding the economic viability and efficiency of different microgrid setups.

Table 5 Various configurations case study

Configurations	Capital cost (৳)	Net present value (৳)	COE (৳ /kWh)	Operating Cost (৳)	Renewable fraction (%)	Payback Period (years)
Base case	0	1,137,574,000	10	31,025,000	0	---
Considered case	155,998,088	231,587,200	1.49	2,061,539	68.7	5.32
Case-I	156,394,088	232,701,600	1.49	2,081,130	68.7	5.33
Case-II	138,600,000	295,534,300	1.95	4,280,062	64.5	5.11

In the context of Table 5, which presents various configurations in a case study, the "Considered case" emerges as the best choice among the options. This conclusion is based on a comprehensive analysis of multiple factors. Firstly, the Considered case exhibits a reasonably competitive capital cost of 155,998,088 ৳, making it financially accessible. Secondly, it boasts the lowest Cost of Electricity (COE) at 1.49 ৳/kWh, signifying cost-effectiveness for consumers. Thirdly, it achieves a high renewable fraction of 68.7%, demonstrating a substantial reliance on renewable energy sources, aligning with sustainability goals. Fourthly, it maintains a relatively short payback period of 5.32 years, indicating a swift return on investment. While Case-I has a lower operating cost, the Considered case strikes a better balance between affordability, environmental benefits, and efficiency, making it the preferred choice.

Table 6 Energy purchase and sell scenario for different configurations

Configurations	Energy Purchased (kWh/year)	Energy Sold (kWh/year)
Base case	3,102,500	0
Considered case	1,329,317	1,148,169
Case-I	1,329,317	1,148,169
Case-II	1,469,931	1,041,450

Table 6 shows the energy purchase and sell scenario for different configurations. In the analysis of various microgrid configurations, we compare the energy purchased and sold in kilowatt-hours per year (kWh/year) for each case. The base case involves purchasing 3,102,500 kWh/year and not selling any energy. The considered case purchases 1,329,317 kWh/year and sells 1,148,169 kWh/year, resulting in a payback period of 5.32 years. Similarly, Case-I and Case-II have their respective energy purchase and sale figures and payback periods. Based on the energy sold and payback period, the considered case appears to be the most favorable choice among the configurations.

Table 7 shows the GHG emissions of various cases. The data table compares emissions of Carbon Dioxide, Carbon Monoxide, Sulfur Dioxide, and Nitrogen Oxides across four cases: Base, Considered, Case-I, and Case-II. In the Base case, the highest Carbon Dioxide emissions are observed at 1,960,780 kg/yr, with no Carbon Monoxide emissions. The Considered Case shows a significant reduction in all emissions, especially in Carbon Dioxide (840,268 kg/yr), making it the most favorable option when considering factors like Cost of Electricity (COE), Net Present Cost (NPC), and payback period.

Table 7 GHG emissions of various cases.

Quantity (kg/yr)	Base case	Considered Case	Case-I	Case-II
Carbon Dioxide	1,960,780	840,268	840,268	928,996
Carbon Monoxide	0	1.55	1.55	0
Sulfur Dioxide	8,501	3,642	3,642	4,028
Nitrogen Oxides	4,157	1,782	1,782	1,970

4.2 Optimal System

The optimal system among the four configurations (Base case, Considered case, Case-I, and Case-II) is the "Considered case" due to several key factors. Firstly, in terms of capital cost, it has a reasonable upfront investment of 155,998,088 ৳, making it competitive with the other configurations. Secondly, it exhibits the lowest Cost of Electricity (COE) at 1.49 ৳/kWh, making it cost-effective for energy consumers. Thirdly, it achieves a high renewable fraction of 68.7%, indicating a significant utilization of renewable energy sources. Fourthly, it has a relatively short payback period of 5.32 years, indicating a quicker return on investment.

Furthermore, the Considered case reduces greenhouse gas (GHG) emissions significantly, with notably lower emissions of Carbon Dioxide, Carbon Monoxide, Sulfur Dioxide, and Nitrogen Oxides compared to the Base case and other configurations. This reduction aligns with environmental sustainability goals. Overall, the Considered case offers a balanced combination of affordability, environmental benefits, and efficiency, making it the optimal choice for the system configuration.

4.2.1 System Architecture

The proposed system comprises a 500 kW Generic Biogas Generator, 1,800 kW SunPower E20-327 photovoltaic (PV) panels, and a 1,440 kW ABB PSTORE-PCS system converter, all connected to the grid using HOMER Load Following dispatch strategy. Additionally, it utilizes a net metering system to connect with the PUST campus, allowing excess energy to be fed back into the grid. This setup enables efficient power generation and distribution while promoting renewable energy integration into the campus's electricity supply.

4.2.2 Fuel Summary

Biogas Consumption Statistics provide a detailed analysis of feedstock usage. The total feedstock consumed stands at 775 tons. This translates to an average daily feedstock usage of 2.12 tons. Breaking it down further, on an hourly basis, the average feedstock consumption is approximately 0.0885 tons. These figures are essential for understanding the scale and efficiency of biogas production, offering insights into resource management and operational effectiveness in the biogas sector. The Figure 7 shows the Biogas Consumption (kg/hr).

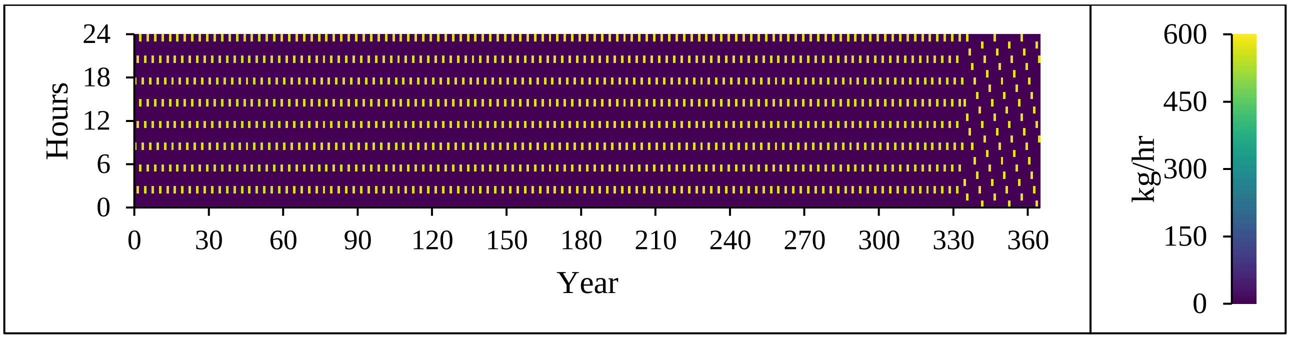

Figure 7 Biogas Consumption (kg/hr)

5. Conclusion

In this study, we have investigated the feasibility and impact of implementing a grid-connected solar-biogas power system at Pabna University of Science and Technology (PUST), Bangladesh, using HOMER Pro software for optimization. The "Considered case" emerged as the optimal system configuration due to its reasonable upfront investment, low Cost of Electricity (COE), high renewable energy utilization, and a relatively short payback period of 5.32 years. This configuration not only provides cost-effective energy but also aligns with environmental sustainability goals by significantly reducing greenhouse gas emissions, including Carbon Dioxide, Carbon Monoxide, Sulfur Dioxide, and Nitrogen Oxides. The financial analysis demonstrated a Total Net Present Cost (NPC) of BDT 231,587,200.00 (2,109,309.88 USD) with a robust Internal Rate of Return (IRR) of 18.4%. The Levelized Cost of Energy (COE) at BDT 1.49 (0.014 USD) per kWh and an operating cost of BDT 2061539.00 (18,776.62 USD) are economically competitive, highlighting a favorable investment opportunity. The future work involves implementing the proposed system with the involvement of stakeholders or company for sustainable energy solutions.

5. Acknowledgement

Authors would like to thank the University Grants Commission (UGC), Bangladesh, for providing the necessary funding for the financial year 2022-2023 to support and complete the project. Additionally, the authors would like to express their gratitude to Pabna University of Science and Technology (PUST), Pabna, for providing opportunities to use the renewable energy lab to support and complete this research project.

6. References

1. A. Paul *et al.*, “Knowledge, attitudes, and practices toward the novel coronavirus among Bangladeshis: Implications for mitigation measures,” *PLoS One*, vol. 15, no. 9 September 2020, 2020, doi: 10.1371/journal.pone.0238492.
2. Y. Zheng, W. Wei, M. Murshed, S. Khan, H. Mahmood, and N. Das, “Repercussions of Hydroelectricity use on Carbon Emissions in Bangladesh: Evidence using Novel Fourier-Bootstrapped ARDL and Fourier-Gradual Shift Causality analyses,” *https://doi.org/10.1177/0193841X221135674*, vol. 47, no. 6, pp. 1025–1065, Oct. 2022, doi:

10.1177/0193841X221135674.
3. M. Washim Akram, M. Arman Arefin, and A. Nusrat, "Prospect of green power generation as a solution to energy crisis in Bangladesh," *Energy Systems*, vol. 13, no. 3. 2022. doi: 10.1007/s12667-020-00421-9.
4. R. Malhotra, "Fossil Energy: Introduction," in *Fossil Energy*, 2020. doi: 10.1007/978-1-4939-9763-3_920.
5. L. O. Williams, "Chapter 1 - Fossil fuels," *An End to Glob. Warm.*, 2002.
6. D. Golomb, "Fossil Fuel Combustion: Air Pollution and Global Warming," in *Managing Air Quality and Energy Systems*, 2020. doi: 10.1201/9781003043461-14.
7. G. Wood, "Fossil fuels in a carbon-constrained world," in *The Palgrave Handbook of Managing Fossil Fuels and Energy Transitions*, 2019. doi: 10.1007/978-3-030-28076-5_1.
8. M. N. Uddin, M. A. Rahman, M. Mofijur, J. Taweekun, K. Techato, and M. G. Rasul, "Renewable energy in Bangladesh: Status and prospects," *Energy Procedia*, vol. 160, pp. 655–661, 2019, doi: 10.1016/j.egypro.2019.02.218.
9. W. Strielkowski, L. Civín, E. Tarkhanova, M. Tvaronavičienė, and Y. Petrenko, "Renewable Energy in the Sustainable Development of Electrical Power Sector: A Review," *Energies 2021, Vol. 14, Page 8240*, vol. 14, no. 24, p. 8240, Dec. 2021, doi: 10.3390/EN14248240.
10. "Where is Bangladesh in the global race towards renewable energy? | The Daily Star." Accessed: Jan. 19, 2024. [Online]. Available: https://www.thedailystar.net/opinion/views/news/where-bangladesh-the-global-race-towards-renewable-energy-3297006
11. "Solar Energy Market in Bangladesh - Size, Share & Industry Analysis." Accessed: Jan. 19, 2024. [Online]. Available: https://www.mordorintelligence.com/industry-reports/bangladesh-solar-energy-market
12. S. Hossain, M. M. Rahman, S. Hossain, and M. M. Rahman, "Solar Energy Prospects in Bangladesh: Target and Current Status," *Energy Power Eng.*, vol. 13, no. 8, pp. 322–332, Aug. 2021, doi: 10.4236/EPE.2021.138022.
13. N. Shirzadi, F. Nasiri, and U. Eicker, "Optimal configuration and sizing of an integrated renewable energy system for isolated and grid-connected microgrids: The case of an urban university campus," *Energies*, vol. 13, no. 14, 2020, doi: 10.3390/en13143527.
14. E. Aykut, B. Dursun, and S. Görgülü, "Comprehensive environmental and techno-economic feasibility assessment of biomass- solar on grid hybrid power generation system for Burdur Mehmet Akif Ersoy University Istiklal Campus," *Heliyon*, vol. 9, no. 11, 2023, doi: 10.1016/j.heliyon.2023.e22264.
15. H. Al-Najjar, C. Pfeifer, R. Al Afif, and H. J. El-Khozondar, "Performance Evaluation of a Hybrid Grid-Connected Photovoltaic Biogas-Generator Power System," *Energies*, vol. 15, no. 9, 2022, doi: 10.3390/en15093151.
16. E. Aykut and K. Terzi, "Techno-economic and environmental analysis of grid connected hybrid wind/photovoltaic/biomass system for Marmara University Goztepe campus," *Int. J. Green Energy*, vol. 17, no. 15, 2020, doi: 10.1080/15435075.2020.1821691.
17. "HOMER Pro - Microgrid Software for Designing Optimized Hybrid Microgrids." Accessed: Jan. 19, 2024. [Online]. Available: https://www.homerenergy.com/products/pro/index.html
18. A. Razmjoo, R. Shirmohammadi, A. Davarpanah, F. Pourfayaz, and A. Aslani, "Stand-alone hybrid energy systems for remote area power generation," *Energy Reports*, vol. 5, pp. 231–241, Nov. 2019,

doi: 10.1016/J.EGYR.2019.01.010.
19. L. Deng, Y. Liu, and W. Wang, *Biogas technology*. Springer, 2020.
20. "NASA POWER | Prediction Of Worldwide Energy Resources." Accessed: Dec. 22, 2023. [Online]. Available: https://power.larc.nasa.gov/
21. B. K. Das and S. M. N. Hoque, "Assessment of the Potential of Biomass Gasification for Electricity Generation in Bangladesh," *J. Renew. Energy*, vol. 2014, pp. 1–10, 2014, doi: 10.1155/2014/429518.
22. M. Zeyad, S. M. M. Ahmed, S. Hasan, and D. M. Mahmud, "Community microgrid: an approach towards positive energy community in an urban area of Dhaka, Bangladesh," *Clean Energy*, vol. 7, no. 4, pp. 926–939, Aug. 2023, doi: 10.1093/CE/ZKAD027.