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Feasibility Assessment of Hybrid Renewable Energy Based EV Charging Station in Libya

Abdullah Abodwair[1], Muhammet T. Guneser[2], Mohamed M. Khaleel[3], Yasser F. Nassar[4], Hala J. El-Khozondar[5], Ziyodulla Yusupov[6], Abdurazaq Elbaz[7].

[1,3,6]Faculty of Engneering, Karabuk University, Karabuk, Turkey.
[2]Faculty of Electrical and Electronics, Istanbul Technical University, Istanbul, Turkey.
[3]Research and Development Department, College of Civil Aviation, Misurata, Libya.
[4]Research Center for Renewable Energy and Sustainable Development, Wadi AlShatti University, Libya.
[5]Electrical Engineering and Smart Systems Dept., Islamic University of Gaza, Gaza Strip, Palestine.
[5]Department of Materials and London Centre for Nanotechnology, Imperial College London, UK.
[7]The Libyan Center for Solar Energy Research and Studies, Tripoli, Libya.

E-*mail:* [1] 2138171025@ogrenci.karabuk.edu.tr , [2] mguneser@karabuk.edu.tr , [3] lykhaleel@yahoo.co.uk , [4] y.nassar@wau.edu.ly , [5] hkhozondar@iugaza.edu.ps , [6] ziyadullayusupov@karabuk.edu.tr , [7] abdalrazaklabz@gmail.com .

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ABSTRACT

This study presents an assessment of the feasibility of implementing a hybrid renewable energy-based electric vehicle (EV) charging station at a residential building in Tripoli, Libya. Utilizing the advanced capabilities of HOMER Grid software, the research evaluates multiple scenarios involving combinations of solar and wind energy sources integrated with energy storage and the utility grid. This analysis provides a novel approach to enhancing urban energy systems with renewable technologies in a region traditionally reliant on fossil fuels.

Furthermore, the study addresses the practical implications for local energy policy, suggesting that such hybrid systems can significantly enhance energy security and support sustainable urban development. The authors studied five scenarios using HOMER. The results reveals that the annual total costs and payback periods are as follows: for Scenario 1 (wind/utility grid), the expenditure totals US$1,554,416 and payback period of 4.8/5.8 years; for Scenario 2 (solar/wind/Utility grid), the amount is US$1,554,506 and payback period of 4.8/5.8 years; and for Scenario 3(solar/wind/storage/utility grid), it escalates slightly to US$1,554,731, all predicated on the utility grid tariffs and payback period of 4.8/5.8 years. Furthermore, in Scenario 4 (solar/utility grid), the annual total cost is significantly reduced to US$30,589 and a payback period of 8.1/14.3 years, while Scenario 5 (solar/storage/utility grid) incurs an even lower expenditure of

*Corresponding author.

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US$28,572, again based on the utility grid tariffs and a payback period of 14.0 years.
The findings contribute valuable insights into the scalability and adaptability of renewable energy solutions, providing a robust framework for policymakers and planners considering similar implementations in other regions. Overall, the research underscores the potential of integrated renewable energy systems to transform urban energy infrastructures, promoting a sustainable and resilient energy future. The HOMER Grid analysis shows that configurations with energy storage are more cost-effective in the long run, even though they require higher initial costs. It also offers important insights into the economic viability and optimization of hybrid renewable energy systems for an EV charging station in Tripoli, Libya. These results highlight the significance of making calculated investments in renewable energy infrastructure and supporting policies for the development of sustainable energy.

تقييم الجدوى الاقتصادية لمحطة شحن السيارات الكهربائية الهجينة المعتمدة على الطاقة المتجددة في ليبيا

عبد الله أبودوير، محمد طاهر جونسر، محمد خليل، ياسر نصار، هالة الخزندار،
زياد الله يوسوبوف، عبد الرزاق الباز.

ملخص: يتقدم هذه الدراسة تقييماً اقتصاديا لجدوى تنفيذ محطة شحن هجينة للسيارات الكهربائية تعتمد على الطاقة المتجددة (EV) في مبنى سكني في طرابلس - ليبيا. ومن خلال الاستفادة من القدرات المتقدمة لبرنامج HOMER Grid، يقوم البحث بتقييم عدة سيناريوهات تتضمن مجموعات من مصادر الطاقة الشمسية وطاقة الرياح المدمجة مع تخزين الطاقة والشبكة الكهربائية العامة. يوفر هذا التحليل نهجاً جديداً لتعزيز منظومات الطاقة باستخدام التقنيات المتجددة في منطقة تعتمد في الاساس على الوقود الأحفوري. وتكمن المساهمة الرئيسية لهذه الدراسة في عرض استراتيجية تكامل مبتكرة تجمع بين الطاقة الشمسية وطاقة الرياح مع منظومة تخزين (البطارية) لضمان إمدادات طاقة موثوقة وفعالة لشحن المركبات الكهربائية. علاوة على ذلك، تسلط الدراسة الضوء على الدور التي يمكن ان تلعبه مثل هذه الأنظمة الهجينة في تعزيز بشكل كبير أمن الطاقة وتدعم التنمية المستدامة. قام المؤلفون بتحليل خمسة سيناريوهات باستخدام برنامج HOMER. بينت النتائج أن إجمالي التكاليف السنوية وفترات الاسترداد هي كما يلي: للسيناريو الاول (طاقة الرياح/الشبكة العامة)، يبلغ إجمالي التكاليف $1,554,416 وفترة استرداد حوالي 4.8-5.8 سنة. وللسيناريو الثاني (الطاقة الشمسية/طاقة الرياح/الشبكة العامة)، قدرت إجمالي التكاليف بحوالي $1,554,506، وفترة استرداد حوالي 4.8-5.8 سنة. أما السيناريو الثالث (الطاقة الشمسية/طاقة الرياح/التخزين/الشبكة العامة)، فإن اجمالي التكاليف يتصاعد قليلاً إلى $1,554,731، ويعتمد كل ذلك على تعريفة الكهرباء في الشبكة العامة، وكانت فترة الاسترداد ايضا 4.8-5.8 سنة. بينما انخفضت التكاليف السنوية الاجمالية بشكل كبير للسيناريو الرابع (الطاقة الشمسية/الشبكة العامة) حيث بلغت $30,589 وبلغت فترة الاسترداد حوالي 8.1-14.3 سنة، في حين أن السيناريو الخامس (الطاقة الشمسية/التخزين/الشبكة العامة) يتكبد تكاليف أقل من $28,572، وتعتمد مرة أخرى على تعريفة الكهرباء في الشبكة العامة وبلغت فترة الاسترداد حوالي 14.0 سنة. سلطت الدراسة الضوء حول قابلية التوسع والقدرة على التكيف لحلول الطاقة المتجددة، مما يوفر إطاراً لواضعي السياسات والمخططين الذين يفكرون في تطبيقات مماثلة في مناطق أخرى. وبشكل عام، يؤكد البحث على إمكانات أنظمة الطاقة المتجددة المتكاملة لتحويل البنى التحتية للطاقة في المناطق الحضرية، وتعزيز مستقبل الطاقة المستدامة والمرنة. كما تُظهر النتائج أن الانظمة التي تحتوي على منظومات تخزين الطاقة تكون أكثر فعالية من حيث التكلفة على المدى الطويل، على الرغم من أنها تتطلب تكاليف أولية أعلى. كما قدم البحث تصورات مهمة حول تحسين أنظمة الطاقة المتجددة الهجينة لمحطة شحن السيارات الكهربائية في طرابلس، ليبيا. كما واوصت الدراسة بتشجيع الاستثمارات في تطوير البنية التحتية للطاقة المتجددة ودعم السياسات لتطوير الطاقة المتجددة والمستدامة.

الكلمات المفتاحية – الطاقة الشمسية؛ طاقة الرياح؛ الطاقات المتجددة الهجينة؛ محطات شحن السيارات الكهربائية؛ ليبيا.

1. INTRODUCTION

Because they are abundant and ecologically benign, renewable energy sources like solar, bio, and wind are gradually replacing fossil fuels. These environmentally friendly energy options play a major role in the global transition to cleaner energy sources because they drastically lower carbon emissions and environmental degradation. Renewable energy sources can be used singly or in combination with other energy sources to create hybrid systems that are more dependable and efficient. These systems are adaptable; they can operate off the grid, offering energy independence in isolated locations or for purposes, or on the grid, integrating with current electrical networks [1-5]. Renewable power capacity is projected to expand significantly over the next five years, with solar photovoltaic (PV) and wind energy anticipated to comprise a record-breaking 96% of this increase [6-8]. This dominance is primarily due to the lower generation costs associated with solar PV and wind compared to both fossil fuel and non-fossil fuel energy sources in the majority of countries. Additionally, continued policy support is bolstering this growth trajectory. It is forecasted that by 2028, the additions of solar PV and wind capacity will more than double compared to their levels in 2022, setting new records annually and culminating in a combined capacity nearing 710 GW by the end of the forecast period [9,10]. This trend underscores the accelerating shift towards renewable energy as a cornerstone of global efforts to achieve sustainable energy futures. In 2022, wind power generation achieved a record increase of 265 TWh, a 14% rise, bringing the total to over 2,100 TWh. This growth ranked second among all renewable power technologies, trailing only solar PV [10]. However, to align with the Net Zero Emissions by 2050 Scenario, which projects wind power generation to reach approximately 7,400 TWh by 2030, it is necessary to elevate the average annual growth rate to around 17% [11]. To meet this ambitious target, annual capacity additions must surge from about 75 GW in 2022 to 350 GW by 2030. Achieving such a significant expansion will demand considerably enhanced efforts from both policymakers and the private sector [12,13]. Key focus areas must include streamlining permitting processes for onshore wind developments and reducing the costs associated with offshore wind projects, both critical to accelerating capacity growth and fulfilling the ambitious 2030 targets. In 2023, battery storage emerged as the fastest-growing commercially available energy technology, with its deployment more than doubling on a year-on-year basis [14,15]. This robust expansion was evident across various applications, including utility-scale battery projects, behind-the-meter batteries, mini-grids, and solar home systems for electricity access, collectively contributing an additional 42 GW of battery storage capacity worldwide [15,16]. Moreover, the deployment of electric vehicle (EV) batteries increased by 40%, with 14 million new EVs introduced, representing the majority of batteries utilized in the energy sector [17-20]. It is important to highlights that, battery storage systems are gaining increasing significance in both utility-scale and behind-the-meter applications. This trend is driven by declining costs and the growing proportion of electricity generated from solar and wind sources. The projected increase in EV sales to approximately 17 million units by 2024, making up over 20% of global automotive sales, has significant implications for climate change mitigation [21-23]. This surge in EV adoption can lead to substantial reductions in greenhouse gas emissions by replacing internal combustion engines with more energy-efficient alternatives and fostering greater integration of renewable energy sources. This trend underscores the transition of EVs towards a ubiquitous presence in an increasing array of national markets [24-27]. Despite the confluence of challenges such as narrow profit margins, the fluctuating costs of battery metals, elevated inflation rates, and the gradual withdrawal of purchase incentives in certain jurisdictions, the sector's expansion remains robust. In the initial quarter of 2024, EV sales experienced an approximate 25% surge from the same period in the preceding year, mirroring growth rates observed in 2022 [24]. Predictions for 2024 suggest that EV market penetration could escalate to 45% in China, 25%

in Europe, and surpass 11% in the United States. This anticipated growth is supported by competitive dynamics among manufacturers, reductions in the prices of batteries and vehicles, and sustained policy initiatives [24]. In addition to the substantial initial costs associated with EVs, owners often face significant additional expenses related to establishing necessary charging infrastructure at their residences or workplaces. One of the most substantial hurdles to more rapid EV adoption is the high cost associated with establishing grid connections for parking facilities within buildings. Introducing initiatives where charging stations are considered assets of the building could reduce the financial burden on individuals by decreasing the upfront investment required for home or office EV charging setups [25-31]. Furthermore, the implementation of smart charging technologies, including Vehicle-to-Grid (V2G) and Vehicle-to-Building (V2B), offers the potential to transform EVs into valuable energy assets. These technologies enable new business models, such as aggregation, that could significantly lower the total cost of ownership (TCO) for EV users by optimizing energy usage and potentially generating revenue [32-34]. To maximize the impact of transport electrification, EVs should be viewed as distributed energy resources. The batteries within EVs present an opportunity to enhance the penetration of renewable energy sources by synchronizing energy production and demand, and by leveraging their flexibility through grid services such as V2G or through aggregation policies. This approach requires rethinking traditional business models and necessitates accompanying regulatory adjustments and adaptations in the electricity market. For EVs to be effectively designated as distributed energy resources, integration of the charging infrastructure into the building's energy management system is essential. This integration facilitates the effective participation of EVs in energy management strategies, ensuring they contribute positively to grid stability and energy efficiency. In Libya, the nominal capacity of power generation facilities in 2019 was estimated at approximately 14,500 MW. However, due to ongoing political and security instability, the effective available generating capacity was substantially reduced to around 44% of the nominal, equivalent to 6,320 MW. In 2019, the peak electrical demand in Libya reached 7,500 MW, surpassing the available power generation capacity by 1,200 MW [35-39]. Consequently, various regions within Libya experienced prolonged power outages throughout the day. Figure 1 illustrates the distribution of Libyan electricity demand across different utility sectors in 2023, based on the most recently published and recorded data [40]. The residential sector accounted for 51.1% of the electrical demand, marking it as the largest consumer, followed by commercial and public services of 11.2% of the demand.

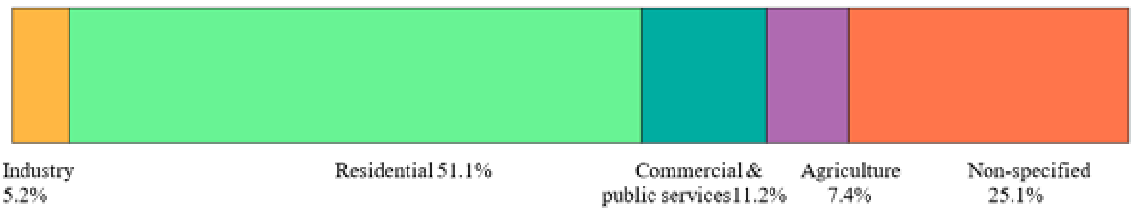


Figure 1. Electricity consumption by sector in Libya for 2023 [40].

In Libya, demographic and economic expansion have been driving annual increases in electricity demand. Data from the annual reports of the Libyan General Electricity Company (GECOL) indicate that from 2003 to 2010, electricity demand in Libya grew at an annual rate of 12%. Should this trend persist, it is projected that by 2030, electricity demand will escalate to approximately 14 GW, representing a doubling, or 100% increase, in demand relative to the levels recorded in 2019 [40]. Anticipated surge in electricity demand by 2030 will necessitate substantial development of Libya's electrical infrastructure, alongside significant investments in renewable energy sources (RES) and EV charging station infrastructure. This expansion aims to ensure uninterrupted power generation to meet the growing demand. Consequently, there is a pressing need for comprehensive research in Libya to examine the implications of integrating RES and EV charging stations into the power network, specifically focusing on power quality and the stability of the power-protection system. In the current landscape, RES and EV charging stations are increasingly adopted due to their cost-effectiveness, the abundance of natural resources, and the benefits of clean energy [41,42]. There exists a limited corpus of academic research focused on the feasibility assessment of hybrid renewable energy-based EV charging stations within select urban centers in Libya. Several studies have been conducted in various cities globally. According to [43], the article explored the advancements, challenges, and opportunities associated with EV development in Sub-Saharan Africa (SSA). It proposes strategies to accelerate the region's transition to EVs. Despite noteworthy progress, the shift towards EVs in SSA continues to confront substantial obstacles that require urgent attention. In [44], this article investigated the operational potential of a hybrid energy system with battery storage in Bizerte, the northernmost city in Africa, located in Tunisia. Following this, the article utilized the HOMER simulation software to simulate and optimize the technical-economic feasibility of the system. Various system configurations, both with and without battery storage components, were explored and analyzed. In this study [45], the optimal configuration of a hybrid energy system was analyzed using meteorological data and HOMER software. The chosen system exhibited the most favorable economic parameters, including the lowest Levelized Cost of Energy (LCOE) at $0.6208 per kg, LCOE at $9.34 per kg. These figures confirm the system as the most cost-effective solution for the proposed hydrogen project in Al-Kharj. Moreover, recent research [34] focused on the modeling and analysis of integrating renewable energy sources and EVs into a microgrid configuration. This microgrid includes four critical components: a diesel generator serving as the primary power source, a combination of a photovoltaic (PV) farm and a wind farm for electricity generation, and a V2G system strategically situated near the microgrid's load center. A potent software program called HOMER (Hybrid Optimization of Multiple Energy Resources) is used to plan and improve hybrid energy systems. To identify the most dependable and affordable energy solutions, it assists in modeling and assessing the performance of various combinations of storage, conventional systems, and renewable energy sources. Because of its adaptability, HOMER can be used to assess both off-grid and on-grid systems, which makes it a crucial tool for planning and implementing renewable energy projects. Several researchers used HOMER in their energy system simulations for hybrid modes [46-51].

This study aims to:

1. Create and present a cutting-edge integration approach that boosts the dependability and effectiveness of urban energy systems by integrating solar, wind, and battery storage.
2. Highlight the advantages of combining solar and wind energy to encourage the adoption of renewable technologies in areas that have historically relied on fossil fuels.
3. Implement inventive energy management and storage techniques to guarantee a steady and dependable energy source for electric vehicle (EV) charging.
4. Investigate how renewable energy sources can help support sustainable urban energy systems and lower carbon emissions.

2. THE DIFFICULTIES AND CHALLENGES FACED BY THE ELECTRICAL ENERGY SECTORS AND POWER GRIDS IN LIBYA

GECOL holds the responsibility for managing the entirety of Libya's electrical sector, which encompasses generation, transmission, and distribution activities. Libya's power generation primarily depends on thermal electricity produced from fossil fuels, notably oil and gas. The key facilities for power generation within the Libyan electricity network are strategically located:

east of Tripoli, with a capacity of 1,400 MW; Tobruk, with a capacity of 740 MW; and west of Tripoli and Misratah, each with a capacity of 600 MW. However, the ongoing civil conflict has restricted the current operational power generation capacity to merely 44% of the total installed capacity. In this context, the installed power generators comprise 19 power-generation units that are currently out of service. In 2019, the power generated was sufficient to meet only 25% of the electrical energy demand. The political and security instability in the region has led to a rapid increase in power shortages and outages. For instance, in 2019, the average duration of power blackouts in the western region of Libya amounted to six hours per day.

As the population grows, the demand for electrical energy, an essential component of human life, has surged in Libya. This increase is particularly evident over the last three years, marked by a significant rise in construction projects which have contributed to a dramatic escalation in electrical demand. GECOL projects that the peak electrical demand will reach approximately 14,834 MW by 2030, up from 10,795 MW in 2020. The electrical infrastructure grid in Libya has not been sufficiently upgraded to accommodate future demand and is beset by numerous challenges. Firstly, significant power losses occur due to the absence of a regular maintenance schedule for power plants. Secondly, there is an elevated risk of power outages due to a shortage of spare parts. Additionally, environmental challenges arise from the emissions produced by thermal power plants. Clearly, in 2018, Libya ranked 55th globally in greenhouse gas emissions, with 54 million metric tons of CO_2 emitted. Consequently, the implementation of renewable energy systems, such as photovoltaic (PV) and wind power plants, has been identified as a primary objective of GECOL to simultaneously enhance the power producing capacity and mitigate emissions of greenhouse gases.

The article makes several noteworthy contributions to the field of renewable energy applications in infrastructure development, particularly in regions like Libya where traditional energy resources are predominantly relied upon. Below are the key contributions of this research:

- Innovative Integration of Renewable Energy Sources:

This study pioneers the practical integration of multiple renewable energy sources—solar and wind—with energy storage systems to power an EV charging station. This approach not only diversifies the energy mix but also enhances the reliability and efficiency of energy supply, particularly in an urban residential setting.

- Advancement in Localized Energy Solutions:

By conducting this feasibility assessment at a strategically selected location in Tripoli, the study demonstrates the potential for localized renewable energy solutions to meet specific community needs. This is particularly significant in Libya, where the energy demand is rising and the infrastructure needs diversification to include more sustainable options.

- Utilization of Cutting-edge Simulation Tools:

Employing HOMER Grid software represents a significant methodological advancement in the design and optimization of microgrids. This tool allows for detailed and accurate simulations of complex scenarios involving renewable energy, storage, and utility grids, providing insights into their operational feasibility and economic viability.

- Economic and Environmental Impact Analysis:

The research provides a comprehensive analysis of the economic and environmental impacts of each energy scenario. It not only assesses direct financial benefits like cost savings and payback periods but also evaluates broader impacts such as CO_2 emissions reduction. This dual focus aids policymakers and investors in making informed decisions that align with economic goals and sustainability objectives.

- Practical Implications for Policy and Planning:

The findings from this study offer practical insights for urban planners, energy policy makers, and private investors about the feasibility, scalability, and impact of hybrid renewable energy systems in urban settings. The detailed scenario analysis informs future planning and investment in infrastructure that supports sustainable urban development.

- Enhancement of Energy Security:

By integrating renewable energy sources with existing utility grids and incorporating storage solutions, the proposed system significantly enhances energy security. This is crucial for Libya, considering the potential fluctuations in energy supply and the need for stable energy access to support growing urban populations and economic activities.

- Scalability and Adaptability:

The methodology and findings of this study are scalable and adaptable to other regions and settings. The comprehensive data collection and parameter settings, along with the robust simulation process, provide a blueprint that can be customized to assess other types of renewable energy projects across different geographical and climatic conditions. Thus, this article makes significant contributions to the field of renewable energy deployment in urban environments, providing a viable model for the integration of diverse energy sources in a grid-connected setup.

3. OPPORTUNITY AND CHALLENGES OF INSTALLING SOLAR PV, WIND, AND EV CHARGING STATION IN LIBYA

Libya is located in the Maghreb region of North Africa, positioned at a latitude of 26.3347° N and a longitude of 17.2692° E. Around 90% of its territory is categorized as desert. Figures 2 and 3 illustrate photovoltaic and wind power potentials, respectively. The area of Libya is approximately 1,759,540 square kilometers, and the country is served by a highway network totaling 83,200 kilometers, of which 47,590 kilometers are paved. The latest estimates for 2023 indicate that the number of cars has reached 5,483,760. The transportation sector is the largest consumer of fuel, with fuel consumption reaching about 5,545 thousand tons. Additionally, the transportation sector consumes about 17,262 terajoules of electricity annually. The amount of CO_2 emitted from this sector is estimated at about 18,246 million tons annually [52].

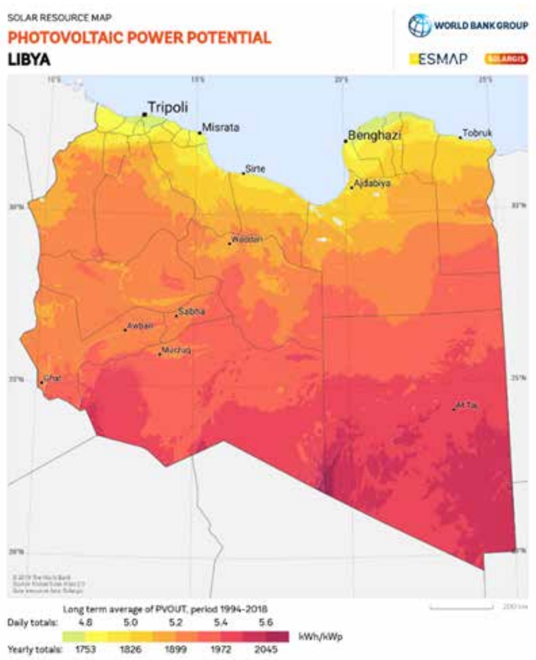


Figure 2. Photovoltaic power potential in Libya [53].

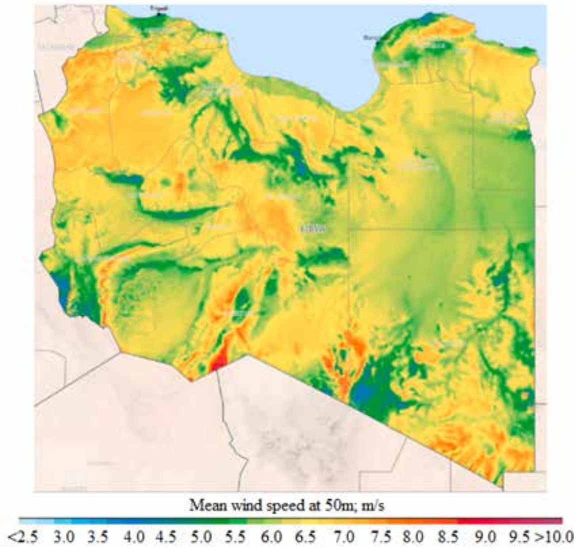


Figure 3. Wind power potential in Libya [54].

A. Opportunities:

- Resource Availability:

Libya is endowed with one of the highest levels of solar irradiance globally, averaging over 3,000 hours of sunshine per year, coupled with consistent wind currents particularly in the coastal regions. This geographic advantage presents a prime opportunity for harnessing solar and wind energy at a large scale.

- Reduction in Energy Import Costs:

By tapping into its renewable resources, Libya can reduce its reliance on imported fuels for power generation, thereby saving substantial foreign exchange reserves and reducing vulnerability to global oil price fluctuations.

- Sustainable Energy Development:

Transitioning to renewable energy aligns with global sustainability goals and can position Libya as a leader in renewable energy in the region. This shift can attract international grants and funding aimed at environmental sustainability.

- Technological Advancement:

The development of solar, wind, and EV infrastructure can stimulate the local technology sector, encouraging innovation and modernization across related industries, such as manufacturing and services.

- Tourism and Image Boost:

Implementing green initiatives can improve Libya's international image, potentially boosting tourism and attracting environmentally conscious tourists and investors.

B. Challenges:

The installation of PV systems, wind farms, and EV charging stations in Libya faces several distinct challenges, largely due to a combination of technical, economic, and socio-political factors:

- Political and Security Instability: Libya's ongoing political turmoil and security issues pose significant risks to the implementation and maintenance of renewable energy infrastructure. These conditions can deter investment and disrupt project development, management, and operation.
- Economic Constraints: Despite its vast oil reserves, Libya's economy has suffered due to prolonged conflict, affecting its financial capability to invest in new technologies. Funding

renewable energy projects is particularly challenging given the current economic instability.

- Infrastructure Limitations: The existing electrical grid in Libya is outdated and has been damaged by conflict, leading to frequent outages and reduced capacity. Integrating renewable energy sources and EV charging infrastructure requires substantial upgrades to the existing grid to handle new types of loads and to ensure stability.
- Technical Expertise and Workforce Training: There is a shortage of local technical expertise in renewable energy technologies. Developing a skilled workforce is essential for the installation, maintenance, and troubleshooting of advanced technologies like solar PV, wind turbines, and EV charging stations.
- Regulatory and Policy Framework: Libya lacks a comprehensive regulatory framework that supports renewable energy projects. Without incentives, clear guidelines, or governmental support, it can be difficult for these projects to get off the ground.
- Environmental and Geographical Considerations: While Libya has significant solar and wind resources, the harsh desert environment can be detrimental to the equipment. Sand and dust can reduce the efficiency of solar panels and increase the wear and tear on wind turbine components.
- Logistical Challenges: The large geographic spread of potential sites for wind and solar farms, coupled with the current state of roads and transportation infrastructure, complicates the logistics of moving materials and workers to installation sites.
- Cultural and Social Acceptance: Transitioning to renewable energy sources and introducing technologies like EV charging stations require public acceptance and behavioral changes. Building awareness and gaining the support of local communities are crucial for the successful adoption of these technologies.

Addressing these challenges requires coordinated efforts between the government, private sector, international partners, and local communities to create a conducive environment for renewable energy and EV infrastructure development in Libya.

4. METHODOLOGY

In this study, researcher employed a detailed and methodology to evaluate the feasibility of establishing a hybrid renewable energy-powered EV charging station at a residential building in Tripoli, Libya. HOMER advanced capabilities is used to simulate various energy configurations to assess their economic viability and environmental impact. The methodology incorporates the analysis of multiple scenarios involving different combinations of renewable energy sources and storage options integrated with the utility grid. This process is underpinned by a thorough collection of site-specific data, technical specifications, and environmental conditions to ensure the accuracy and relevance of our feasibility assessments. Through this methodology, we aim to identify the most efficient and sustainable energy solution for the proposed EV charging station. The selection of specific types of solar cells, wind turbines, frequency converters, and batteries was based on the outcomes of local studies [55,56]. A table detailing the technical and electrical characteristics of these components is provided in the appendices.

A. Study Location and Context

The feasibility assessment of a hybrid renewable energy-based EV charging station is conducted at a strategically chosen site—an apartment building in Tripoli, Libya. Figure 4 demonstrates the precise location of the selected residential area. This location is pinpointed at latitude 32°51.7'N and longitude 13°10.3'E, encompassing four floors and serviced by the General Electric Company of Libya (GECOL). The proximity to the power grid and urban infrastructure makes this an ideal site for deploying a hybrid renewable energy system.

Figure 4. Location of the selected residential area.

B. Solar energy (P_{PV})

The real PV panel power according to real operation conditions of surface cell's temperature (T_{cell}) and global tilted solar irradiation (H_g) is correlated by [57]:

$$P_{PV} = P_{STC}\left[1+\beta_{p,T}(T_{cell}-T_{STC})\right]\times\frac{H_g}{H_{STC}} \qquad (1)$$

Where P_{PV} is the real PV power (W); P_{STC} is the PV power under Standard Test Condition STC; $\beta_{p,T}$ is the temperature coefficient (%/°C); T_{STC} and H_{STC} denote the STC temperature (°C) and solar radiation (W/m^2), respectively. The cell's temperature (T_{cell}) is estimated as [58]:

$$T_{cell} = T_\infty + 0.07H_g \qquad (2)$$

Where: T_∞ is hourly ambient air temperature (°C).

C. Wind energy

Three requirements must be met by the wind turbine to maximise energy output: low cut-in speed, rated wind speed that is equal to or greater than wind speed, and high cut-off speed. The power of wind turbine as a function of wind speed are expressed using equation 3 [59, 60].

$$E_W = \begin{cases} P_{rat}\left(\dfrac{V_{Z,t}-V_{cut-in}}{V_{rat}-V_{cut-in}}\right), & V_{cut-in} \prec V_{Z,t} \prec V_{cut-off} \\ 0 & , \; V_{Z,t} \le V_{cut-in} \; OR \; V_{Z,t} \ge V_{cut-off} \end{cases} \qquad (3)$$

Where: P_{rat} is the rated power of the wind turbine at rated wind speed V_{rat}, $V_{(cut\text{-}in)}$ and $V_{(cut\text{-}off)}$ are the cut-in and cut-off wind speeds, and $V_{Z,t}$ is the wind speed at the wind turbine hub height (h_Z) and it is calculated from:

$V_{Z,t} = V_{0,t}\left(\dfrac{h_Z}{h_0}\right)^{\alpha}$, where, $V_{0,t}$ is the wind speed at a certain elevation (h_0) and α is the wind shear coefficient [61].

D. Economic and Environmental Analysis

The LCOE of electrical energy generated by the proposed hybrid renewable energy system with considering the CO_2 social cost C_{CO2} may be calculated as [62]:

$$LOCE = \frac{\frac{i(1+i)^n}{(1+i)^n-1}C_{HRS} + OM_{HRS} - C_{CO_2}}{E} \qquad (4)$$

Where:

C_{HRS} represent the average capital costs of the proposed HRES in US\$, and OM_{HRS} is the operation and maintenance cost of HRES. E indicates the annual energy yields of HRES in kWh/year, i is the interest rate and is assumed to be equal to 2%, and n is the plant's lifespan and is assumed to be 30 years [63]. And C_{CO2} represent the CO_2 social cost, which estimated from:

$$C_{CO_2} = EF_{CO_2} \times G_{elec} \times \phi_{CO_2} \qquad (5)$$

EF_{CO_2} is the emission factor of CO_2 [978 kg CO_2/MWh], G_elec is the annual energy generated by the HRES [MWh], and ϕ_{CO_2} indicates to the international price of CO_2. The average carbon price has been set at least $75 per ton CO_2 by the end of the decade to succeed the global climate goals, and would rise to $85 a ton in 2030 [64].

The amount of CO_2 saved (Q_{CO2}) may be estimated as follows [65]:

$$Q_{CO_2} = EF_{CO_2}\left[E_{HRE} - E_{Grid}\right] \qquad (6)$$

Where E_{HRE} and E_{Grid} are the energy generated by the HRES and the utility grid in MWh, respectively.

The payback time money (PT) can be estimated by [66]:

$$PT = \frac{C_{HRS}}{AR} \qquad (7)$$

Where AR Is the average annual return

E.Software and Analytical Tools

The study employs HOMER Grid to obtain the best suggested scenario. Figure 5, illustrates a hybrid renewable energy-powered EV charging station integrated with utility grid. This tool is crucial for assessing economic viability and operational feasibility, providing detailed outputs on cost-effectiveness, energy efficiency, and system sustainability.

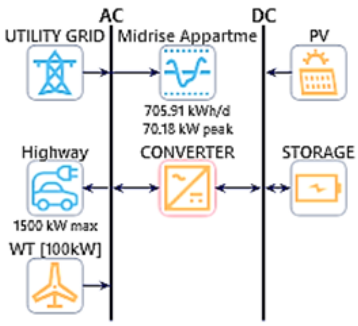


Figure 5. A hybrid renewable energy-powered EV charging station integrated with utility grid.

F. Energy Scenarios

The research explores five distinct scenarios to identify the most effective configuration for the hybrid renewable energy-powered EV charging station:

- **Scenario 1:** Integration of wind energy with utility grid.
- **Scenario 2:** Hybrid energy system consists of solar energy/wind energy/utility grid.
- **Scenario 3:** Hybrid energy system consists of solar energy/wind energy/energy storage/ connected to the utility grid.
- **Scenario 4:** Integration of solar energy system with utility grid.
- **Scenario 5:** Hybrid energy system consists of solar energy/energy storage/connected to the utility grid.

Each scenario is modeled to assess its performance under local environmental conditions and utility rates, thereby determining the optimal setup for maximum efficiency and reliability.

G. Data Collection and Parameter Settings

Data on the technical specifications of the proposed hybrid renewable energy systems and EV integration are detailed in Table 1 [65-67]. This includes the capacity of each energy system, and storage capabilities. Moreover, Geographic and meteorological data specific to Tripoli, including solar irradiance, wind speed, and utility rate structures, are incorporated into the HOMER Grid simulations. Table 2 indicates essential meteorological data for multiple cities in Libya [65].

Table 1. The parameter and technical specification of a hybrid renewable energy-powered EV integrated with utility grid.

Parameter	Technical Specification
Utility grid	415 V, 50Hz
Wind turbine	100.0 kW
PV	30.0 kW
Converter	33.0 kW
Battery storage	118.0 Ah

The utility grid is configured to operate at a voltage of 415 V with a frequency of 50 Hz, ensuring compatibility with standard industrial and commercial equipment requirements. The renewable energy generation system includes a wind turbine with a substantial capacity of 100.0 kW, designed to harness wind energy efficiently. Complementing this, a photovoltaic (PV) system is installed with a capacity of 30.0 kW, which converts solar radiation into electrical energy through solar panels. For energy conversion and regulation, the system is equipped with a converter of 33.0 kW. This converter is crucial for matching the output from the renewable sources—both wind and solar—to the specifications of the utility grid, as well as managing voltage and current to optimize the energy transfer process. Lastly, the energy storage component of the system consists of a battery with a capacity of 118.0 Ah. This battery storage is integral for maintaining energy supply stability, allowing for energy accumulation during peak production periods and its subsequent release during times of low production or high demand, thereby enhancing the overall efficiency and reliability of the energy system.

Table 2. An essential meteorological data for multiple cities in Libya [65].

City	Daylight h		Gobal horizontal solar irradiation W/m²		Temperatue °C			Wind speed m/s		Relative Hummidity %		Rainfall mm	
	Avg.	max	Avg.	Max	Min	Avg.	Max	Avg.	Max	Min.	Avg.	Avg.	Max
Tripoli	12:10	14:18	437	1030	1	21	39	4	17	16	62	0.03	6
Ajdabiya	12:10	14:06	471	1057	2	21	40	5	15	15	64	0.02	3
Tubroq	12:10	14:12	464	1041	1	21	40	5	16	22	70	0.014	2
Benghazi	12:07	13:48	450	1047	2	19	37	5	18	19	68	0.025	5
Al-Kufra	12:09	13:54	517	1207	-1	22	47	4	11	2	27	0.001	2
Ghat	12:09	13.42	503	1200	1	23	46	4	14	4	26	0.003	2
Murzuq	12:09	13:42	533	1224	1	23	46	5	13	2	27	0.001	4
Sebha	12:09	13:48	510	1161	-1	23	46	4	15	4	31	0.003	3
Al-Jufra	12:09	14:00	485	1180	1	21	46	4	16	3	41	0.007	3
Sirte	12:10	14:06	453	1203	1	21	45	4	17	5	56	0.013	5
Ghadamis	12:10	14:06	475	1151	-3	22	48	4	16	4	33	0.007	2
Gharyan	12:10	14:12	480	1195	-4	19	45	4	18	6	45	0.02	3

It is important to highlight that the city of Tripoli experiences significant sunlight exposure with an average daily daylight duration of approximately 12:10h, peaking at 14:18h minutes during the longest days. Additionally, Tripoli is characterized by robust solar energy potential, evidenced by the average global horizontal solar irradiation of 437 W/m^2, which can reach up to 1030 W/m^2 under optimal conditions. In terms of temperature, Tripoli showcases a wide range with a minimum recorded temperature of 1°C, an average temperature around 21°C, and a maximum that can soar up to 39°C. This variation indicates a climate that can support diverse energy management and agricultural strategies. Wind conditions in Tripoli are moderate yet consistent, with average wind speeds around 4 m/s and occasionally peaking at 7 m/s. This provides a decent opportunity for wind energy exploitation, although it is less prominent compared to solar energy potential due to the higher irradiation levels. Furthermore, the relative humidity in Tripoli is remarkably low, averaging at 0.03% and reaching a maximum of 6%. This exceptionally dry climate underscores the need for efficient water management and irrigation strategies in both urban planning and agriculture.

H. Simulation Process

Using HOMER Grid, each scenario is simulated over a projected operational period to evaluate several key performance indicators such as net present cost, cost of energy, system efficiency, and greenhouse gas emissions. The simulation process includes varying load demands typical for an EV charging station and considers potential grid outages and fluctuations to ensure robustness and reliability.

I. Evaluation and Optimization

The outputs from HOMER Grid provide a comparative analysis of each scenario, highlighting their economic and environmental impacts. The study prioritizes scenarios that offer the lowest cost of energy and highest reliability while minimizing CO_2 emissions. Sensitivity analyses are also conducted to understand the impact of changes in fuel prices, solar and wind availability, and government incentives on the feasibility of each scenario.

J. Assumptions, limitations and uncertainties

In order to make the analysis not complicate, the authors adopted the following assumptions: There is a large and reliable grid capable of providing and absorbing any shortage or excess of energy; Fixed operating cost which includes maintenance, insurance and labor costs; Constant efficiencies for all the instruments; The land and land preparing costs are not included; The CO_2 emission factor is considered 0.978 kg/kWh for the electricity generation system in Libya [68]. The main limitation of the present study is that it does not provide a sensitivity analysis of the effect of various design and operating parameters and their weights on the investment decision. The major sources of uncertainty are the data availability, model selection and parameter estimation. It reported that the uncertainty in solar irradiation reaches 5% [69]. The price of renewable energy facilities is also considered as a source of uncertainty; it remarked that the variance in the prices of the PV modules exceeded 360% [70]. Also, the currency exchange rate is considered as one of the uncertainty sources in the results.

5. RESULT AND DISCUSSION

This section presents the findings from the simulation of five distinct energy scenarios using the HOMER Grid software, a sophisticated tool developed by HOMER Energy for optimizing grid-connected power systems and designing microgrids. Each scenario was carefully designed to test the integration of various combinations of renewable energy sources and storage solutions with the utility grid, aiming to determine the most economically viable and environmentally sustainable option for a hybrid renewable energy-based EV charging station located in Tripoli, Libya.

- Scenario 1: Wind/Utility Grid investigates the feasibility of integrating wind turbines with the existing utility infrastructure.
- Scenario 2: Solar/Wind/Utility Grid evaluates the combined impact of solar photovoltaics and wind energy in conjunction with the utility grid.
- Scenario 3: Solar/Wind/Storage/Utility Grid; explores the benefits of adding storage to the mix of solar and wind energy, providing insights into the enhanced reliability and efficiency of the system.
- Scenario 4: Solar/Utility Grid focuses solely on the implications of deploying solar energy systems integrated with the utility grid.
- Scenario 5: Solar/Storage/Utility Grid assesses the effectiveness of solar panels paired with energy storage systems, highlighting their potential to stabilize energy supply and reduce reliance on grid electricity.

Through the simulations, each scenario was assessed for its performance metrics including net present cost, energy reliability, carbon footprint reduction, and overall system efficiency. The results are analyzed in light of current energy policies, economic conditions, and technological advancements in Libya. This discussion is not only synthesizes the comparative advantages and limitations of each scenario but also contextualizes the findings within the broader goals of sustainable development and energy security in the region. The use of HOMER Grid enables a comprehensive evaluation by modeling the interactions between multiple technologies and variable utility rates, ensuring that the conclusions drawn are robust and applicable to real-world settings.

A. Scenario 1: Wind/Utility Grid

Scenario 1 utilizes wind turbines in conjunction with the utility grid to provide a reliable power supply while reducing dependence on conventional energy sources. This system is particularly effective in regions with high wind resources, offering significant cost savings and environmental benefits by lowering carbon emissions. It is a robust solution for areas looking to leverage local wind patterns to decrease energy costs and enhance sustainability. Table 3 presents comprehensive financial analysis of Wind/Utility Grid system implementation. The annual total cost amounts to US$1,554,416 based on the tariff (Utility Grid) for Scenario 1, as outlined in the appendixes Table A1.

Table 3. Comprehensive financial analysis of Wind and Utility Grid system implementation Scenario 1.

Factor	Value
Average annual energy bill savings:	US$1,586,077.39
Capital cost (CAPEX)	US$6,300,000.00
Payback time (simple/discounted):	4.8/5.8 years
Internal Rate of Return (IRR):	20.44%
Project lifetime savings over 25 years:	US$39,651,935
CO_2 savings	30,467 ton/year

Where capital cost (CAPEX) is fixed, one-time cost associated with the acquisition of land, structures, building materials, and machinery used in the manufacturing of goods or the provision of services. Internal Rate Return (IRR) is the anticipated annual rate of growth for an investment. The average annual savings on energy expenditures amount to US$1,586,077.39. The capital expenditure required for implementation is quantified at US$6,300,000.00. The system exhibits a payback period, calculated under simple and discounted cash flow methods, of 4.8 and 5.8 years respectively. The Internal Rate of Return (IRR) for the project is calculated at 20.44%. Over the projected operational lifespan of 25 years, the total savings accrued from the project are estimated to be US$39,651,935. Figure 6 presents Cash Flow for Scenario 1.

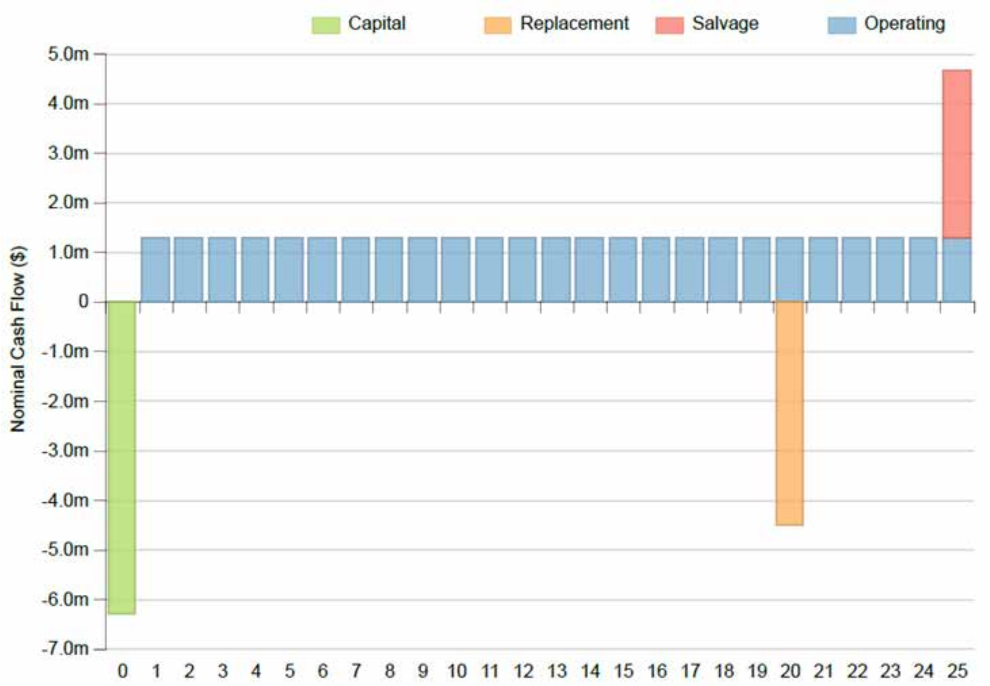
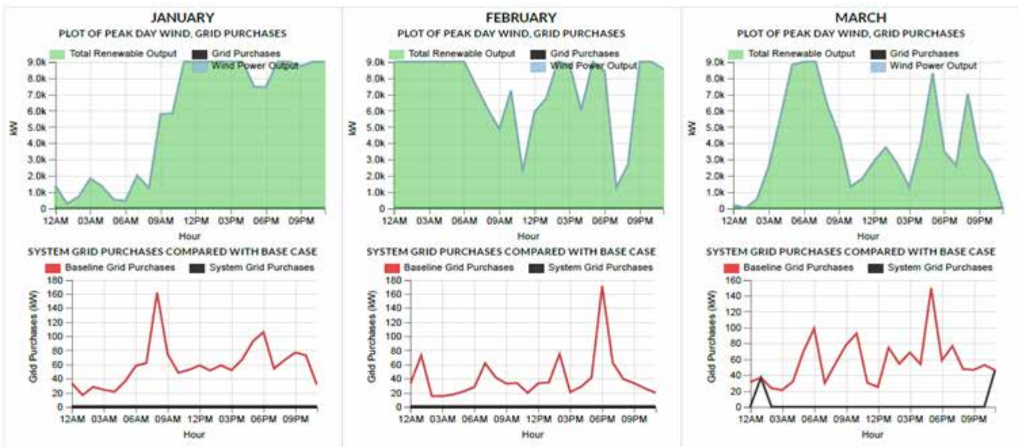


Figure 6. Cash Flow for Scenario 1.

The Cash Flow Summary for Scenario 1: Wind/Utility Grid provides a detailed visualization of the financial transactions over the life of the project. This summary encapsulates all critical financial metrics, including capital expenditures, operating expenses, and the resultant savings over time. Figure 7 illustrates the plot of peak day wind and grid purchases during one year for scenario 1.



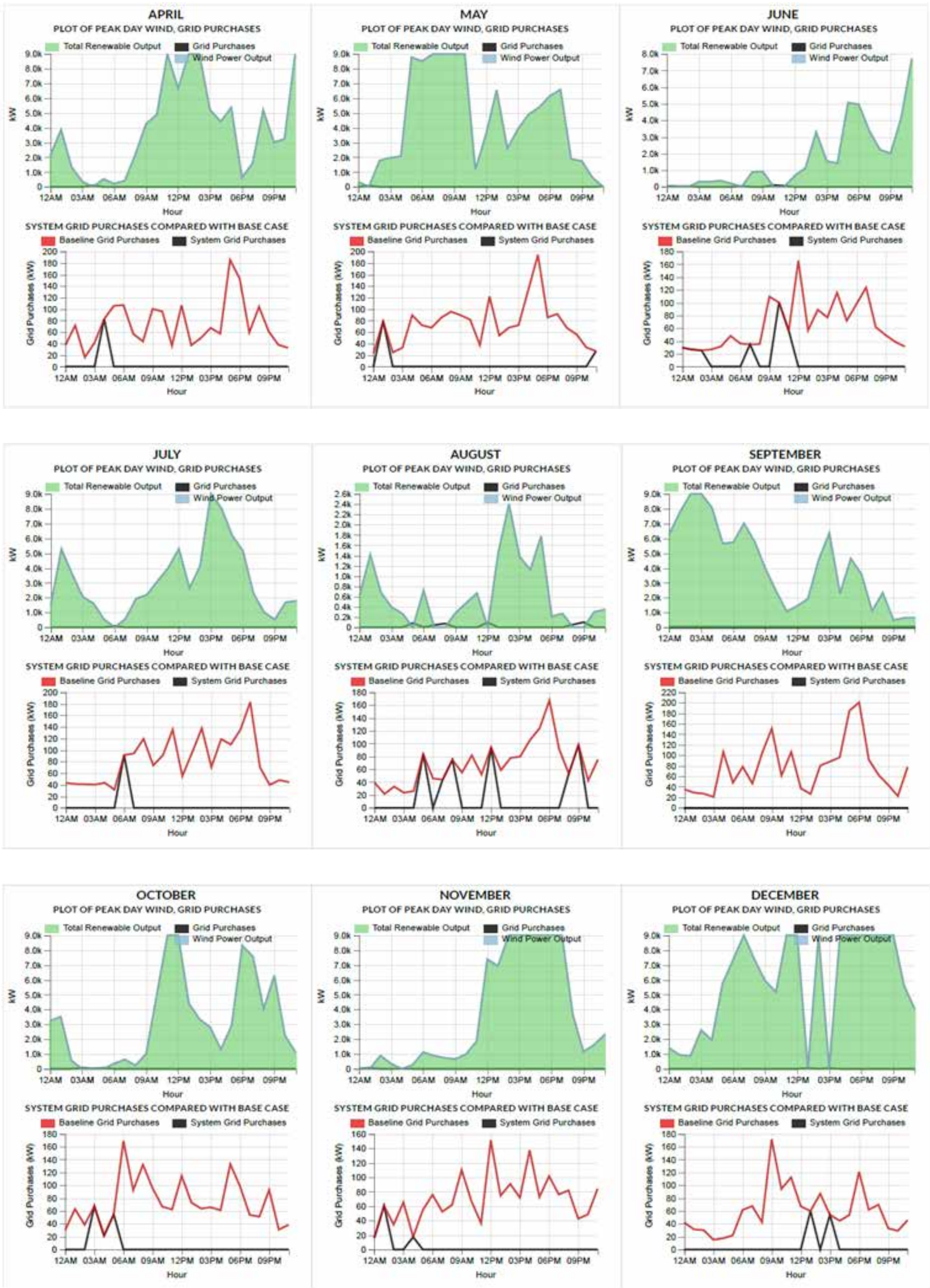


Figure 7. The plot of peak day wind and grid purchases during one year.

The Performance Summary for scenario 1: Wind/Utility Grid offers an insightful analysis of how the integration of wind turbines with the existing utility grid impacts overall system performance. This summary encompasses various performance metrics that illustrate the efficiency, sustainability, and financial benefits of the system. Figure 7 shows that the dependency on the grid decreases and reach its minimum in windy days. This means a reduction of burning fossil fuel and decrease of CO_2 emission.

B. Scenario 2: Solar/Wind/Utility Grid

Scenario 2 represents a hybrid renewable energy system that combines solar photovoltaics (PV) and wind turbines with the existing utility grid to maximize energy production and minimize reliance on conventional power sources. This integrated approach leverages the complementary nature of solar and wind energy, ensuring a more consistent and reliable energy supply throughout the day and across different weather conditions. Table 4 indicates comprehensive financial analysis of solar/Wind/Utility Grid system implementation Scenario 2. The annual total cost amounts to US$1,554,506 based on the tariff (Utility Grid) for Scenario 2, as illustrated in the appendixes Table A2.

Table 4. Comprehensive financial analysis of Solar/Wind/Utility Grid system implementation Scenario 2.

Metric	Value
Average annual energy bill savings:	US$1,586,167.39
CAPEX:	US$6,302,426.00
Payback time (simple/discounted):	4.8/5.8 years
Internal Rate of Return (IRR):	20.43%
Project lifetime savings over 25 years:	US$39,654,185
CO_2 savings	30,469 ton/year

The average annual reduction in energy expenditures achieved through this project is quantified at US$1,586,167.39. The total capital expenditure required for initiating this system is US$6,302,426.00, which encompasses all necessary costs for the installation and integration of the system components. The financial analysis of the investment reveals a straightforward payback period of 4.8 years, with a discounted payback period, accounting for the time value of money, extending slightly longer to 5.8 years. The project's Internal Rate of Return, an indicator of its profitability over time, is impressively calculated at 20.43%. Over the operational lifespan of 25 years, the projected total savings accruing from this system amount to US$39,654,185, substantiating a significant long-term financial benefit from the implementation. Figure 8 highlights Cash Flow for Scenario 2.

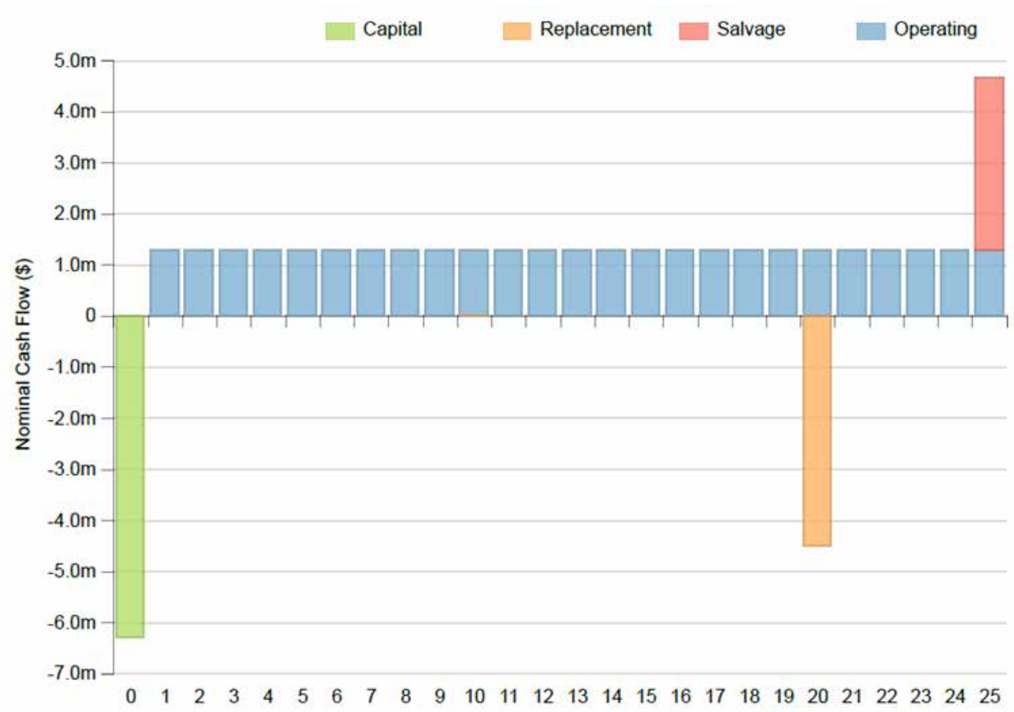
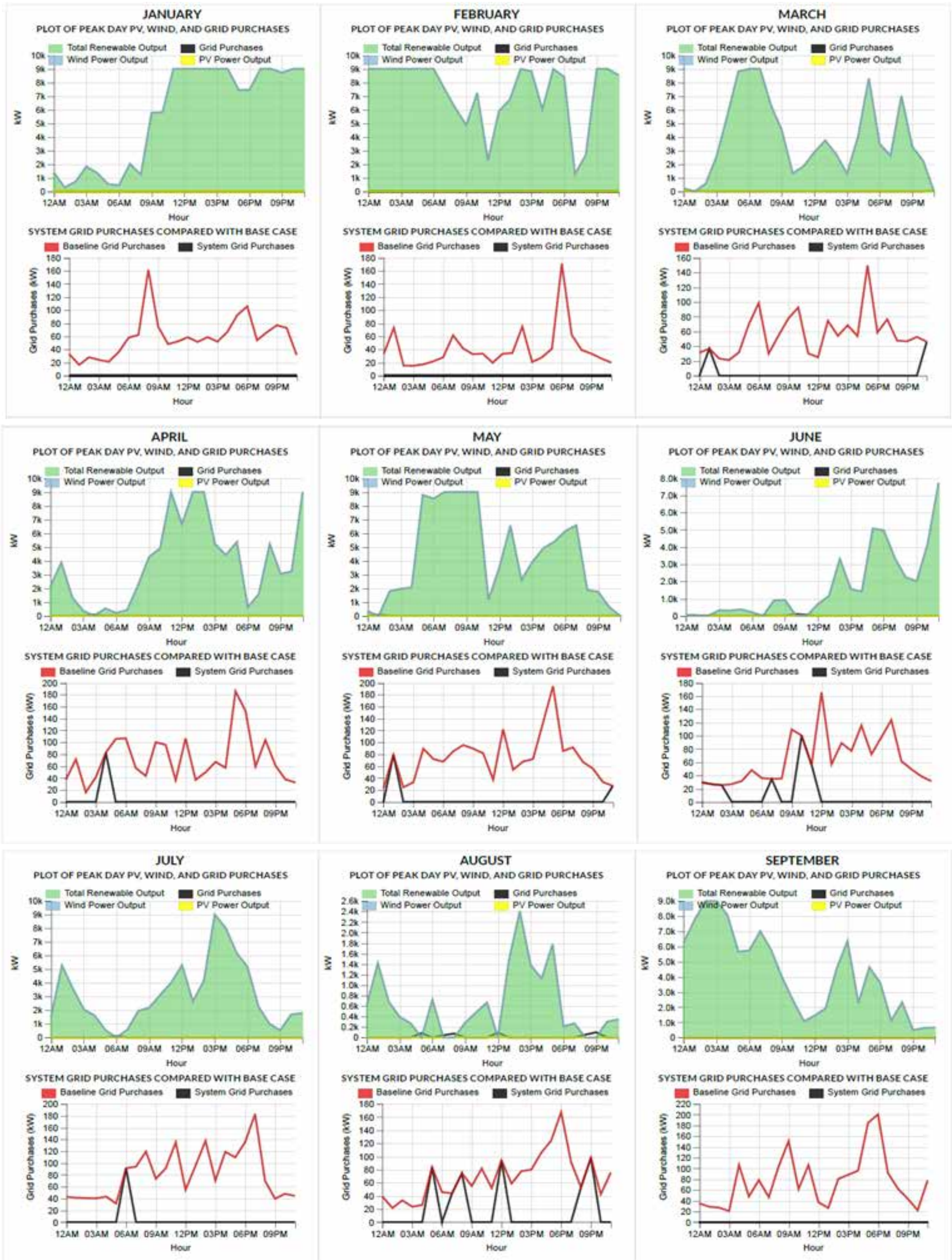


Figure 8. Cash Flow for Scenario 2.

This bar graph illustrates the nominal cash flow over a 25-year period, categorized into Capital, Replacement, Salvage, and Operating costs. Initially, there is a significant capital expenditure in Year 0, with a steep decline to nearly -7 m. Throughout Years 1 to 24, the graph shows consistent annual operating costs, depicted by light blue bars indicating a slight positive cash flow each year. In Year 24, there is also a substantial replacement cost represented by a large orange bar, which dips to around -3 m. The final year, Year 25, marks a significant positive cash flow, as shown by a tall red bar, suggesting a salvage value or a final revenue spike of approximately 4.5 m, highlighting the lifecycle costs and benefits of the investment with major expenditures at the beginning and end, and steady, minor positive cash flows during the operational phase. Figure 9 illustrates the plot of peak day wind, PV and grid purchases during one year for scenario 2.



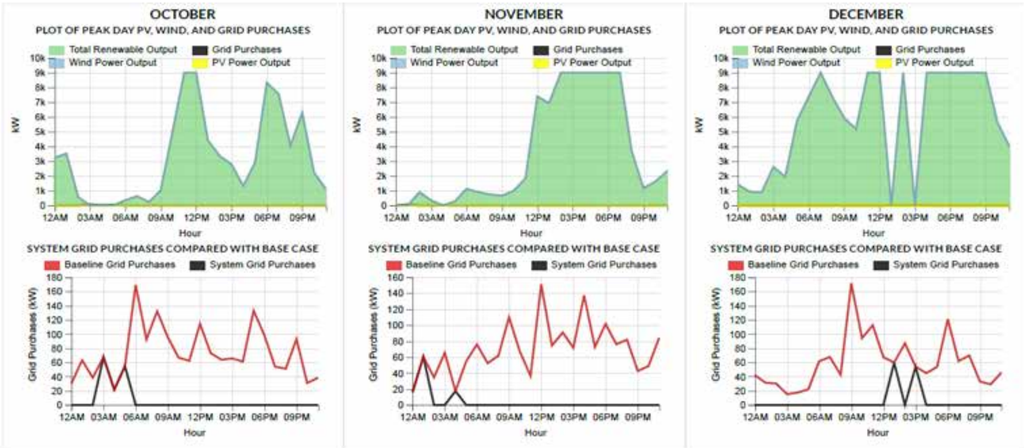


Figure 9. The plot of peak day wind, PV and grid purchases during one year for scenario 2.

Scenario 2 is designed to offer considerable savings on energy bills, with an average annual saving of $1,586,167.39. The initial capital expenditure required to set up this system is approximately $6,302,426.00. Despite the substantial upfront cost, the system promises a rapid payback time of 4.8 years on a simple basis and 5.8 years when discounted. Over the life of the project, which spans 25 years, the total projected savings amount to $39,654,185. In addition, an attractive aspect of Scenario 2 is its high Internal Rate of Return (IRR), which stands at 20.43%. This rate indicates a strong profitability potential, making it an appealing investment for stakeholders considering long-term benefits and financial returns from renewable energy installations.
Moreover, the system incorporates both solar photovoltaic (PV) panels and wind turbines. The PV components are priced at $0.30 per watt, summing up to a capacity of 7.09 kW. Additionally, the system includes 90 units of XANT M-21-ETR wind turbines, each rated at 100kW. The combined installation and component costs align with the total capital expenditure, and the annual operational expenses are estimated to be around $270,071. Figure 9 show that the dependency of the fossil fuel is minimized except for August where the load is increasing dramatically due to the hot weather.
Besides that, Monthly analysis of energy charges after the installation of Scenario 2 demonstrates significant reductions in costs throughout the year. These reductions are pivotal in achieving the high annual savings forecasted, which substantiate the system's efficiency in cost management and energy savings. Beyond the financial advantages, Scenario 2 significantly contributes to environmental sustainability. It drastically reduces carbon dioxide emissions annually, with the exact figures tailored to the specific generation sources of the grid. This reduction in greenhouse gases is a critical factor in the system's value proposition, emphasizing its role in promoting eco-friendly energy solutions.

C. Scenario 3: Solar/Wind/Storage/Utility Grid

Scenario 3 represents a highly efficient and economically viable solution for energy management and sustainability. By combining solar panels, wind turbines, and storage batteries, this system effectively harnesses and balances renewable energy sources to maximize savings and minimize environmental impact. Table 5 presents comprehensive financial analysis of Solar/Wind/Storage/UTILITY GRID system implementation. The annual total cost amounts to US$1,554,731based on the tariff (Utility Grid) for Scenario 3, as outlined in the appendixes Table A3.

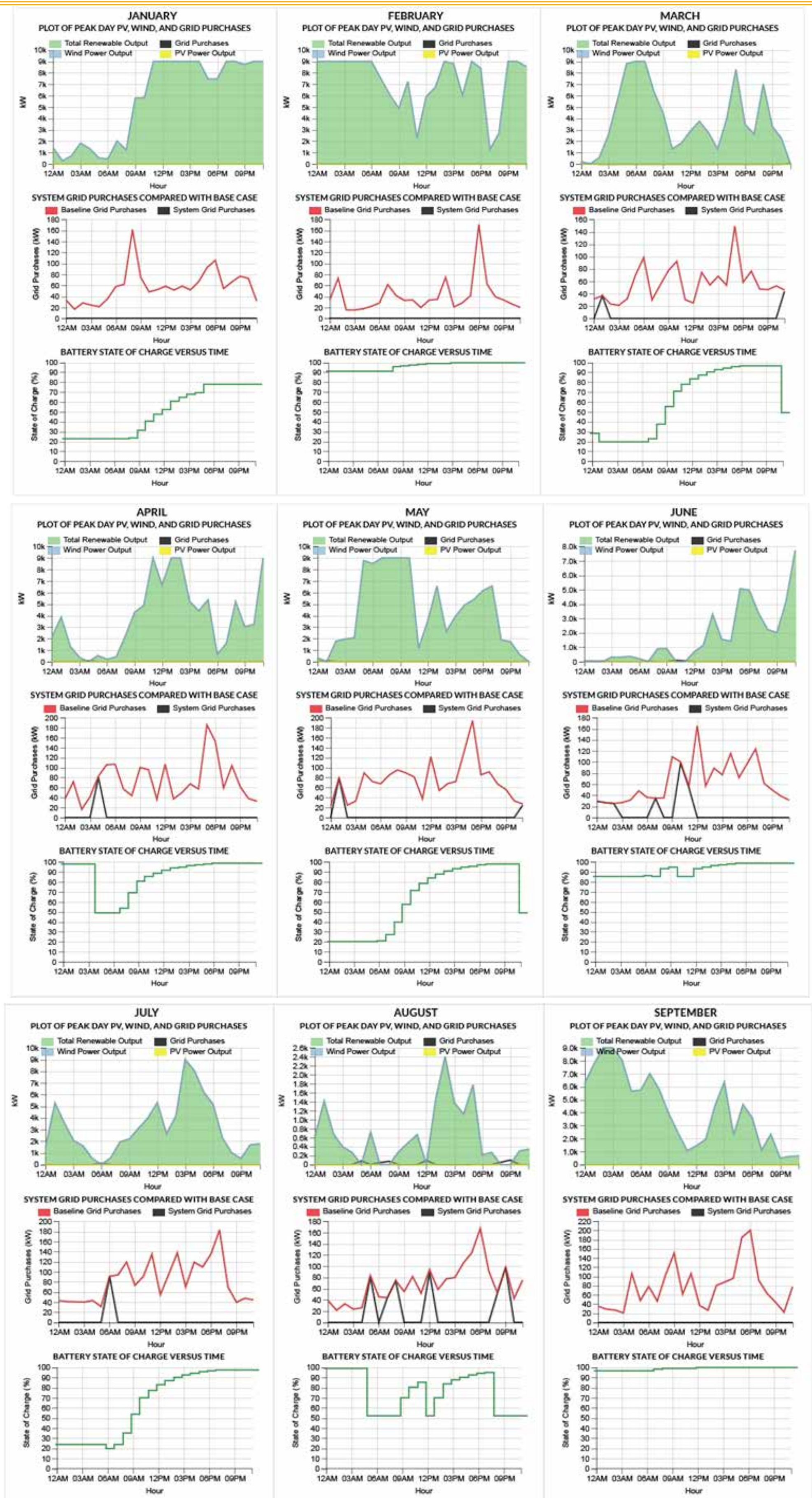
Table 5. Comprehensive financial analysis of Scenario 3 system implementation.

Metric	Value
Average annual energy bill savings:	US$1,586,392.39
CAPEX:	US$6,310,952.00
Payback time (simple/discounted):	4.8/5.8 years
Internal Rate of Return (IRR):	20.40%
Project lifetime savings over 25 years:	US$39,659,810
CO_2 savings	30,472 ton/year

With a capital expenditure of $6,310,952.00 and a compelling internal rate of return of 20.40%, the system offers significant financial returns, boasting an average annual savings of $1,586,392.39 and total projected savings of $39,659,810 over 25 years. The quick payback period of 4.8 years further underscores its cost-effectiveness. Additionally, the integration of storage capabilities enhances the system's resilience, allowing for better energy management during peak and off-peak times, thereby stabilizing the grid and providing more consistent energy availability. This system not only aligns with financial goals but also with environmental sustainability by significantly reducing CO_2 emissions, marking it as a forward-thinking solution for modern energy challenges. Figure 10 illustrates cash flow for scenario 3.

Figure 10. Cash flow for scenario 3.

This chart provides a visual representation of the cash flow dynamics of an energy system, highlighting the typical financial lifecycle of initial investment, ongoing operational costs, periodic large expenditures for replacements, and eventual recoupment of some value at the end. It is a useful tool for understanding financial planning and the long-term financial commitments involved in renewable energy projects. Figure 11 illustrates the plot of peak day for scenario 3 during one year.


JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
PLOT OF PEAK DAY PV, WIND, AND GRID PURCHASES
Total Renewable Output
Grid Purchases
Wind Power Output
PV Power Output
kW
Hour
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
Baseline Grid Purchases
System Grid Purchases
Grid Purchases (kW)
BATTERY STATE OF CHARGE VERSUS TIME
State of Charge (%)

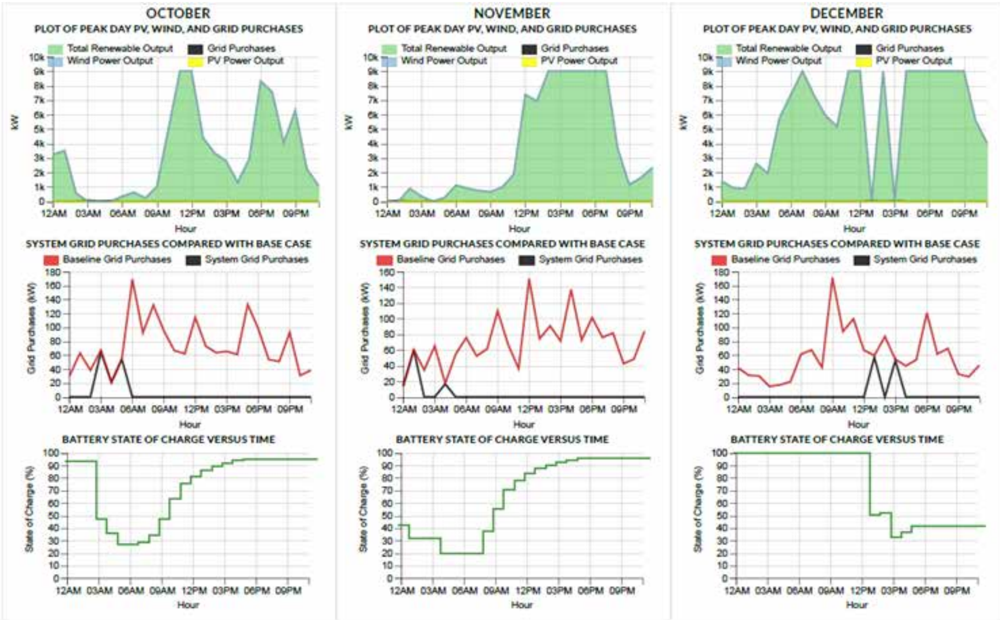


Figure 11. The plot of peak day for scenario 3 during one year.

Scenario 3 exemplifies a sophisticated integration of renewable energy technologies and storage solutions, marking it as a highly effective system for modern energy needs. The combination of solar panels, wind turbines, and storage units within this system not only maximizes energy generation from renewable sources but also ensures consistent energy availability through effective storage and management. Financially, the system is remarkably viable, featuring a rapid payback period, high internal rate of return, and substantial long-term savings, thereby presenting a compelling case for investment. Moreover, the environmental benefits associated with Scenario 3, primarily its significant reduction in CO_2 emissions, align well with global sustainability goals, making it an essential model for future energy systems. Its ability to stabilize the grid and provide reliable power supply further underscores its strategic importance in an evolving energy market. Thus, Scenario 3 stands out as a forward-thinking solution that addresses both economic and ecological aspects of energy production, offering a blueprint for the future of renewable energy infrastructure.

D. Scenario 4: Solar/Utility Grid

The exploration of sustainable energy solutions has become a paramount concern in today's rapidly evolving energy landscape, marked by growing environmental awareness and the escalating costs of traditional energy sources. In this context, the integration of renewable energy systems presents a viable pathway toward reducing energy expenditures and minimizing ecological footprints. This paper examines the financial viability and environmental benefits of a specific energy system—referred to here as " Scenario 4". This system embodies a strategic combination of renewable energy technologies and storage solutions, optimized to enhance energy efficiency and stability. This article dissects the key financial metrics of this system, including its capital expenditure, average annual energy bill savings, payback periods, internal rate of return, and projected lifetime savings, to evaluate its potential as a sustainable investment in the face of contemporary energy challenges. Table 6 presents comprehensive financial analysis of Scenario 4 system implementation. The annual total cost amounts to US$30,589 based on the tariff (Utility Grid) for Scenario 4, as outlined in the appendixes Table A4.

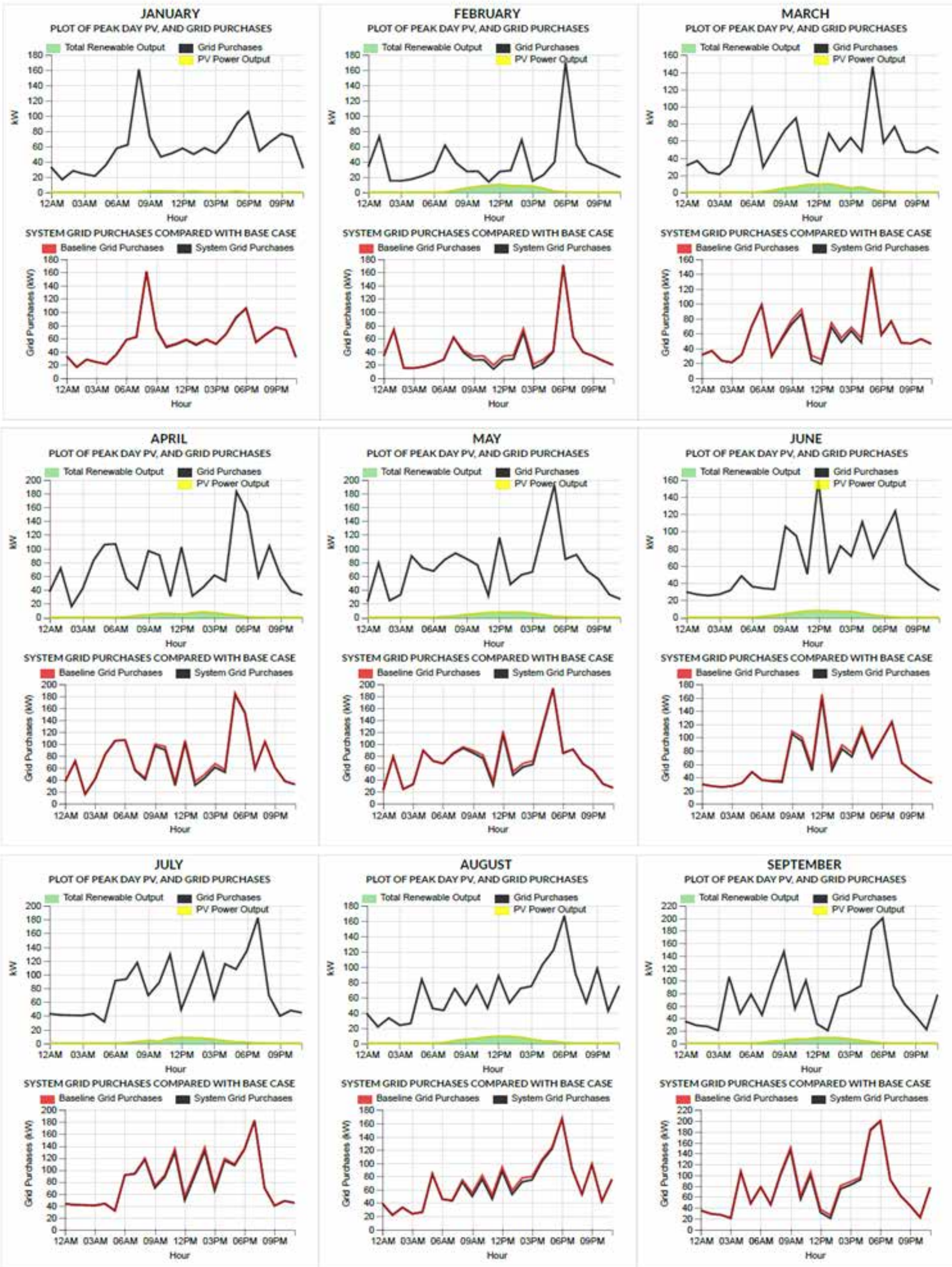
Table 6. Comprehensive financial analysis of Scenario 4 system implementation.

Metric	Value
Average annual energy bill savings:	US$1,072.87
CAPEX:	US$7,713.85
Payback time (simple/discounted):	8.1/14.3 years
Internal Rate of Return (IRR):	9.62%
Project lifetime savings over 25 years:	US$26,822
CO_2 savings	20.608 ton/year

The financial metrics for the specified system reveal a modest yet consistent economic advantage in terms of energy cost savings. In term of average annual energy bill savings. The system provides annual savings amounting to approximately $1,072.87. This figure reflects the system's ability to reduce operational costs on a yearly basis. However, due to capital expenditure (CAPEX), the initial investment required for this system is relatively low at $7,713.85. This initial outlay is crucial for understanding the system's financial feasibility and scale of deployment. Following to this, the simple payback period is estimated at 8.1 years, while the discounted payback period extends to 14.3 years. These durations indicate the time needed for the savings generated by the system to cover the initial capital cost. The longer discounted payback period accounts for the time value of money, suggesting a slower recovery of investment when considering the cost of capital. In term of internal rate of return (IRR), an IRR of 9.62% suggests that the project has a moderate rate of return. This percentage is critical for investors assessing the profitability of the project relative to other potential investments with similar risk profiles. Moreover, over the span of 25 years, the total savings accrued from the system are projected to be $26,822. This long-term saving is indicative of the system's overall financial benefit and underscores its capacity to provide economic value over its operational life. Figure 12 demonstrated cash flow for scenario 4.

Figure 12. Cash flow for scenario 4.

This type of cash flow visualization is crucial for assessing the financial viability of long-term investments like energy systems. It helps investors and decision-makers understand the timing and scale of expenditures and returns, including ongoing costs and the impact of significant investments or replacements during the system's lifecycle. The presence of replacement costs and salvage value also highlights the importance of considering end-of-life scenarios in the overall economic planning of energy projects. Figure 13, illustrates the plot of peak day for scenario 4 during one year.



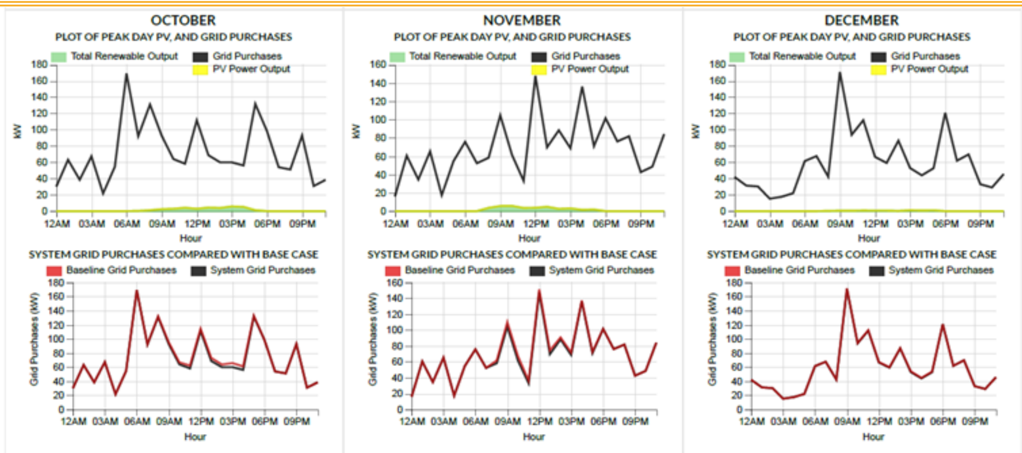


Figure 13. The plot of peak day for scenario 5 during one year.

Scenario 4 as outlined in the HOMER Grid Report, emphasizes a streamlined integration of solar panels with the existing utility grid, omitting additional renewable sources or storage components. This system is designed for simplicity and effectiveness, relying solely on solar energy to offset utility power usage. Moreover, this system benefits from relatively low operational demands compared to more complex setups that include wind or storage elements. The maintenance of solar panels is straightforward, which can contribute to lower ongoing costs and less technical complexity in daily operations. In essence, Scenario 4' provides an effective solution for harnessing solar energy to decrease reliance on traditional power grids, promoting both economic savings and environmental benefits. Its simplicity and cost-effectiveness make it particularly suitable for scenarios where easy deployment and maintenance are crucial.

E. Scenario 5: Solar/Storage/Utility Grid

Scenario 5 is designed to integrate solar energy generation with battery storage and utility grid connectivity. This configuration leverages the benefits of solar power while enhancing system reliability and efficiency through energy storage. Table 7, highlights comprehensive financial analysis of Scenario 5 system implementation. The annual total cost amounts to US$28,572 based on the tariff (Utility Grid) for Scenario 5, as outlined in the appendixes Table A5.

Table 7. Comprehensive financial analysis of Scenario 5 system implementation.

Metric	Value
Average annual energy bill savings:	US$3,089.11
CAPEX:	US$28,389.65
Payback time (simple/discounted):	14.0/ years
Internal Rate of Return (IRR):	5.46%
Project lifetime savings over 25 years:	US$77,228
CO_2 savings	59.337 ton/year

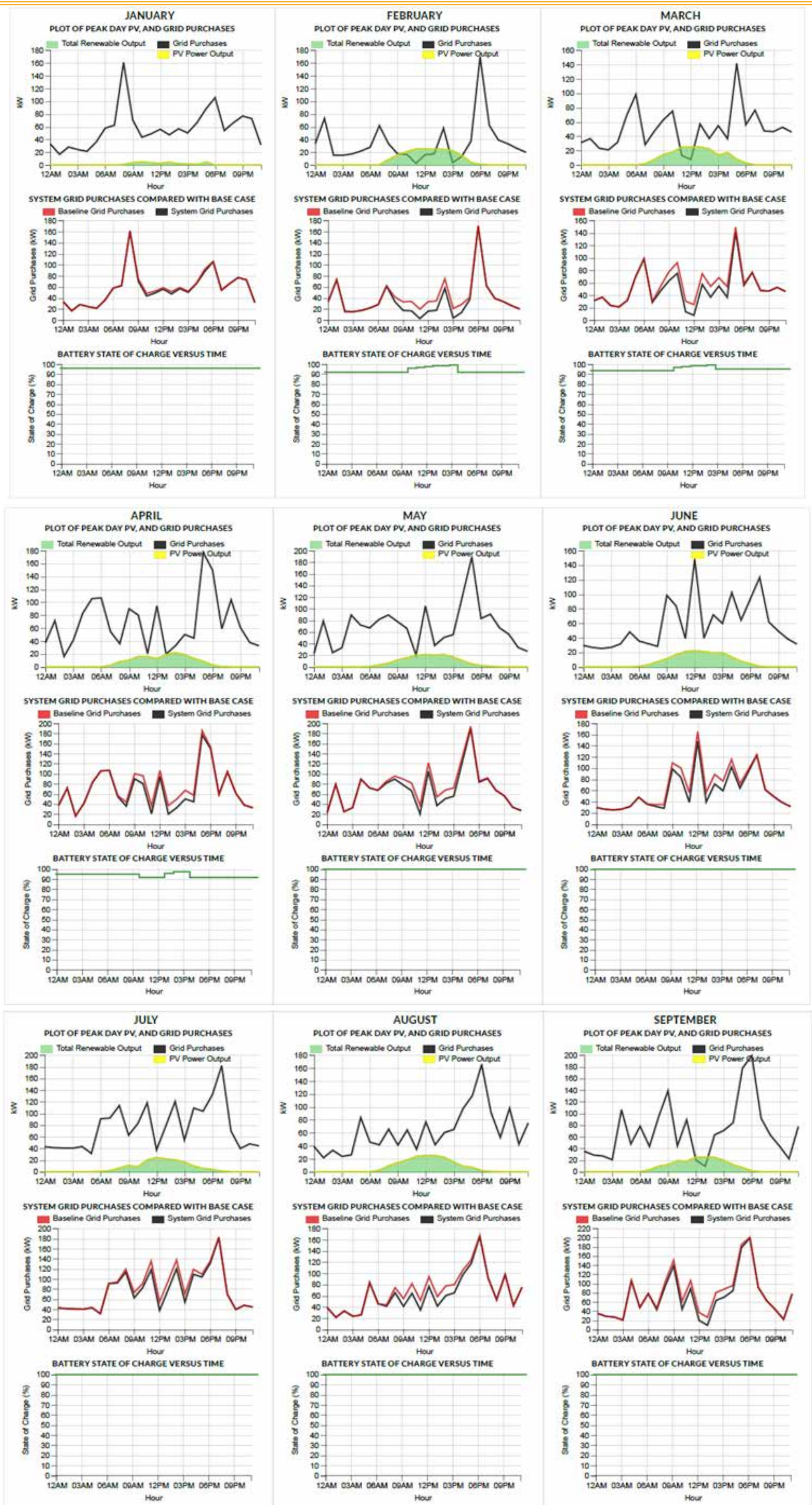
The financial specifics provided for "System #5: Solar + Storage: STORAGE + UTILITY GRID" allow for a comprehensive analysis of its investment potential and cost-effectiveness. The initial cost to establish this system is $28,389.65. This reflects a significant investment, typically due to the integration of both high-capacity solar panels and advanced storage solutions. The system provides an estimated annual savings of $3,089.11 on energy bills. These savings are facilitated by the system's ability to generate renewable energy and store excess power, reducing the need to purchase electricity from the grid, especially during peak pricing periods. The payback period for this system is calculated at 14.0 years. This timeline indicates how long it will take for the savings generated by the system to cover the initial capital costs.

A 14-year payback period is relatively long, which might be attributed to the higher upfront costs associated with the storage components. Internal Rate of Return (IRR) of 5.46% is considered modest in terms of investment returns. While it shows a positive return, it is relatively low, suggesting that the financial risk may be higher or the financial gains less lucrative compared to other investment opportunities. This rate might be acceptable depending on the specific financial goals and risk tolerance of the investor. Over a projected operational lifespan of 25 years, the system is anticipated to achieve total savings of $77,228.

This long-term saving showcases the system's ability to continue providing economic benefits well beyond its payback period, contributing to its overall appeal as a sustainable investment. The outlined financial metrics suggest that while " scenario 5" offers significant long-term savings and environmental benefits, the relatively high initial costs and modest IRR indicate that it is a conservative investment. This system would be especially appealing in regions with high electricity rates or for individuals prioritizing energy independence and sustainability over immediate financial returns. Figure 14 shows cash flow for scenario 5.

Figure 14. Cash flow for scenario 5.

Scenario 5: Solar + Storage: STORAGE + UTILITY GRID exemplifies a sophisticated approach to integrating renewable energy solutions into residential or commercial infrastructures. The system's design incorporates advanced solar photovoltaic panels and a robust battery storage unit to optimize energy usage and enhance self-sufficiency. Figure 15 presents the plot of peak day for scenario 5 during one year.


JANUARY
PLOT OF PEAK DAY PV, AND GRID PURCHASES
Total Renewable Output
Grid Purchases
PV Power Output
kW
Hour
SYSTEM GRID PURCHASES COMPARED WITH BASE CASE
Baseline Grid Purchases
System Grid Purchases
Grid Purchases (kW)
BATTERY STATE OF CHARGE VERSUS TIME
State of Charge (%)
12AM 03AM 06AM 09AM 12PM 03PM 06PM 09PM
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER

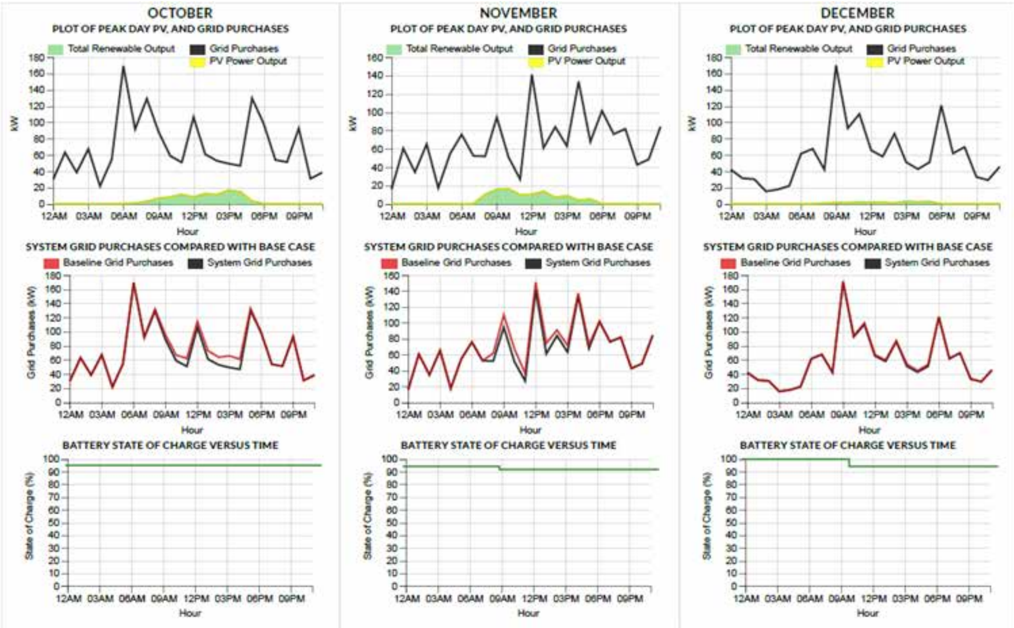


Figure 15. The plot of peak day for scenario 5 during one year.

Scenario 5: Solar/Storage/Utility Grid combines solar panels with battery storage to enhance energy efficiency and independence from the grid. This system involves a considerable initial investment of $28,389.65, justified by the integration of advanced technology for solar energy collection and storage. Annually, it offers savings of approximately $3,089.11 on energy bills by leveraging stored solar energy to reduce grid dependency during peak times. The financial return includes a payback period of 14.0 years and an internal rate of return of 5.46%, reflecting a moderate profitability that underscores the system's long-term viability rather than immediate returns. Over a projected 25-year lifespan, the total savings amount to $77,228, highlighting the system's capacity to provide substantial economic benefits over time while contributing to environmental sustainability through reduced carbon emissions.

The authors results comply with other researchers who also use similar strategies. For example, in study by Podder et al. [71], authors discussed the use of solar photovoltaic (PV) and biogas energy solution for EV charging. With a net present cost of $93,530 and a 25-year lifespan, the 4.5 kW solar PV system is found to be the most efficient after a cost analysis using HOMER software. System costs are covered in the first 12 years, and financial benefits are realized in the next 13 years. The study finds that the system provides an environmentally and financially viable solution for renewable energy-based EV charging and emphasizes the reduction of greenhouse gas emissions. Though authors used smaller hybrid system, they end with similar results to the current study.

The study of Appalanidu and Srinivasa [72] suggests a grid-connected photovoltaic-based microgrid for EV charging to address concerns about the infrastructure needed for EV charging as they gain popularity. Its goal is to study a fictitious EV population charging while designing and modeling the microgrid. The simulations consider actual EV loads and assess supply-load mismatches, energy mix, and solar plant power generation. The weather influences power output, according to the results, and sensitivity analysis reveals how scaled EV sessions affect microgrid power balances. All things considered, grid-connected microgrids guarantee smooth EV charging even in the event of onsite solar energy generation uncertainties.

Al Wahedi and Bicer [73] suggests a standalone renewable energy-based charging station as a solution to the problem of satisfying EV charging demand without taxing the electrical grid. The study models and simulates, considering geographical and meteorological conditions, the ideal configuration in four cities of Qatar using HOMER software. The best approach, according to the findings, is to combine battery storage, fuel cells, CPV/T systems, wind turbines, and bio-generators. The method can be applied in a variety of locations because the net present cost varies from $2.53M to $2.92M and the cost of electricity from $0.285 to $0.329 per kWh.

6. CONCLUSION

To sum up, the HOMER Grid analysis offers important new information about the viability and best practices for hybrid renewable energy systems designed for an EV charging station in Tripoli, Libya. Five different configurations were analyzed by the simulations, spanning from standalone systems to integrated solar, wind, and energy storage systems. Despite higher initial capital costs, the energy storage-incorporating scenarios (Scenarios 3 and 5) offer better long-term cost-effectiveness, according to the economic analysis. Better use of excess energy is made possible by storage systems, which also lessen reliance on the grid for power during peak tariff periods. System reliability and operational efficiency are enhanced when renewable energy is integrated with grid support. By balancing generation and storage, Scenario 3 (Solar/Wind/Storage) effectively accommodated variability in renewable energy supply and demand, demonstrating a particularly robust performance. The study emphasizes how hybrid systems, especially those that combine solar and wind power, can greatly reduce carbon emissions and support global sustainability initiatives.

The results support the use of increasingly sophisticated hybrid systems that integrate storage technologies. These configurations are more cost-effective in the long run because of their higher efficiency and lower operating costs, even though they are more expensive initially. These findings highlight the significance of infrastructure investments and policies that encourage the adoption of renewable energy technologies for Libya's investors and policymakers. These kinds of strategic choices serve not only the current energy needs but also the long-term economic and environmental objectives. The HOMER Grid analysis is a good example of how advanced modeling tools can be used to plan renewable energy systems strategically. The knowledge gained will be crucial in determining Libya's future energy policies, especially regarding developing sustainable energy development and growing the country's EV infrastructure.

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Conflicts of Interest: The authors declare that they have no conflict of interest.

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APPENDIXES

Table A1: Tariff (Utility Grid) of Scenario 1

Annual Total	Monthly Total	Fixed charges	Demand Charges and Peak Demand		Energy Charges, Consumption, and Sales			
- US$1,554,416	*-US$156,963*	US$0	97 kW	US$0	3,142,515 kWh	2,319 kWh	- US$156,963	**January**
	- US$143,720	US$0	109 kW	US$0	2,877,776 kWh	2,416 kWh	- US$143,720	**February**
	- US$147,694	US$0	139 kW	US$0	2,959,166 kWh	3,783 kWh	- US$147,694	**March**
	- US$145,025	US$0	103 kW	US$0	2,904,384 kWh	2,779 kWh	- US$145,025	**April**
	- US$143,635	US$0	145 kW	US$0	2,877,495 kWh	3,424 kWh	- US$143,635	**May**
	- US$112,967	US$0	121 kW	US$0	2,265,645 kWh	4,501 kWh	- US$112,967	**June**
	- US$97,297	US$0	158 kW	US$0	1,954,202 kWh	5,905 kWh	- US$97,297	**July**
	- US$91,214	US$0	163 kW	US$0	1,832,897 kWh	6,154 kWh	- US$91,214	**August**
	- US$103,759	US$0	137 kW	US$0	2,082,078 kWh	4,922 kWh	- US$103,759	**September**
	- US$116,912	US$0	133 kW	US$0	2,343,626 kWh	3,841 kWh	- 116,912	**October**
	- US$136,570	US$0	134 kW	US$0	2,736,103 kWh	3,357 kWh	- US$136,570	**November**
	- US$158,660	US$0	86 kW	US$0	3,176,628 kWh	2,450 kWh	- US$158,660	**December**

Table A2: Tariff (Utility Grid) of Scenario 2

Annual Total	Monthly Total	Fixed charge	Demand Charges and Peak Demand		Energy Charges, Consumption, and Sales			
- US$1,554,506	*-US$156,970*	US$0	97 kW	US$0	3,142,635 kWh	2,314 kWh	-US$156,970	**January**
	- US$143,726	US$0	109 kW	US$0	2,877,895 kWh	2,409 kWh	- US$143,726	**February**
	- US$147,701	US$0	138 kW	US$0	2,959,306 kWh	3,774 kWh	- US$147,701	**March**
	- US$145,032	US$0	102 kW	US$0	2,904,531 kWh	2,772 kWh	- US$145,032	**April**
	- US$143,644	US$0	145 kW	US$0	2,877,649 kWh	3,413 kWh	- US$143,644	**May**
	- US$112,976	US$0	121 kW	US$0	2,265,794 kWh	4,487 kWh	- US$112,976	**June**
	- US$97,306	US$0	158 kW	US$0	1,954,356 kWh	5,890 kWh	- US$97,306	**July**
	- US$91,222	US$0	163 kW	US$0	1,833,046 kWh	6,141 kWh	- US$91,222	**August**
	- US$103,767	US$0	136 kW	US$0	2,082,213 kWh	4,907 kWh	- US$103,767	**September**
	- US$116,920	US$0	133 kW	US$0	2,343,759 kWh	3,831 kWh	- US$116,920	**October**
	- US$136,576	US$0	134 kW	US$0	2,736,218 kWh	3,352 kWh	- US$136,576	**November**
	- US$158,666	US$0	86 kW	US$0	3,176,743 kWh	2,442 kWh	- US$158,666	**December**

Table A3: Tariff (Utility Grid) of Scenario 3

Annual Total	Monthly Total	Fixed charges	Demand Charges and Peak Demand		Energy Charges, Consumption, and Sales			
- US$1,554,731	*-US$156,984*	US$0	97 kW	US$0	3,142,829 kWh	2,249 kWh	-US$156,984	January
	- US$143,742	US$0	109 kW	US$0	2,878,130 kWh	2,349 kWh	-US$143,742	February
	- US$147,722	US$0	138 kW	US$0	2,959,598 kWh	3,691 kWh	-US$147,722	March
	- US$145,054	US$0	102 kW	US$0	2,904,857 kWh	2,696 kWh	-US$145,054	April
	- US$143,666	US$0	144 kW	US$0	2,877,979 kWh	3,334 kWh	-US$143,666	May
	- US$112,997	US$0	121 kW	US$0	2,266,120 kWh	4,408 kWh	-US$112,997	June
	- US$97,329	US$0	155 kW	US$0	1,954,679 kWh	5,781 kWh	-US$97,329	July
	- US$91,246	US$0	162 kW	US$0	1,833,374 kWh	6,039 kWh	-US$91,246	August
	- US$103,787	US$0	136 kW	US$0	2,082,500 kWh	4,822 kWh	-US$103,787	September
	- US$116,936	US$0	130 kW	US$0	2,343,995 kWh	3,762 kWh	-US$116,936	October
	- US$136,589	US$0	134 kW	US$0	2,736,387 kWh	3,294 kWh	-US$136,589	November
	- US$158,678	US$0	86 kW	US$0	3,176,895 kWh	2,375 kWh	-US$158,678	December

Table A4: Tariff (Utility Grid) of Scenario 4

Annual Total	Monthly Total	Fixed charges	Demand Charges and Peak Demand		Energy Charges, Consumption, and Sales			
US$30,589	*US$2,418*	US$0	161 kW	US$0	0 kWh	34,548 kWh	US$2,418	**January**
	US$2,136	US$0	171 kW	US$0	0 kWh	30,512 kWh	US$2,136	**February**
	US$2,444	US$0	147 kW	US$0	0 kWh	34,915 kWh	US$2,444	**March**
	US$2,399	US$0	183 kW	US$0	0 kWh	34,265 kWh	US$2,399	**April**
	US$2,687	US$0	193 kW	US$0	0 kWh	38,386 kWh	US$2,687	**May**
	US$2,741	US$0	160 kW	US$0	0 kWh	39,154 kWh	US$2,741	**June**
	US$3,050	US$0	183 kW	US$0	0 kWh	43,567 kWh	US$3,050	**July**
	US$3,014	US$0	167 kW	US$0	0 kWh	43,063 kWh	US$3,014	**August**
	US$2,662	US$0	200 kW	US$0	0 kWh	38,032 kWh	US$2,662	**September**
	US$2,480	US$0	169 kW	US$0	0 kWh	35,428 kWh	US$2,480	**October**
	US$2,330	US$0	148 kW	US$0	0 kWh	33,282 kWh	US$2,330	**November**
	US$2,228	US$0	171 kW	US$0	0 kWh	31,827 kWh	US$2,228	**December**

Table A5: Tariff (Utility Grid) of Scenario 5

Annual Total	Monthly Total	Fixed charges	Demand Charges and Peak Demand		Energy Charges, Consumption, and Sales			
US$28,572	*US$2,290*	US$0	161 kW	US$0	0 kWh	32,711 kWh	US$2,290	**January**
	US$1,996	US$0	170 kW	US$0	1 kWh	28,517 kWh	US$1,996	**February**
	US$2,270	US$0	142 kW	US$0	0 kWh	32,431 kWh	US$2,270	**March**
	US$2,209	US$0	177 kW	US$0	0 kWh	31,563 kWh	US$2,209	**April**
	US$2,489	US$0	189 kW	US$0	0 kWh	35,556 kWh	US$2,489	**May**
	US$2,543	US$0	153 kW	US$0	0 kWh	36,327 kWh	US$2,543	**June**
	US$2,840	US$0	182 kW	US$0	0 kWh	40,571 kWh	US$2,840	**July**
	US$2,811	US$0	166 kW	US$0	0 kWh	40,154 kWh	US$2,811	**August**
	US$2,487	US$0	199 kW	US$0	0 kWh	35,525 kWh	US$2,487	**September**
	US$2,321	US$0	169 kW	US$0	0 kWh	33,153 kWh	US$2,321	**October**
	US$2,210	US$0	141 kW	US$0	1 kWh	31,566 kWh	US$2,210	**November**
	US$2,107	US$0	170 kW	US$0	0 kWh	30,103 kWh	US$2,107	**December**