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Impact of Net Metering on Hybrid Renewable Energy System Economics in Mymensingh, Bangladesh

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Abstract: The integration of net metering into hybrid renewable energy systems significantly enhances their economic viability and promotes wider adoption of renewable technologies. This study employs Homer software to simulate and optimize various hybrid configurations, revealing that the inclusion of net metering reduces the cost of energy (COE) from $0.058 to $0.036 per kWh for systems comprising photovoltaic (PV) panels, wind turbine, diesel generators,and batteries. Net metering not only provides financial incentives for excess energy production but also improves grid stability and efficiency. Sensitivity analysis shows that rising diesel prices increase the COE for hybrid systems, emphasizing the economic benefits of net metering in mitigating such impacts. Additionally, net metering helps offset higher costs related to interest rates and capacity shortages, ultimately fostering a more resilient and cost-effective energy infrastructure. This study underscores the critical role of net metering in advancing sustainable energy solutions and supporting the transition to a renewable energy future.

Keywords: PV system; Hydropower; Techno-economic feasibility; Homer.

1.Introduction

The Quranic verse 13:3 states: "And it is He who has made the earth a [place of] settlement for you and placed upon it rivers and mountains and of everything, He has created pairs; He has caused the night to cover the day. Indeed, in that are signs for a reflecting people." This verse can indeed be interpreted to promote sustainability and the responsible use of natural resources, aligning closely with the goals of renewable energy systems. Bangladesh offers a promising opportunity for implementing renewable energy systems to alleviate its acute power shortage [1] depends heavily on fossil fuels for electricity generation, which leads to environmental pollution [1]. However, renewable energy sources including solar, wind, and hydro have seen significant advancements in recent years, providing eco-friendly alternatives [2][3].

Photovoltaic (PV) systems, in particular, capture solar energy with minimal environmental impact [2]. Lead-acid batteries are frequently used for the energy storage, but they are not ideal for prolonged use [4]. Alternatively, converting electrical energy into hydrogen through electrolysis for fuel cells offers a sustainable long-term solution [5][6]. While hydrogen production shows potential, solar and wind energy also serve as viable options [7]. However, their reliance on climate conditions poses challenges for continuous power generation [8][9]. Consequently, traditional fossil fuel-based power generation systems, such as diesel generators, are often utilized to ensure a consistent electricity supply [10] [11].Renewable energy systems, such as solar panels, wind turbines, and hydroelectric power, utilize natural resources without depleting them, thus promoting sustainability. Adopting hybrid renewable energy systems with net metering can significantly reduce energy costs and environmental impactat Mymensingh in Bangladesh. Net metering provides financial incentives for excess energy production, lowering energy bills, encouraging investment in renewable technologies, and promoting grid stability and efficiency.Efficiency and utility of generated energy will be reducing waste, and lowering the overall environmental impact.

Numerous researchers have investigated various methodologies, with a particular emphasis on decision-making processes [12]-[23], simulation techniques, and related approaches. In line with the simulation methodology, one study proposed a solution to address rural electricity demand using conventional methods like diesel generators [24]. Another study highlighted the negative impact of rising fossil fuel prices on rural communities and the environment, stressing the need for cleaner energy alternatives [25]. The feasibility of non-polluting PV and wind energy sources as competitive alternatives to conventional energy sources was demonstrated in[26].Techno-economic analyses of hybrid renewable energy systems have been thoroughly examined, offering thecomprehensive insights into the economic viability and performance evaluation of such systems [27]. Reviews of various models used for optimizing hybrid renewable energy systems have contributed to the advancement of efficient and sustainable energy solutions [28]. Renewable energy systems integrated with net metering provide a two-way flow of electricity, allowing consumers to both consume and produce electricity. This setup not only promotes renewable energy adoption but also enhances grid stability and efficiency. A study by Anderson et al. [29] demonstrated the benefits of net metering in promoting renewable energy integration by providing the financial incentives for excess energy production. The authors highlighted how net metering encourages investment in renewable energy technologies and reduces overall energy bills for consumers. Additionally, net metering promotes grid stability by balancing supply and demand, ultimately contributing to a more resilient and sustainable energy infrastructure. For instance, the study conducted by Smith et al. [30] investigated the impact of net metering on renewable energy adoption in residential areas. They found that households with access to net metering programs were more likely to invest in solar photovoltaic systems, leading to increased renewable energy capacity and reduced reliance on conventional energy sources (Smith et al.). Furthermore, Johnson et al. [31] examined the economic benefits of net metering for hybrid renewable energy systems, demonstrating significant cost savings and improved return on investment when combining solar and wind power generation with net metering (Johnson et al.). Similarly, Martinez et al. [32]discussed the policy implications of net metering and its role in facilitating the transition to sustainable energy systems.

Renewable energy and net metering are closely intertwined concepts that complement each other to promote sustainable energy practices and enhance the economic viability of renewable energy systems. Net metering is a policy framework that allows consumers who generate their own electricity through renewable sources, such as solar or wind power, to feed excess electricity back into the grid. This excess electricity is credited to their utility bills, effectively reducing their overall energy costs.The financial benefits of net metering make renewable energy systems more attractive and financially viable for residential consumers. Doe and Smith [33] conducted research highlighting that residential applications of net metering can reduce electricity bills by up to 30%. This significant cost reduction encourages homeowners to invest in renewable energy systems such as solar panels, which in turn promotes the widespread adoption of clean energy technologies.Moreover, net metering also optimizes the use of renewable energy systems by ensuring efficient utilization of generated electricity. Instead of wasting unused or excess power, it is fed back into the grid for others to utilize. This reduces strain on traditional power plants and enhances grid stability through distributed generation.The combination of renewables and net metering has several positive impacts on both the environment and the economy. Firstly, it leads to a cleaner environment by reducing greenhouse gas emissions associated with traditional fossil fuel-based electricity generation. Renewable energies produce minimal carbon dioxide emissions compared to fossil fuels, making them an environmentally friendly alternative.Secondly, this synergy contributes to a more stable and efficient energy grid. Distributed generation from various individual sources helps diversify the supply mix while reducing transmission losses over long distances. It also enhances grid resilience by decentralizing power production during natural disasters or system failures.Lastly, this collaboration between renewables and net metering accelerates development and innovation within the renewable energy sector itself. The increased demand for solar panels or wind turbines drives technological advancements while creating jobs in manufacturing, installation, maintenance sectors associated with these technologies.While Doe and Smith offer broader insights into residential applications of net metering's benefits on reducing electricity bills; this study provides a focused examination within a specific geographic region that further highlights its feasibility in practical implementation scenarios.

The primary objective of the paper is to evaluate the economic benefits and feasibility of implementing net metering in hybrid renewable energy systems. Net metering is a billing mechanism that allows users to receive credits for any excess electricity they generate from their renewable energy systems and feed back into the grid.The study focuses on evaluating the economic impact of implementing net metering specifically in Mymensingh, Bangladesh. Mymensingh is selected as a region of significant importance within the country due to its potential for renewable energy generation and its relevance to national energy goals.By analyzing the economics of implementing net metering in hybrid renewable energy systems, the researchers aim to assess whether this mechanism can provide financial incentives for individuals or organizations to invest in such systems. They evaluate factors like investment costs, payback periods, savings through reduced electricity bills, and potential income from selling excess electricity back to the grid. The study aims to quantify these economic benefits and determine whether net metering makes hybrid renewable energy systems financially viable in Mymensingh.

The remaining is represented as follows: Section 2 presents geographic characteristics of study area; Section 3 is the methodology that introduces the results and discussion for suggested hybrid power plant; Section 4 explains Sensitivity analysis;and the last one is for the conclusions.

2. Methodology

2.1 Geographic characteristics

The study area named sadar is located atMymensinghdistrict in Bangladesh on the bank of the old Bhrahmaputra river with $24^{o}75^{/}$N latitude and $90^{o}407^{/}$E longitude.

2.2Material and methods for HOMER

This section serves as a crucial reference for researchers who want to understand how a study was conducted and potentially build upon or validate its findings.

2.2.1 HOMER/ Simulation Configuration

The HOMER software framework incorporates simulation, optimization, and sensitivity analysis to accurately assess energy balance across different seasons. By simulating energy configurations, HOMER dynamically models energy production and consumption, ultimately determining feasible solutions over the system's lifetime. Additionally, the framework calculatesthe levelized cost of energy (LCOE) as a key metric for evaluating energy system economics. Following the relation for calculation of NPC is as-

$$NPC = I + \sum_{i=1}^{n} (C_y)[\frac{1}{(1+d)^i}]$$

I is the initial investment, n is the life span of project,C_y is the yearly cost including Operation,Maintenance and replacement, d is for discount rate. The levelized cost of the energy is expressed as-

$$COE = \frac{NPC}{\sum_{i=1}^{n}(E_y)[\frac{1}{(1+d)^i}]}$$

E_y is yearly served electricity.

2.2.2 Configuration of the proposed system

This section serves as a crucial reference for researchers who want to understand how a study was conducted and potentially build upon or validate its findings.The Homer software is the electricity energy modeling program for HRES(Homer Renewable Energy System). Homer software is the capable tool for designing, simulating that analyzes hybrid power systems. The program flowchart of the Homer software for Mymensingh, Bangladesh is displayed in Fig. 1.The detailed specifications of them is depicted here.

2.2.3 PV array

The PV array forms a critical component of the energy system, constituting the interconnection of individual PV modules. The HOMER software evaluates power of PV array by using the following equation-

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S}$$

Where,f_{PV} is PV derating factor, Y_{PV} represents the rated capacity of the PV array (KW), I_T introduces global solar radiation (beam plus diffuse) incident on the surface of PV array (KW/m^2), and I_S is the standard radiation rate (KW/m^2). A wide range of photovoltaic (PV) panel sizes, spanning from 0 kW to 4500 kW, were evaluated for optimization across all locations. Ultimately, a 0.75 kW PV panel, with a capital cost of $85, was incorporated into the energy scheme in fig.2. This selection reflects a careful consideration of both capacity requirements and cost-effectiveness in designing the energy system.

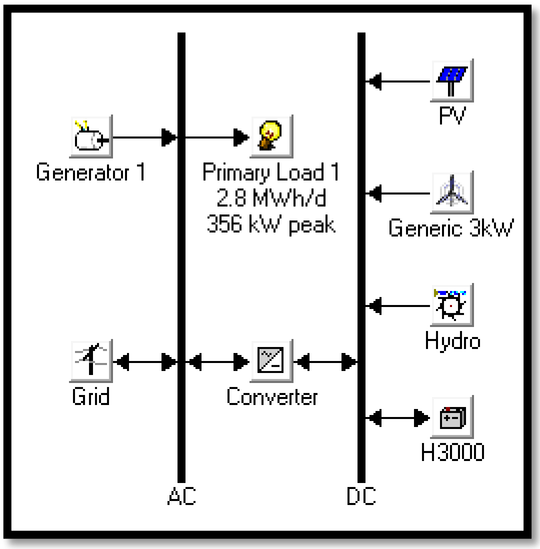


Fig. 1: The simulation setup for the Homer software includes both scenarios with and without a net metering system in Mymensingh, Bangladesh.

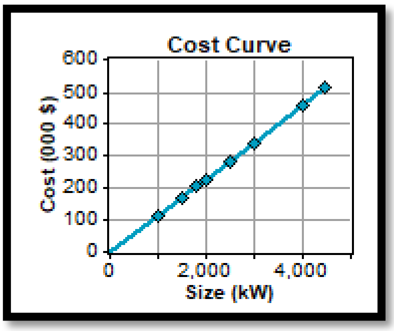


Fig. 2: PV array size vs capital cost

2.2.4 Diesel Generator

To enhance reliability, a 24 kW diesel generator with a capital cost of $10,058 has been integrated into the energy scheme, providing backup power when renewable sources are insufficient [34]. The generator has an annual fuel consumption of 5000 liters and an operational lifetime of 15,000 hours. Optimization considers various sizes of diesel generators ranging from 0 kW to 300 kW to ensure uninterrupted power supply.

2.2.5 Converter

The converter, comprising rectifier and inverter, plays acrucial role in the energy system by dynamically adapting to PV system operation. It efficiently converts AC to DC during active PV power generation and vice versa for grid or off-grid usage. Priced at $651 for a 2 kW unit with 90% efficiency over 15 years[35], its versatility spans from 0 to 400 kW, ensuring optimal energy conversion and system performance. This component optimizes energy utilization and grid compatibility, emphasizing its importance in the overall scheme.

2.2.6 Estimation of electrical Loads

The overall load system must meet is referred to as the electric loadin Fig.3. The average primary load of study area, Mymensingh in Bangladesh, is 2832 kWh/day, 356 kW peak, with a load factor of 0.332.

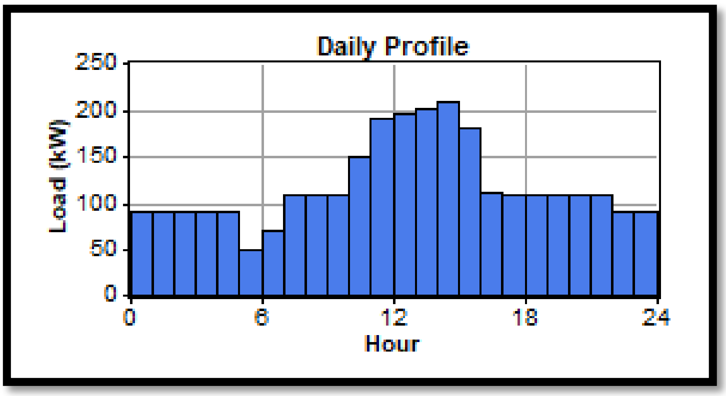


Fig. 3: Dailyload profile vs hour

2.2.7Resource assessment

The HOMER model is pivotal in this study, facilitating the exploration of diverse energy resource combinations, including solar, wind, and hydro, to identify the most suitable system configuration. Through systematic resource assessment, HOMER evaluates with factors ensuring an economically viable and sustainable energy mix that meets demand.

2.2.7.1 Analysis of the solar energy

The coordinates of an area (longitude and latitude) are imported to Homer program to verify feasibility study of solar energy potentiality in the Mymensingh Sadar of Bangladesh forthe proposed hybrid power system. The monthly solar radiation data have been taken from National Aeronautics and Space Administration (NASA) database from the year1983 to 2012[36, 37]. Fig. 4 indicatesthe daily radiation with clearness index that is low for July and August. The daily annual calculated solar radiation is4.64 $kWh/m^2/day$.

2.2.7.2 Analysis of wind energy

The potential of the study area for wind energy is achieved inthe form of generated electricity. The wind turbine outputs by using Homer software present the technical-economic feasibility of the hybrid system. Fig. 5 shows the average monthly wind speed data for research area in different months. The data for the wind resources have been used for the year fromof 1983 to 2012[37,38]. Accordingto wind resources, a few advancedparameters are presumed; Weibull value (k) is set around 2, that measures wind speed distribution, autocorrelation factor that quantifies randomness of wind which is set to be 0.85, the diurnal pattern strength is set to be 0.25 that implies how the wind speed differs in time during a day, and the hour of peak wind speed is set to be 15. A single unit with a capital cost of $3000, along with equivalent replacement costs, was evaluated for deployment. With a lifespan of 15 years, options for hub heights at both

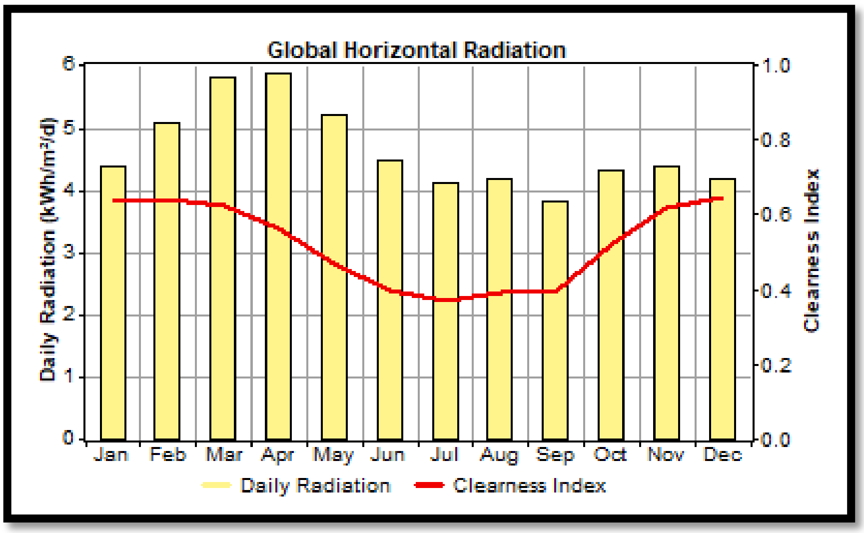


Fig. 4: The solar daily radiation and the clearness index of the research area.

25 m and 30 m were examined. The scaled annual average, measured at 2.73 m/s, was taken into account for assessing the performance and feasibility of the unit.

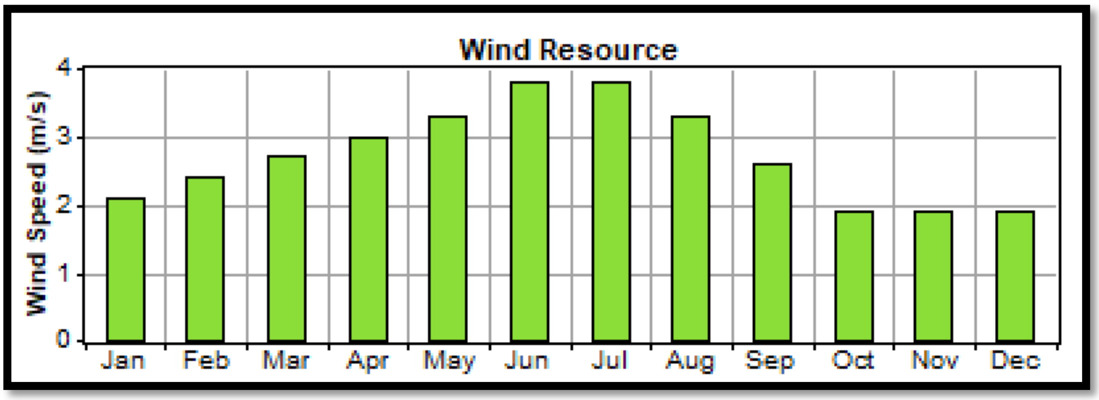


Fig. 5: Wind speed data of different months at Mymensingh sadar.

2.2.7.3Analysis of hydro power potential

The hydropower generation utilizesthe energy of falling water to generate electricity. The representation of this hybrid project is proposed according to study area location Mymensingh sadar, Mymensingh near the bank of the Old Bhrahmaputra river.There is a need to build a dam in the Old Bhrahmaputra river to regulate the turbines of hydro properly.The water discharge data for the Old Bhrahmaputra river are obtained from Bangladesh Water Development Board (BWDB), Mymensingh[39]. The average water discharge data ratehas been taken from the year of 2000 to 2020. The stream flow data is measured by Acoustic Doppler Current Profiler (ADCP) meter, the hydro acoustic current meter. The scaledannual average discharge of stream flow is 29579 L/s.

2.3 Economic and constraints

The study assumes a project lifetime of 25 years, demonstrating a commitment to long-term sustainability and economic viability. A conservative annual interest rate of 13% to 15% is applied to the financial analysis, considering the time value of money and investment factors. Notably, the system allows for flexibility by not imposing maximum annual capacity shortages, although a 5% to 10% shortage is considered acceptable in the context of renewable energy.

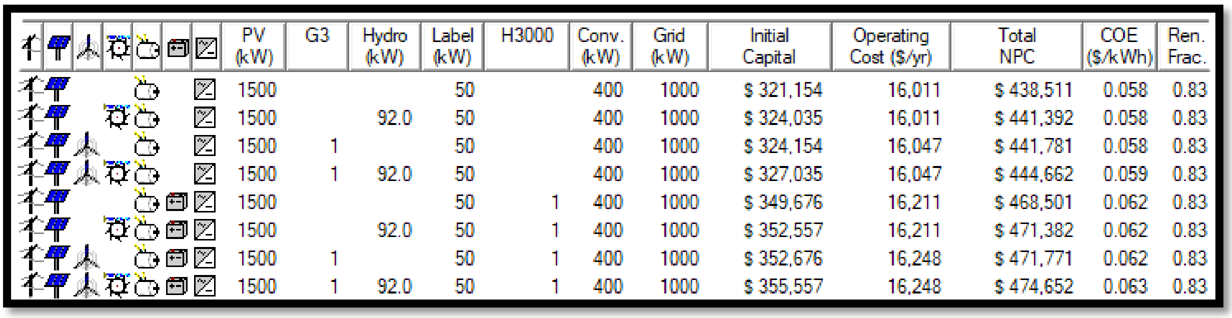
2.4 Storage battery

Given the variability and intermittent nature of renewable energy sources, the integration of batteries is essential to ensure a stable supply of electricity. In this research, the Hoppecke oPzS battery model [40] was chosen for energy storage purposes. This battery type features a nominal voltage of 2V with a capacity of 6kWh, and the capital cost for each battery unit is $28522.

3. Results and discussion for suggested hybrid power plant

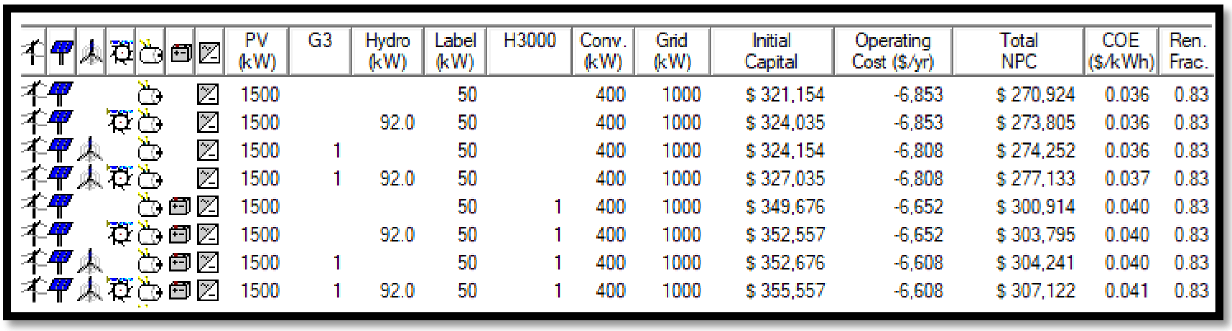
To assess the performance of different systems, researchers input comprehensive data into the Homer software. This data includes detailed information about the system components, such as solar panels, wind turbines, batteries, and generators. It also incorporates data on energy consumption patterns and costs. Once the input data is provided, the Homer software conducts simulations to evaluate how various hybrid configurations would perform over a project's lifetime.During the simulation process, each component's behavior is modeled based on its technical characteristics. Mathematical algorithms are then used to optimize system performance. The software calculates energy outputs from renewable sources by taking weather conditions into account. Optimization algorithms are utilized to determine how energy flows can be managed effectively in order to meet load demands while minimizing costs.The simulations performed by Homer offer valuable insights into system performance under different conditions. Researchers can use these insights to evaluate the feasibility of different hybrid configurations, identify any potential issues related to energy supply-demand balance or component reliability, estimate generation capacity shortages or surpluses over specific time periods (e.g., months or years), and compare various scenarios in terms of cost-effectiveness.

The optimization outcomes presented in Fig. 6 demonstrate the effectiveness of different hybrid configurations in minimizing the cost of energy and promoting renewable technology. In the absence of net metering, Fig. 6a shows that a hybrid system combining PV panels, wind power, a diesel generator, and a battery achieves the lowest cost of energy at $.058 per unit, with an impressive renewable fraction of 83%. This configuration proves to be highly cost-effective while utilizing renewable energy sources to a significant extent.However, considering sustainable environmental development as a priority, an alternative hybrid configuration is explored in Fig. 6a – one that includes PV panels, wind power generation, battery storage management, hydropower generation, a diesel generator for backup purposes when needed, and converter for efficient grid integration. This more complex configuration yields slightly higher costs of energy ($.063) compared to the previous one due to additional components and capacity shortage (5%), but it still maintains an impressive renewable fraction of 83%.Moving on to Fig. 6b where net metering effects are taken into account, net metering provides various benefits such as financial incentives for excess energy production, reduced overall energy bills, increased investment in renewable energies, and improved grid efficiency.Consequently, the optimization results show that incorporating net metering leads to even more cost-effective solutions. The most optimal configuration includes PV panels along with wind power generation, a diesel generator for backup purposes when needed, and battery storage management (COE: $ .036). Another alternative hybrid option adds components such as hydropower generation and converter for enhanced sustainability; this configuration has slightly higher costs ($ .041), but still maintains an impressive renewable fraction (83%) despite capacity shortage (5%).In essence, these optimization results highlight how different hybrid configurations can contribute significantly tosustainable development by effectively utilizing renewable technologies while considering factors such as costs, capacity shortages or constraints, and net metering effects. By reducing costs through financial incentives and encouraging greater investment in renewables along with improved grid efficiency through excess energy production incentives offered by net metering programs can play crucial roles in making these systems even more economically viable for consumers.



PV (kW)	G3	Hydro (kW)	Label (kW)	H3000	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
1500			50		400	1000	$ 321,154	16,011	$ 438,511	0.058	0.83
1500		92.0	50		400	1000	$ 324,035	16,011	$ 441,392	0.058	0.83
1500	1		50		400	1000	$ 324,154	16,047	$ 441,781	0.058	0.83
1500	1	92.0	50		400	1000	$ 327,035	16,047	$ 444,662	0.059	0.83
1500			50	1	400	1000	$ 349,676	16,211	$ 468,501	0.062	0.83
1500		92.0	50	1	400	1000	$ 352,557	16,211	$ 471,382	0.062	0.83
1500	1		50	1	400	1000	$ 352,676	16,248	$ 471,771	0.062	0.83
1500	1	92.0	50	1	400	1000	$ 355,557	16,248	$ 474,652	0.063	0.83

(a)



PV (kW)	G3	Hydro (kW)	Label (kW)	H3000	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
1500			50		400	1000	$ 321,154	-6,853	$ 270,924	0.036	0.83
1500		92.0	50		400	1000	$ 324,035	-6,853	$ 273,805	0.036	0.83
1500	1		50		400	1000	$ 324,154	-6,808	$ 274,252	0.036	0.83
1500	1	92.0	50		400	1000	$ 327,035	-6,808	$ 277,133	0.037	0.83
1500			50	1	400	1000	$ 349,676	-6,652	$ 300,914	0.040	0.83
1500		92.0	50	1	400	1000	$ 352,557	-6,652	$ 303,795	0.040	0.83
1500	1		50	1	400	1000	$ 352,676	-6,608	$ 304,241	0.040	0.83
1500	1	92.0	50	1	400	1000	$ 355,557	-6,608	$ 307,122	0.041	0.83

(b)

Fig. 6:The simulation results from the Homer software were analyzed for two scenarios: (a) without a net metering system and (b) considering the effects of the net metering system.

4. Sensitivity analysis

The factors mentioned explain why the cost of energy can be higher without net metering. Net metering allows for the efficient utilization of excess energy generated by renewable systems, ensuring that it is not wasted and can be used during periods of high demand. Without net metering, this surplus energy goes unused and leads to wasted generation capacity.Furthermore, net metering provides a financial incentive for consumers to invest in appropriately sized renewable energy systems. The compensation received for excess generation encourages consumers to size their systems optimally, maximizing the use of renewable energy and reducing reliance on traditional sources. Without this incentive, consumers may be less motivated to invest in larger systems, potentially leading to capacity shortages and increased reliance on more expensive non-renewable sources.Net metering in 7(b) also plays a crucial role in stabilizing the grid by allowing excess renewable power to be fed back into the system when needed. This helps manage fluctuations in supply and demand, reducing operational costs associated with balancing the grid without net metering in

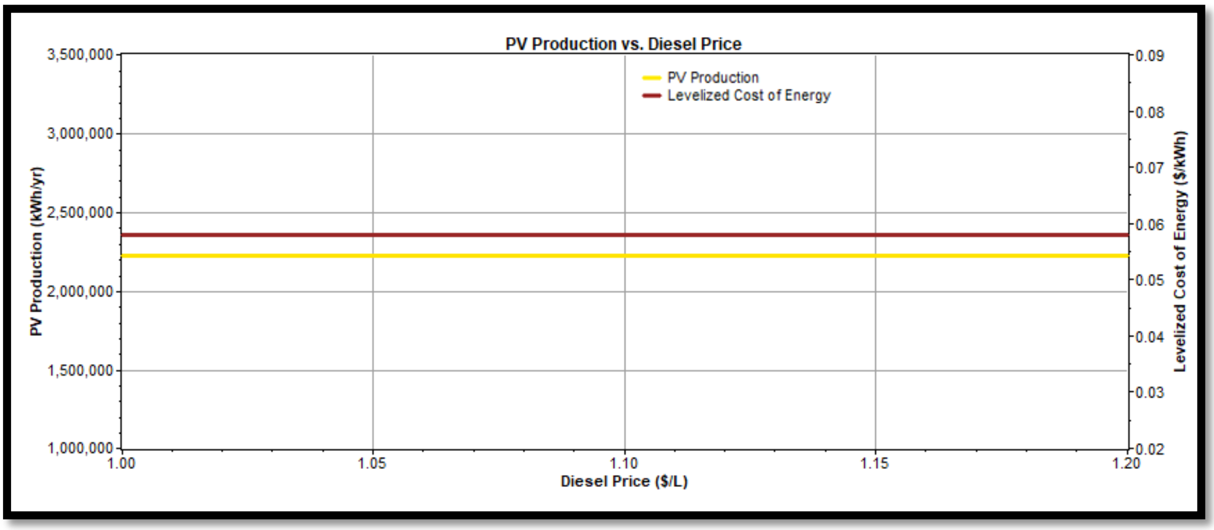
7(a).Finally, reduced investment in renewables due to lower financial returns without net metering can lead to an overreliance on fossil fuels or other expensive non-renewable sources. This further increases costs and exacerbates capacity shortages.Overall, net metering incentivizes efficient use of renewable resources, encourages appropriate sizing of renewable energy systems, stabilizes the grid during fluctuating conditions, and promotes investment in renewable energy projects. In its absence, inefficiencies arise, capacity shortage s may occur, greater operational costs are incurred, and dependence on fossil fuels increases. These factors contribute to higher COE without net metering and underline the importance of implementing such policies to promote sustainable energy development.

The cost of energy calculated without considering net metering in HOMER simulation is higherin (8(a)) than when net metering in (8(b)) is considered due to the benefits that net metering provides in balancing the load on the electrical grid.Net metering allows for a two-way flow of electricity between the grid and the consumer's renewable energy system, such as a photovoltaic or fuel cell system. When excess electricity is generated by the consumer's system, it can be fed back into the grid and credited to their account. This means that during periods when their energy generation exceeds their consumption, they can effectively "sell" this excess electricity back to the grid.The efficient demand management facilitated by net metering helps smooth out demand peaks and troughs on the grid. It allows utility companies to optimize their operations by reducing or avoiding costly peak-demand power generation from conventional sources. Instead, they can rely more on distributed renewable energy sources from consumers with surplus generation capacity.By incorporating net metering into HOMER simulations, this effective balance of supply and demand on the grid is considered. This leads to optimized utilization of renewable energy resources and reduced reliance on conventional power plants during peak-demand periods. As a result, operational costs for utility companies are lowered since they do not have to procure expensive peak-load power as frequently.Lower operational costs for utility companies can translate into lower overall costs of electricity production (COE), which can then be passed on to consumers. Thus, considering net metering in HOMER simulations leads to more accurate estimations of COE that reflect potential cost savings resulting from efficient demand management through balanced load profiles on the electrical grid.So, incorporating net metering in HOMER simulations accounts for its positive impact on load balancing and overall cost optimization in electricity production systems. By considering these factors accurately, a more comprehensive understanding of how net metered systems contribute towards lowering COE is obtained compared to scenarios without net metering considerations.

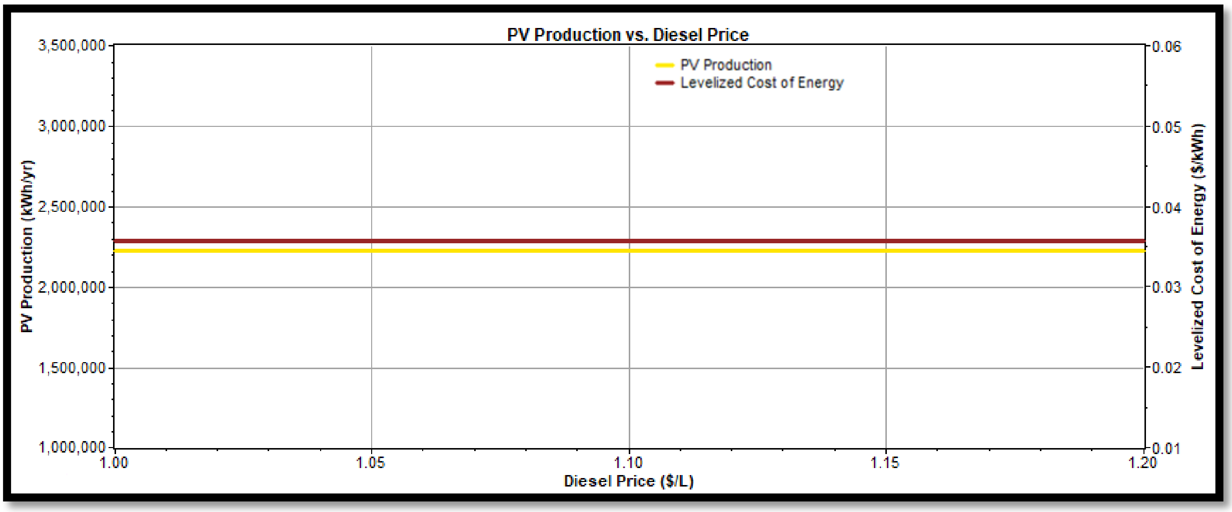
The cost of energy calculated without considering net metering (9a) in HOMER simulation is better than when net metering effects (9b) are considered, particularly regarding inverter efficiency. This is because net metering allows consumers to reduce their total energy bill by feeding excess electricity back into the grid.When net metering is implemented, consumers only pay for their net energy consumption, which is the total electricity they consume minus the energy they have fed back into the grid. This significantly reduces their overall energy costs. As a result, the levelized cost of electricity (COE) from the consumer's perspective is lower when net metering is factored in.On the other hand, without net metering, consumers would be billed for all the electricity they consume from the grid at full rates. This means that even if they have excess generation from their renewable energy system, they won't receive any financial benefit for it. Consequently, their COE would be higher due to paying more for every unit of electricity consumed.In terms of inverter efficiency, considering net metering effects can also impact system performance and cost calculations. Inverters play a crucial role in converting DC power generated by renewable sources into AC power suitable for use or injection into the grid. When excess power is fed back into the grid through net metering, inverters become more efficient because less power needs to be converted and transmitted through them.As a result of improved inverter efficiency with net metering, there can be additional savings on system costs and potential reductions in COE calculations compared to scenarios without considering this effect.Overall, including net metering effects such as reduced total energy bills and enhanced inverter efficiency results in lower COE calculations from both consumer perspectives and system performance evaluations.

The difference in the cost of energy (COE) with net metering (10b) and without net metering (10a) can be attributed to several factors, particularly the impact of interest rates.Without net metering, the COE is higher for several reasons. Firstly, there is no financial compensation for excess energy produced by the system. This means that any surplus energy generated goes unused and does not contribute to offsetting the overall electricity costs. As a result, the return on investment for the renewable energy system is reduced, increasing the COE.Secondly, higher interest rates have a significant impact on financing costs and payback periods. When interest rates are high, it becomes more expensive to borrow money to finance the initial investment in renewable energy systems. This increases the total cost of ownership over time as interest payments accumulate. With net metering in place, however, consumers have an opportunity to reduce their electricity bills by feeding excess energy back into the grid and receiving compensation for it. This additional income helps offset some of these financing costs and lowers overall COE even in environments with high interest rates.In summary, net metering provides critical financial benefits that help lower COE by compensating consumers for excess energy production and reducing financing costs associated with high-interest rates. These benefits contribute to improved financial returns on investment and make renewable energy systems more economically viable compared to scenarios without net metering.

The cost of energy (COE) being higher without net metering (11b) can be attributed to several factors related to how net metering impacts energy generation, consumption, and system efficiency.Firstly, without net metering, excess energy generated by renewable energy systems is not efficiently utilized. This means that when the system produces more electricity than is being consumed at a given moment, the surplus energy goes unused. As a result, there is wasted generation capacity that could have otherwise been utilized to offset electricity consumption during periods of high demand. This inefficiency leads to higher COE as the full potential of renewable energy generation is not realized.Secondly, without the incentive provided by net metering, there is less motivation for consumers to invest in optimally sized renewable energy systems. Net metering allows consumers to receive compensation for excess energy they produce and feed back into the grid. This financial benefit encourages consumers to invest in appropriately-sized systems that can meet their electricity needs while also generating surplus power for compensation. In the absence of net metering, consumers may be less inclined to invest in larger renewable energy systems, potentially leading to capacity shortages and increased reliance on traditional sources of electricity.Furthermore, net metering has a stabilizing effect on the grid as it allows excess power from renewable sources to be fed back into the system during periods of high demand or when other sources are unavailable or inefficient. Without this stabilizing effect provided by net metering, grids must manage more fluctuations in supply and demand which can increase operational costs.Lastly, reduced investment in renewable energy due to lower financial returns without net metering may lead to an overreliance on more expensive and less efficient sources of energy. If investments are discouraged due to insufficient compensation for excess generation, it may hinder the growth and development of renew able energy projects. This can exacerbate capacity shortages, increasing reliance on fossil fuels or other non-renewable resources, further driving up costs.

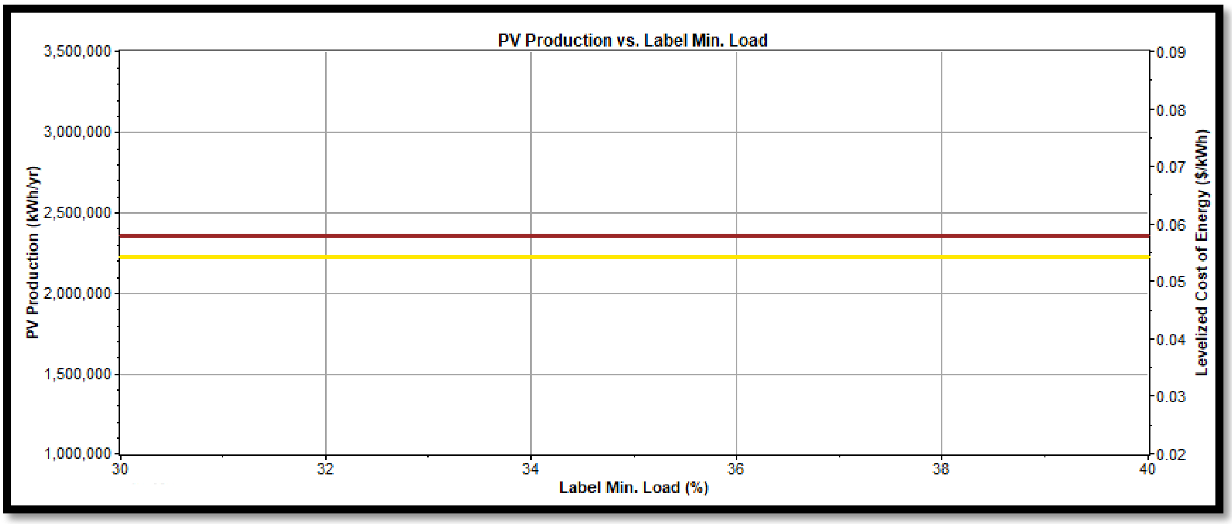


(a)

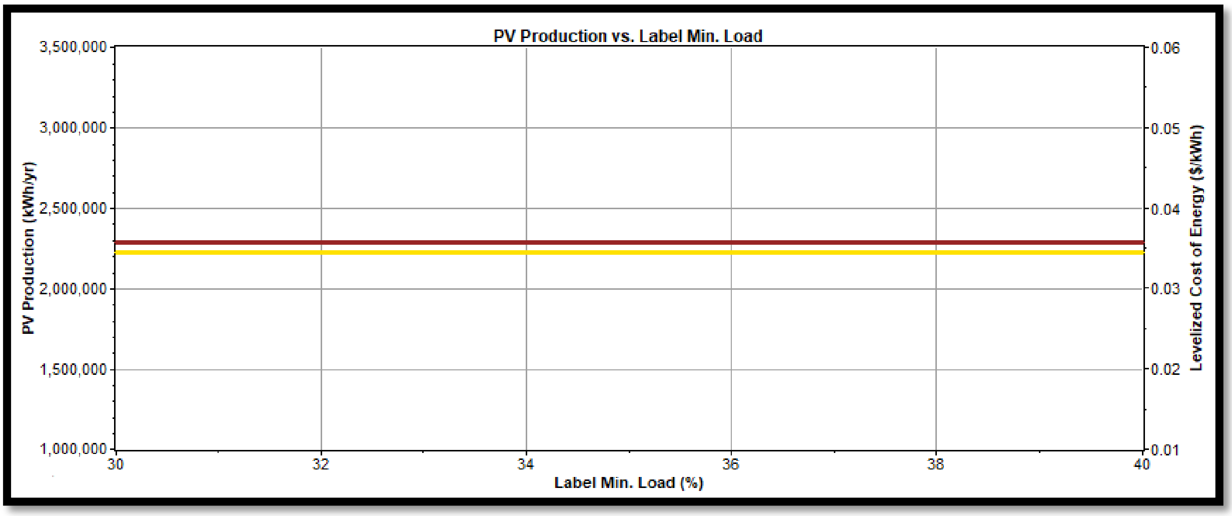


(b)

Fig. 7:The sensitivity analysis was conducted for two scenarios: (a) without a net metering system and (b) considering the effects of the net metering system, specifically regarding the diesel price in the grid-connected system.

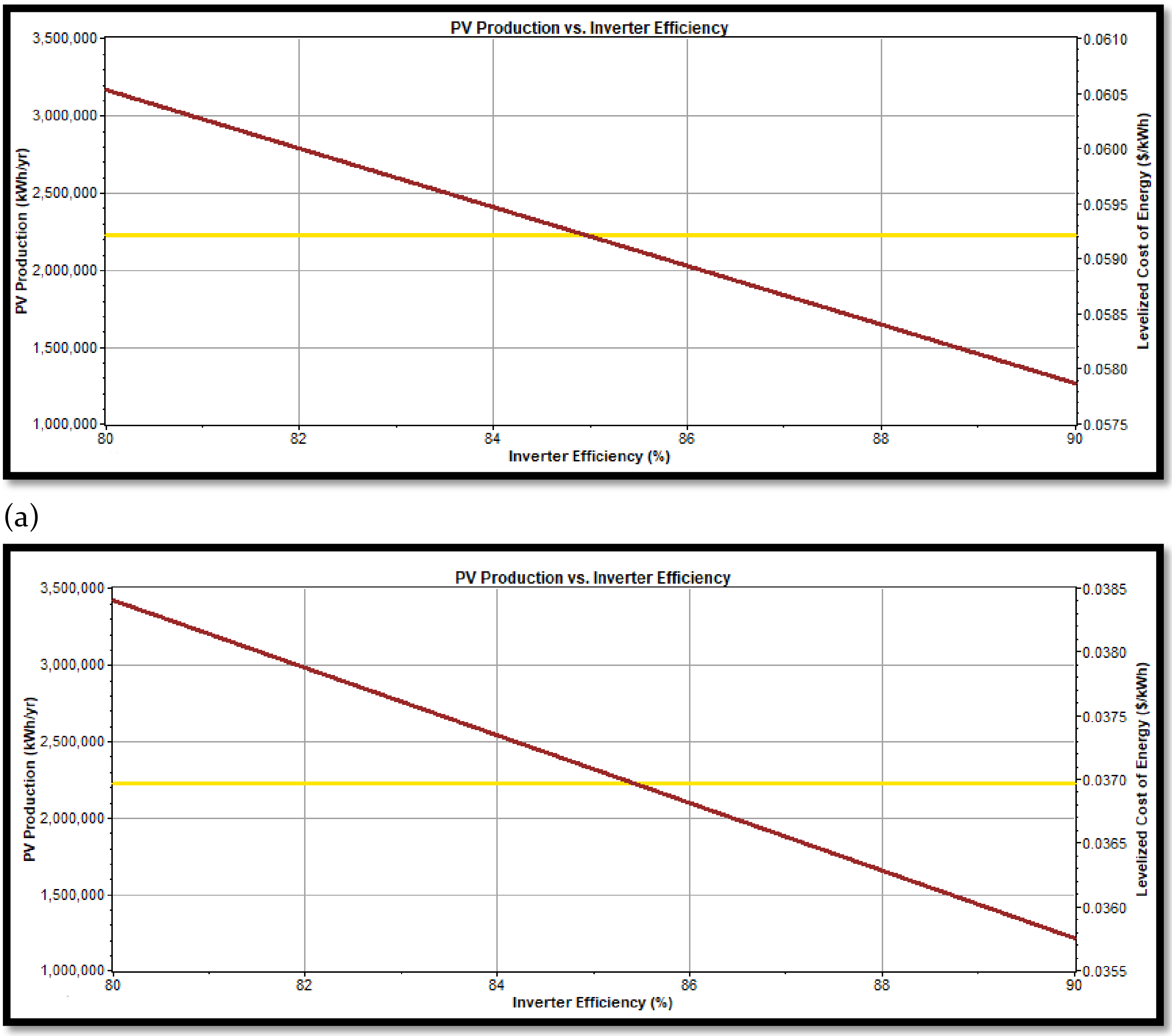


(a)



(b)

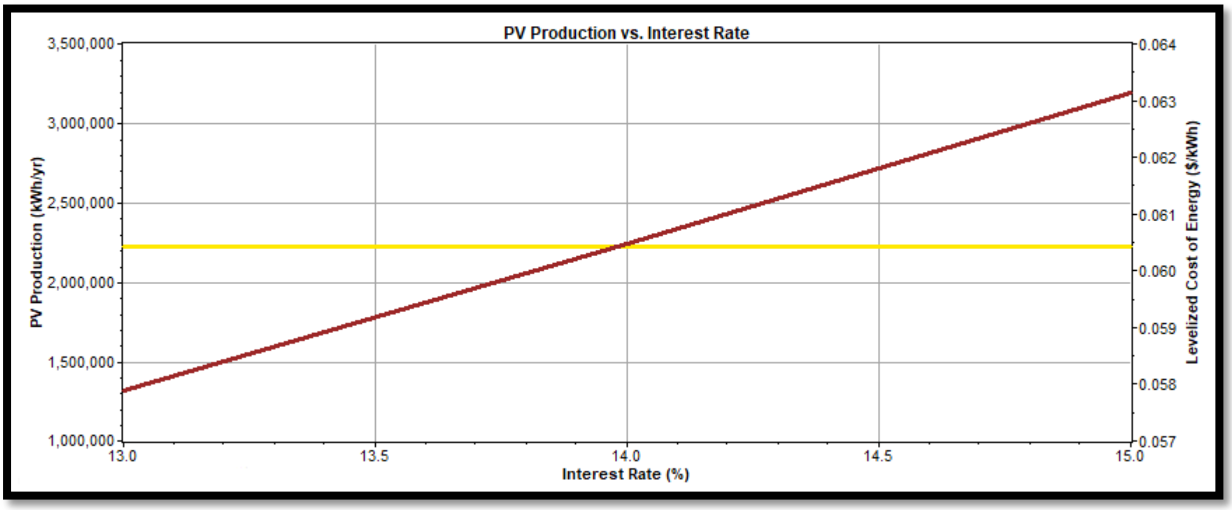
Fig. 8:The sensitivity analysis was conducted for two scenarios: (a) without a net metering system and (b) considering the effects of the net metering system, specifically regarding the minimum(min.) load in the grid-connected system.



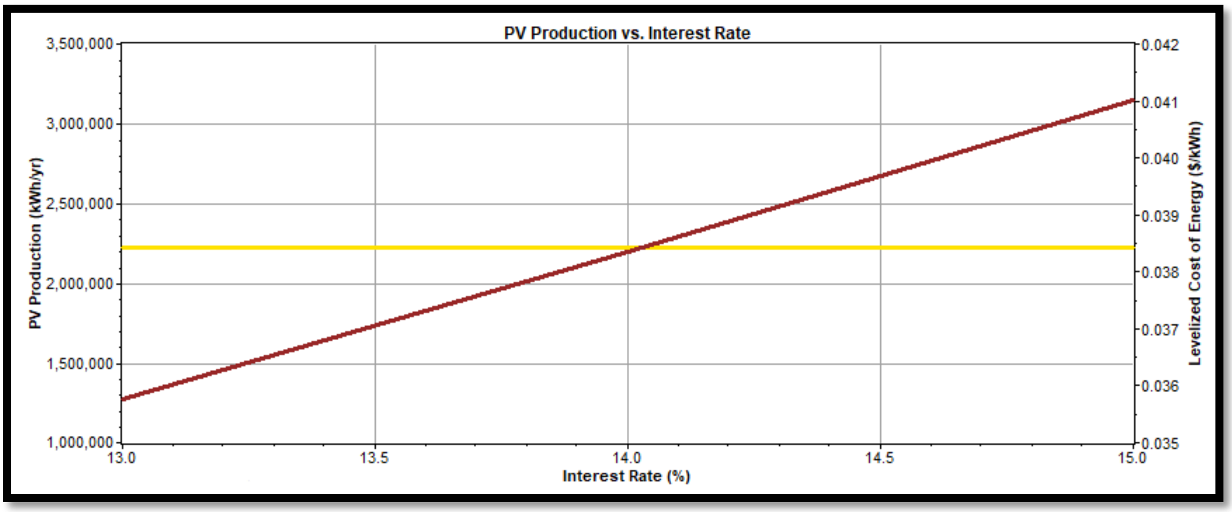
(a)

(b)

Fig. 9:The sensitivity analysis was conducted for two scenarios: (a) without a net metering system and (b) considering the effects of the net metering system, specifically regarding inverter efficiency in the grid-connected system.

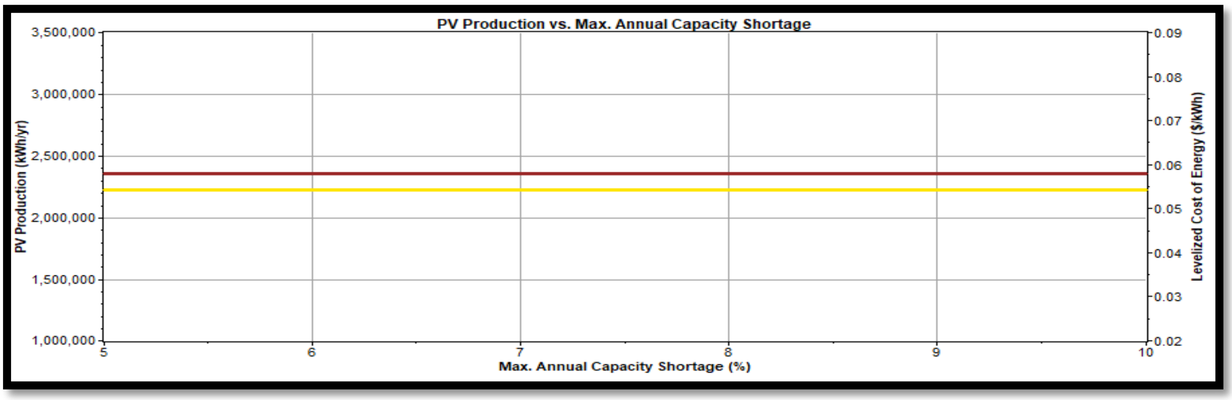


(a)

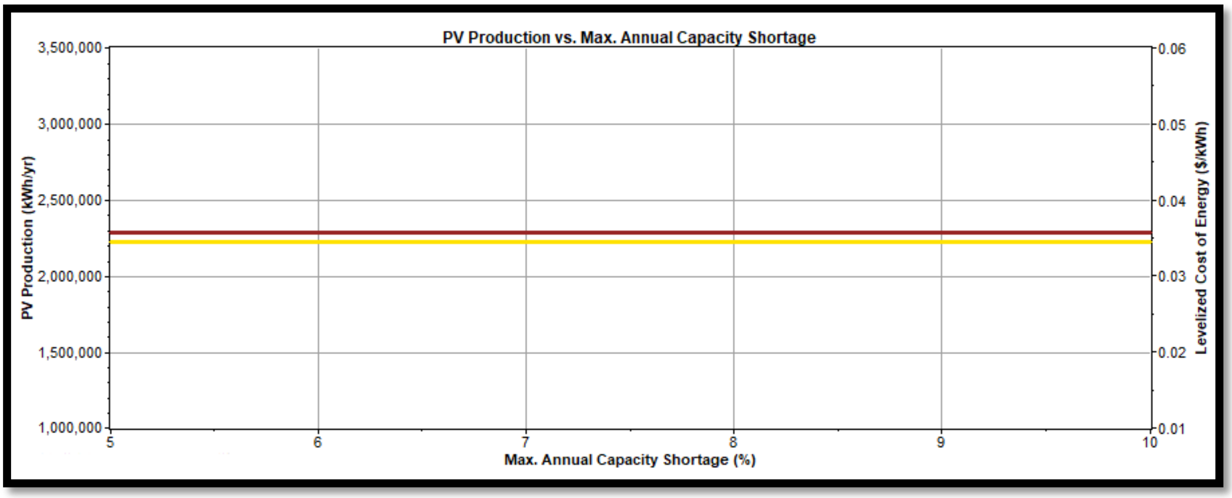


(b)

Fig. 10:The sensitivity analysis conducted for two scenarios: (a) without a net-metering system and (b) considering the effects of the net-metering system, specifically regarding interest rates in the grid-connected system.



(a)



(b)

Fig. 11:The sensitivity analysis conducted for two scenarios: (a) without a net-metering system and (b) considering the effects of the net-metering system, specifically regarding the maximum annual capacity shortage in the grid-connected system.

4. Conclusions

The study underscores the transformative potential of net metering in advancing the adoption of the hybrid renewable energy systems in Mymensingh, Bangladesh. By making renewable energy investments more economically viable and enhancing grid stability, net metering serves as a critical tool in transition towards a sustainable and resilient energy future.The study assesses the performance of various hybrid renewable energy systems using Homer software, which simulates and optimizes configurations. Without net metering, the most cost-effective configuration is a hybrid system comprising PV panels, wind, diesel generator, and a battery, achieving the lowest cost of energy at $0.058 with an 83% renewable fraction. With net metering, the cost of energy decreases to $0.036 for a similar hybrid setup, highlighting the economic and environmental benefits of net metering in promoting renewable energy investment and grid efficiency.

The sensitivity analysis using HOMER software in the study examines the impact of diesel prices on the level cost of energy (COE) for hybrid renewable energy systems. This analysis is crucial as diesel prices are subject to fluctuations and significantly affect the economics of these systems.The results show that as diesel prices increase, COE for hybrid systems also rises. This demonstrates that higher diesel costs make traditional energy sources less compared to renewable energy sources. As a result, implementing net metering becomes even more crucial offsetting these rising costs and improving the overall economic viability of hybrid systems.Net metering allows users to receive credits for any excess electricity they generate from renewable energy systems and feed back into the grid. These credits can be applied towards reducing electricity bills even selling excess electricity back to the grid. By providing financial incentives for excess energy production, net metering effectively lowers the COE for hybrid systems.In addition, reducing costs, net metering also offers other economic benefits. It enhances grid stability by promoting a balanced supply-demand relationship between users and utilities. The surplus electricity generated by users helps meet peak demand periods without relying solely on expensive backup power sources.Furthermore, net metering helps to reduce operational costs associated with managing traditional power plants and transmission lines as it encourages distributed generation closer to load centers. It also offsets higher costs related interest rates and capacity shortages by maximizing self-consumption of generated electricity.Overall, incorporating net metering into hybrid renewable energy systems improves their economic viability by lowering COE, enhancing grid stability, reducing operational costs, and mitigating other financial challenges associated with conventional power sources.

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