Research Article

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# An economic and technological analysis of hybrid photovoltaic/wind turbine/battery renewable energy system with the highest self-sustainability

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**Abstract:** This research established the technoeconomic feasibility of an on-grid hybrid renewable energy system for delivering electricity to the deanery building of the Engineering College at the University of Diyala, Iraq. The most cost-effective system design was discovered by modeling and optimization, with an average daily load of 25.0 kWh and total cost and energy cost of $5142 and $0.05/kWh, respectively. In relation to the energy generated by conventional resources, the designed system is more cost-effective and has a lower carbon footprint of about 13,052 kg/year of $CO_2$ emissions avoided. According to the research, using a hybrid power system to electrify and decarbonize the electrical energy supply could be a reliable and economical way to do both at the same time. Innovation is in integrating the suggested hybrid system so that the use of electricity can effectively be decreased to meet the load. As a result, the system components are not oversized, which reduces system costs and reduces emissions.

**Keywords:** hybrid energy systems; photovoltaic energy; renewable energy; self-sufficiency; wind turbine energy.

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## Introduction

The dramatic increase in fuel prices is an essential and significant optimization challenge in conventional power plants. It is important to combine renewable energy sources into the electric grid to satisfy future demand. Solar energy, wind energy, geothermal, bioenergy, ocean energy, and other renewable energy sources have been placed in a wide variety of locations across the globe, particularly rural regions (Abbas et al. 2021). The most widely used renewable energy sources are establishing powerlines to connect producers to loads, while isolated areas develop small-scale off-grid (microgrid) systems. Expanding renewable energy sources with non-renewable energy sources has also been done to make sure that there will be a long-term and stable power source in the form of renewable energy systems that cannot be interrupted or have high prices (Jaszczur et al. 2021a).

Hybrid renewable energy systems (HRES) are created when renewable energy sources are integrated with other energy sources. Human energy use is not evenly distributed over time, resulting in conflict between energy production and consumption (Hassan 2021a). Renewable energy sources must contribute to these services and have the potential to expand in popularity, which will be enhanced by their usage in combination with energy storage technologies (Ceran et al. 2021). The solution is crucial for utilizing renewable energy sources into the energy infrastructure of regions, while also providing grid operators with a technological solution for real-time energy balance. However, it also facilitates the most effective use of renewable energy sources by reducing load-shedding during periods of surplus supply (Hassan 2022; Hassan et al. 2022). By permitting the islanding of the territory covered by this resource, distributed renewable energy production paired with centralized backup improves the electrical networks resilience. Additionally, a strategically located energy storage system (ESS) improves electricity quality by increasing frequency and voltage control and lowering unreliability by contributing to the transmitted current, which is critical during peak periods of energy supply (Hassan and Jaszczur 2021). Numerous studies have been conducted to determine the optimization of HRES objectives, which might have a significant influence on the economics and technical aspects of the power production process. Karimi and Jadid (2021) used a competitive cooperative game approach for modelling multi-microgrid energy systems. A dynamic leader-follower framework is used to model the interaction between the distribution system operator and the microgrid interconnected system. The distribution system operator calculates the transactive pricing for the energy exchange with the microgrid interconnected system at a high level of optimization. The simulation results indicate that the microgrid interconnected system cost has been reduced, and collaboration among the grids lowers the frequency of interruptions and load shedding. Sanongboon and Pettigrew (Sanongboon and Pettigrew 2021) investigated hybrid energy systems to assess the economic feasibility of electrifying and domestic water heating systems. Different energy models have been explored to have a better understanding of the restrictions associated with electrification and to determine whether energy sources can significantly reduce greenhouse gas emissions while maintaining competitive power pricing. The results suggest that the electrification of residential and commercial space and water heating systems may be a viable alternative to fossil fuel heaters, thus lowering green house gas emissions and increasing energy efficiency. Nourollahi et al. (Nourollahi et al. 2022) provide a hybrid technique to optimize the operation of a domestic energy system made up of solar, fuel cells, boilers, and storage units using robust optimization and stochastic programming. In the optimization of uncertain parameters, they are separated into two groups: badly-behaved and well-behaved variables. Simulated results show that badly behaved variables have a greater influence on system operation than well-behaved variables. Furthermore, it increases the overall cost by 5.2 and 0.47%, respectively. Naderipour et al. (2022) optimized an off-grid hybrid energy system composed of wind turbines (WT), photovoltaic (PV) arrays, and battery (BT) storage with the objective of minimizing total net present cost (NPC) while taking into account the influence of interest rate (IR) variations. The proposed hybrid system is optimized using yearly weather and load data from a selected site. The main objective of optimization is to determine the optimal capacity of the system components, as well as the amount of energy delivered to the load through the inverter, while minimizing the NPC. The dubbed improved grasshopper optimization algorithm (IGOA) is used to determine the capacity of the system with the lowest NPC. The conclusions indicate that the proposed technique, based on IGOA, indicates that the PV/BA system is the best combination for meeting site demand while maintaining a low NPC and high reliability. The results of examining the influence of IR modifications indicate that the cost of energy (COE) is raised by 0.57 and 5.36%, respectively, while the NPC is minimized by 1.67% as a consequence of a 1.2% rise in IR. Hassan (2020) developed a renewable energy system aimed at meeting the electrical load requirements of families while maintaining low energy prices and low $CO_2$ emissions. Through modeling and optimization, photovoltaic solar power systems were examined for application in house electrification. The performance and cost of two scenarios of solar photovoltaic power systems were determined using 1-min resolution simulations and optimizations. The results indicate that both systems perform perfectly. The energy generated for both scenarios matches the targeted electrical demand of houses and recharges the storage units, while the surplus energy feeds the grid. The two solutions that have been created are both environmentally benign and economically feasible. The off-grid solutions total net present value is $6,250, and the energy cost is $0.12/kWh. In comparison, the on-grid systems the total net present value is $6,150, assuming an energy cost of $0.19/kWh.

Sharma, Kodamana, and Ramteke (2022) propose a multi-objective interactive enhancement of an applicant HRES using a genetic algorithm (GA), in which the production costs of HRES, fossil fuel-based energy consumption, and fuel emissions are all minimized concurrently over a finite timeframe, subject to operating parameters. Three optimization strategies are examined: 24 h in advance (strategy 1), 1 h in advance (strategy 2) and 2 h in advance (strategy 3). Strategy 1 uses 8.7% less grid power than strategies 2 and 3. Strategy 1 also sells more electricity to the grid than strategies 2 and 3. This is because strategy 1 matches the load profile of 100 homes.

Atam et al. (2021) proposed a unique green energy solution based on HRES integrated with active smart heaters for large fruit farm freeze protection. To optimize the concentration of active compounds in smart heaters on a large scale, the authors developed a multi-objective, resiliency-based optimization formulation. The result of the optimization process is discretized. A case study compares the suggested optimization approach to a heuristic-based design, which showed a 25.22% decrease in overall pipe length and a 55.11% improvement in optimum heating. In contrast to existing active systems, the green energy system is more environmentally friendly and cheaper. Aziz et al. (2022) offered a novel dispatch strategy for off-grid WT/Diesel (DE)/BT energy systems based on MATLAB and HOMER in order to overcome the constraints of the default HOMER methods. The system is subjected to a full technical, economic and greenhouse gas emission study under load-following and cycle charging dispatch techniques. Apart from providing a more realistic optimization, the results indicate that the suggested method provides the best economic and environmental performance, with a NPC of $56473 and annual $CO_2$ emissions of 6838 kg. Furthermore, the sensitivity analysis demonstrates that the suggested method is not affected by the fluctuation in fuel prices, in contrast to the LF and CC strategies, which are significantly influenced by this variation. Hassan (2020) presented a computational technique for optimizing solar–hydrogen energy systems to provide renewable energy to a typical grid-connected home. The proposed energy system was developed to handle the target electrical demand while increasing the renewable energy percentage by using the maximum capacity of the fuel cells. The simulations were performed using experimental weather data with a 1-min precision. The results demonstrate that the optimal fuel cell capacity was approximately 2.55 kW for a 1.9 kW PV power system. The annual renewable energy percentage grew from 31.82 to 95.82% as a result of the solar system integration with a 2.3 kW fuel cell serving as a strong energy storage unit. Additionally, the economic part of the optimal system levelized the cost of power by around $0.2/kWh. Jaszczur and Hassan (2020) examined self-sustainability enhancement with the use of a solar PV with an ultra-supercapacitor. A technical examination is used to establish the appropriate supercapacitor size for the proposed system. The analyzed performance show that by including small, highly responsive storage energy, self-consumption could be improved by up to 83 and 114%, respectively, when compared to a system with no local energy storage. Additionally, the annual average growth in self-consumption for the provided load approaches 100%. Al Busaidi et al. (2016) conducted a literature review for PV/WT energy systems and provided the potential location for renewable energy system devaloped in Oman. In addition, the study talks about many ways to compare the cost of energy extraction and the efficiency of different hybrid systems using computational methods.

Li et al. (2020) presented a novel, clean and efficient configuration based on FC and an improved boost converter unit to supply telecom towers with a dependable source of power. The work proposes a feedback controller based on a newly established optimization method, called the enhanced chaos world cup optimization algorithm. The suggested approach enables the base transceiver station to operate reliably and efficiently in the presence of oscillations in the telecom load and the FC output voltage. The simulation results of the suggested optimization approach are compared to those of a conventional PI controller, and the new system is shown to have better performance. Khatib et al. and colleagues focus on the construction and size of off-grid PV systems. Furthermore, the authors examine the most recent optimization assessment criteria and methodologies, as well as the complications and disadvantages of off-grid energy system implementations (Khatib, Ibrahim, and Mohamed 2016). The work of Hassan, Jaszczur, and Abdulateef (2016) is focused on modeling, computer simulation, and optimization of a hybrid power system in a rural setting. Solar and wind energy are two renewable options that are being explored. To build the hypothesized hybrid energy system model, the researchers utilized HOMER software. On the basis of modeling outcomes, renewable energy sources can potentially replace conventional energy sources and would be a viable alternative for generating electricity in distant areas at an affordable cost. The electric hybrid system solution to revitalize the specified region resulted in the lowest-cost hybrid power system combination that can fulfill demand reliably at a cost of approx. $0.33/kWh. Kharrich et al. (2020) examine the optimization of multiple hybrid systems. They used five different algorithms to find the best one for both reliability and cost. The results show that the GA algorithms used to find the best economic architect for hybrid microgrid power systems work well.

In addition, a HRES integrated into a ship can provide renewable energy, reduce fuel consumption, and use available renewables to provide low-cost energy and meet electricity requirements. Yuan et al. (2018) investigated experiments utilizing a hybrid system using photovoltaic panels, DG, and BT for commercial ship electricity. On the basis of an analysis of the experimental results, it can be determined that the use of preposed energy has the potential to reduce fuel consumption by 5.11%. Rajanna Siddaiah and Saini concentrate on four important aspects of off-grid hybrid system design: modeling, configuration, and optimization. In addition, this article examines several researchers mathematical models, which are based on technical, economic, optimization, and reliability factors (Siddaiah and Saini 2016). Renewable energy sources must be correctly regulated by a dedicated power converter in both off-grid and grid-connected modes to ensure proper voltage, power regulation, and power quality. Khare, Nema, and Baredar (2016) discuss feasibility analysis, optimal size, modeling, control, and reliability issues, as well as the incorporation of developing technologies and game theory into HRES. Due to advancements in renewable energy usage technology and component cost reductions, HRES has become a cost-effective method of providing reliable electricity to distant and rural locations (Goel and Sharma 2017). As presented by Sos et al. (Sanni et al. 2021), the HRES combines renewable and backup energy sources and benefits from collaboration between energy sources while lowering dependency on grids and other conventional power sources. Al-Sharafi et al. (2017) evaluated the possibilities for hybrid photovoltaic-wind-battery-fuel cell systems to generate electricity and hydrogen in several locations in Saudi Arabia. The research showed that the preposed PV/WT/fuel cell system provided electricity at a minimal levelized cost of $1.21/kWh and hydrogen generation at a cost of $44.05/kg.

The literature identifies a variety of technology categories that could be used to plan and implement hybrid energy systems. Their applicability is contingent upon the generating side accessible sources of energy. The selected components in the HRES may be combined to produce a variety of different configurations for the HRES, depending on the desired load. The PV/WT/BT are evaluated in this research as components of a hybrid renewable energy system designed for maximum sustainability. The choice is made based on the energy method, which shows which HRES components have the best total energy efficiency when all parts of the system are used together. The innovation is integrating the suggested hybrid system that reduces electricity taken from the grid, which can effectively be renewable energy to meet the load. As a consequence, oversizing system components is avoided, decreasing system costs as well as decreasing emission effects.

# Methodology

A case study of a university building in Diyala, Iraq, was investigated to establish the technological and economic viability of a HRES set with grid for electricity supply at a highly sustainable level. The following sections detail the process for optimal HRES configuration.

### The modeling approach

Local sources of renewable energy, electrical load demand profiles, technical specifications for system components, and economic input, as well as any relevant legislation, all serve as inputs to the hybrid power system design process. Following the combination of the abovementioned inputs, the ideal solution is discovered using HOMER and MATLAB via modeling and optimization. Simulations have been performed on each proposal in the search space to determine the configurations that are feasible given the constraints. The optimum design was determined to be the configuration with the lowest NPC.

### Model design and component specification

Figure 1 illustrates an on-grid HRES scheme. The proposed model includes photovoltaic panels, wind turbines, and batteries to store energy and the converter is used to change the mode of operation. The simulation is additionally enhanced with a grid module to determine the economic breakeven point for off-grid HRES development. The specifications of the HRES components are presented in Table 1.

### Governing equations for the proposed model

**Technical metrics:** The electrical power produced by the HRES analysis at every moment $t$ can be characterized as follows:

$$P_{HRES,t} = P_{PV,t} + P_{WT,t} + P_{BT,t} + P_{Grid,t} \quad (1)$$

where $P_{HRES,t}$ is the electrical power produced by HRES at time $t$ in (kW), $P_{PV,t}$ is the PV array power (kW), $P_{WT,t}$ is the WT power (kW), $P_{BT,t}$ is the battery power (kW) and $P_{Grid,t}$ is the power taken from the grid (kW).

The power produced by a photovoltaic array is expressed in kilowatts as (Jaszczur et al. 2019a; Hassan 2021b; Hassan et al. 2019):

$$P_{PV,t} = \eta_{PV} C_{PV} \cdot [1 + \alpha_P (T_{C,t} - 25)] \cdot \left(\frac{H_{T,t}}{H_{T,STC}}\right) \quad (2)$$

where $\eta_{PV}$ is the PV derating factor (%), $C_{PV}$ is rated capacity of the PV array (kW), $\alpha_P$ is the PV cell temperature power coefficient is taken −0.37%/°C (Jaszczur et al. 2018; Jaszczur et al. 2019), $H_{T,t}$ is the incident solar radiation (kW/m$^2$), $H_{T,STC}$ is the solar irradance (kW/m$^2$) at standard conditions, $T_{C,t}$ is the temperature of the PV cell (°C).

The power generated by WT can be described as follows (Ceran, Hassan, Jaszczur, Sroka (2017); Jaszczur et al. 2020; Styszko et al. 2019):

$$P_{WT,t} = \frac{\rho_r}{\rho_o} \cdot P_{st,t} \quad (3)$$

where $P_{st,t}$ is power generated by (kW) under standard air density which is measured using the WT power curve (Jaszczur et al. 2021), and $\rho_o$ and $\rho_r$ are the standard and real air densities (kg/m³), respectively.

The main effect on battery power is the battery state of charge could be estimated using formulas (Noronha and Munishamaih 2021):

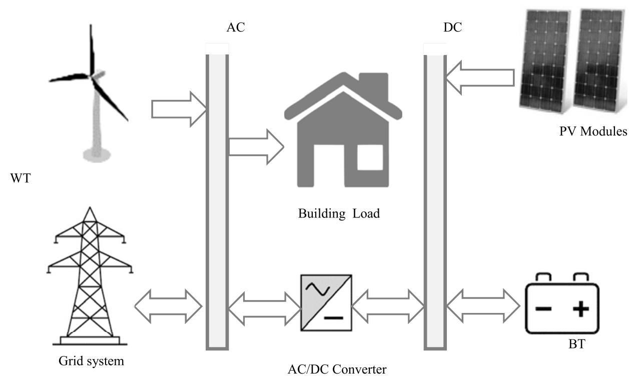


**Figure 1:** Proposed on-grid PV/WT/BT energy system.

**Table 1:** Specifications of the HRES components.

| Component | Size | Technology | Efficiency, % | Ref. |
|---|---|---|---|---|
| PV module | 0.45 kWp | Monocrystalline, sunceco | 21 | Monocrystalline (2021) |
| Converter | 25 kW | Absopulse | 98 | Absopulse Inverter (2021) |
| BT | 200 A | Vision | – | Battery (2021) |
| WT | 1.25 kW (AC) | Tulipo | – | Tulip Wind Turbine (2021) |

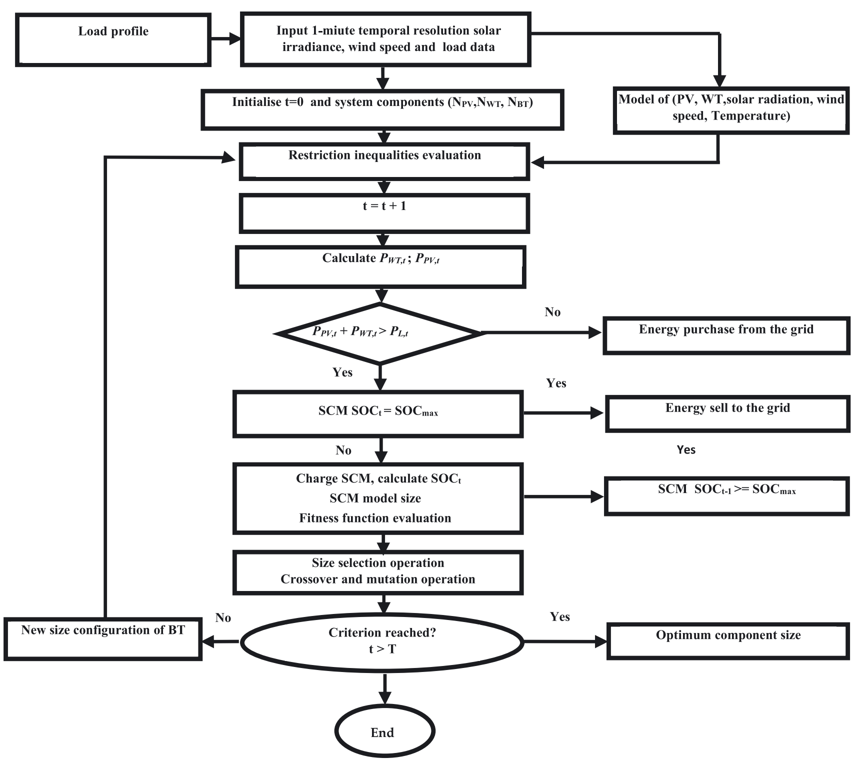


**Figure 2:** A flowchart of the energy system distribution.

Charging,

$$P_{BT,t} = P_b(t-1)\cdot(1-s_d) + (P_n(t) - P_k(t)/(\eta_N)\cdot\eta_b \tag{4}$$

discharging,

$$P_{BT,t} = P_b(t-1)\cdot(1-s_d) - (P_n(t)/(\eta_b)\cdot P_k(t)) \tag{5}$$

where $P_k(t)$ the demand of the load at the time $t$, $P_b(t\text{-}1)$ is the power at the end of interval $t$, $P_n(t)$ is the energy generated by PV array at the time $t$, $\eta_b$, $\eta_N$ is the battery charger and inverter efficiency, respectively and $s_d$ is the self-discharge factor. Figure 2 shows the flow chart of a simulation of an energy system.

**Economic metrics:** Finance is essential to determine the viability of a project. The following economic metrics are included in this study: the NPC, the levelized COE.

The total NPC is the model of primary economic outcome, indicating the sum of all expenses incurred over the project lifespan. Capital expenses, replacement costs, costs of maintenance and operation, pollution fines, and grid electricity purchase prices are all included in the costs, can be denoted as (Elgammi, Aokaly, and Aldali 2021; Hoang 2019; Madhanmohan, Saleem, and Kovilakam 2020):

$$NPC = \frac{C_{\text{ann}}}{CRF(i, R_p)} \tag{6}$$

where, $CRF()$ is capital recovery factor, $C_{ann}$ is the total annualised cost ($/year), $R_p$ is the preposed system lifespan (year) and $i$ is the interest rate (%).

The COE can be represented as (Arora 2021; Heidarnejad and Noorpoor 2021; Maheri 2016; Okonkwo et al. 2021; Okonkwo, Okwose, and Abbasoglu 2017; Sharifi and Hashemi 2015; Taner 2019):

$$COE = \frac{C_{ann}}{E_{AC,DC} + E_{Fed\,to\,grid}} \tag{7}$$

where $E_{AC,\,DC}$ is the energy costs ($/kWh), $E_{Fed\ grid}$ is the energy grid sales ($/kWh).

## Case of study

This research focuses on the denary building of the Engineering College at the University of Diyala (33.7733° *N*, 45.1495° E). The building has two floors with an area of 1650 $m^2$, occupied by academic electrical devices such as printers, screens, computers, etc., where the electrical load consumption has been measured experimentally for a one-year span.

## Grid energy system

The grid system is imported to assess the economics of on-grid HRES in comparison to electricity grid augmentation. The Iraqi grid energy system is 220 V and the grid energy prices are taken based on the Iraqi Ministry of Energy regulations for purchase at $0.35 kWh and for sale at $0.11 kWh (Iraqi Ministary of Electricity 2021).

## Renewable energy resources

The weather data were measured by a weather station located on the roof of the invistigated building. Figure 3a–d show the region daily and monthly averages of weather data for each month of the year. According to Figure 3C, June has the highest average daily solar radiation, at around 6.91 kWh/$m^2$/day. The yearly solar irradaince is estimated to be roughly 4.6 kWh/$m^2$/day with an average clearness index of 0.51. The yearly average temperature is scaled to 23.7 °C, a temperature that has little effect on photovoltaic efficiency. As seen in Figure 3d, August has the highest average temperature of 34.45 °C, which can have a detrimental effect on the production of electricity from photovoltaic panels. With a height above sea level of 59 m (Elgammi, Aokaly, and Aldali 2021; Hassan et al. 2021), Figure 3d shows the wind speed on a monthly average. The annual average wind speed is 3.5 m/s, indicating that this location does not have a high potential for wind energy.

## Electrical load profile

The electrical load demand of the specified building was obtained experimentally with 1-min resolution for the year 2021. On average, annual load demand is 24.7 kWh/day, with a high of 13.0 kW. Figure 4a–b show the daily and monthly averages of the measured load profile.

## Economical inputs

This section describes the economic inputs to the modeling process. The project is planned to be 20 years, which corresponds to the average lifespan of the primary renewable components. The inflation and discount rates are assumed to be1% and 5%, respectively. The economic characteristics for each system component are derived based on the availability of the selected site, which is summarized in Table 2.

# Results and disscution

This section provides the optimization and simulation conclusions for the proposed HRES for renewable energy

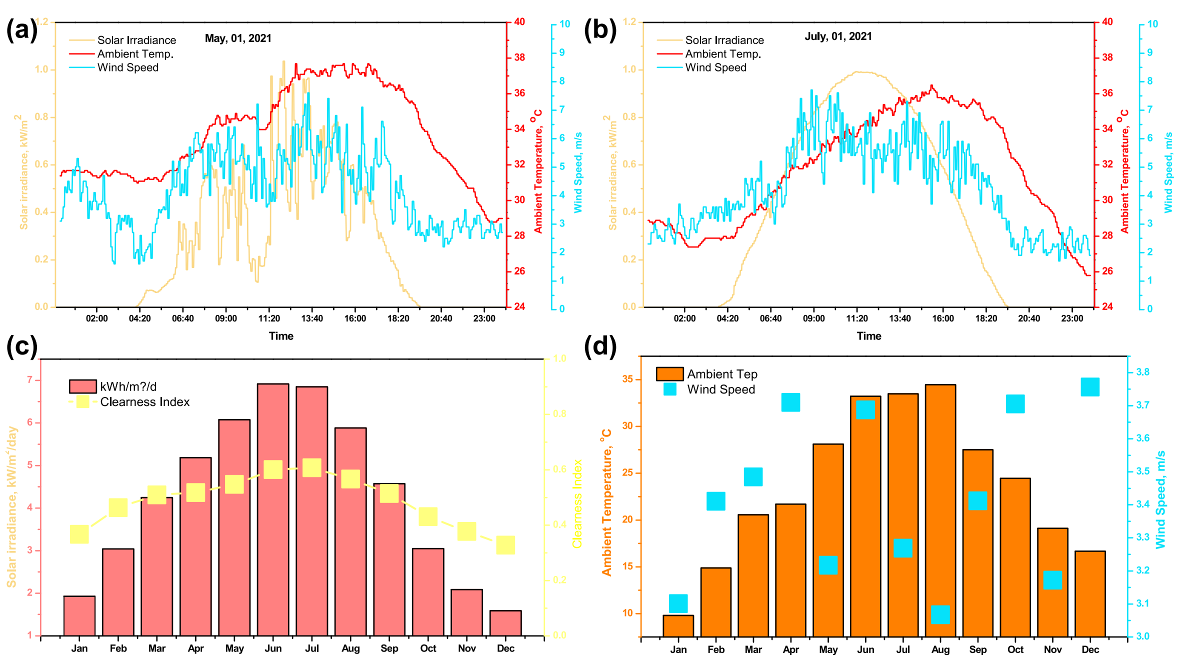


**Figure 3:** Daily (a) and (b) and monthly average (c) and (d) of solar irradaince, ambient temperature and wind speed.

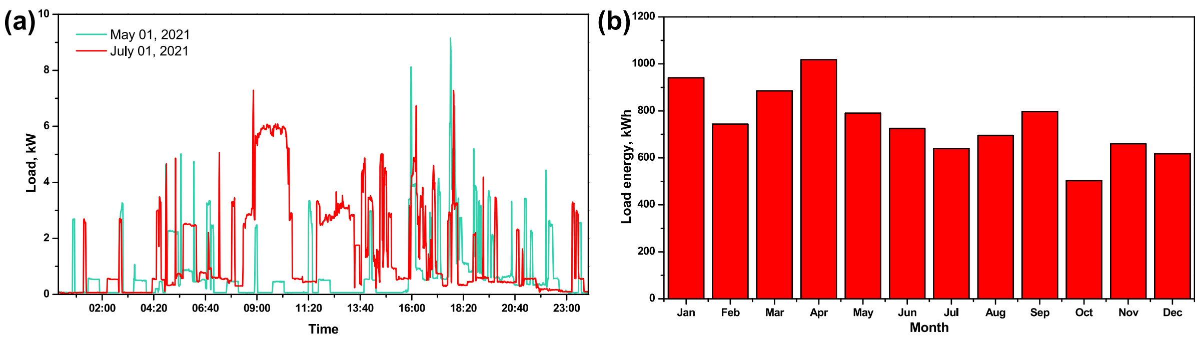


**Figure 4:** Daily (a) and monthly average (b) electrical laod.

**Table 2:** Economic inputs for the components of the HRES system.

| Component | Size | Capital ($) | Replacement ($) | Maintenace ($/year) | Life span (Year) |
|---|---|---|---|---|---|
| PV | 0.45 kWp | 150 | 140 | 10 | 20 |
| WT | 2.5 kW | 600 | 500 | 20 | 20 |
| BT | 200 A | 200 | 200 | 10 | 5 |
| Converter | 25 kW | 5000 | 5000 | 9 | 15 |

supplying the University building. Additionally, general observations about the system environmental and economic conditions are made. HOMER and MATLAB softwares are utilized in the computations using experimental data for the target electrical load, solar irradiation, wind speed, and ambient temperature. The numerical computations were performed at a 1-min resolution. The photovoltaic array was placed at ($\beta$ = 30°, $\gamma$ = 0° south-facing), ensuring that it received the highest yearly solar irradiance. The effects of temperature on the energy generated by a PV array were considered, with the PV cell power temperature coefficient set to $\alpha_P$ = −0.38%/°C and the derating factor set to 95%, which includes system component losses. The goal of the analysis is to determine how much energy is self-sustaining and how it moves through a system that includes parts of renewable energy.

Using experimental renewable energy resources, the annual average of solar irradiance, ambient temperature, and wind speed is 4.6 kW h/m$^2$/day, 23.7 °C, and 3.42 m/s, respectively. Furthermore, the annual electricity consumption is 9017.6 kWh, with a project lifespan of 20 years. The optimal system configurations are thoroughly analyzed from the various options. Table 3 shows the representative techno-economic performance of optimum design.

**Table 3:** Optimum HRES components capcity.

| Component | Capacity |
|---|---|
| PV | 9 kWp (20 module) |
| WT | 6 (units) |
| BT | 1 |

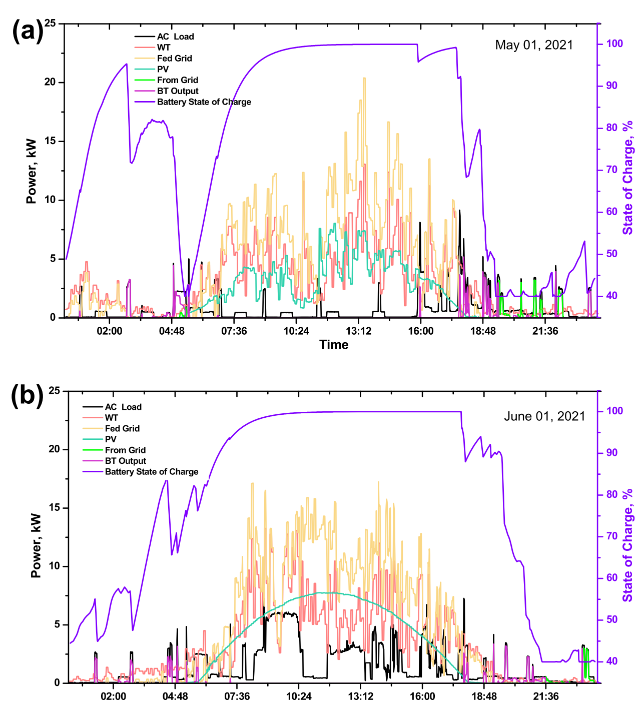


**Figure 5:** Daily distribution of power flow.

## Daily energy flow

Figure 5a,b illustrate the power distribution for the two days chosen (May 01, and June 01 for the year of 2021). The energy flow for the chosen days is shown in Table 4. The electrical energy consumption for the day of May 01 was 17.5 kWh, and the energy delivered by the PV array and WT was 41.16 kWh and 70.14 kWh, respectively. On the day of June 01, the electrical energy consumption was 35.52 kWh, and the renewable energy generated by the PV array and WT was 62.63 kWh and 78.29 kWh, respectively. The battery was designed only to charge from renewable energy and for both days had no high-energy delivery to the desired load (see Table 4).

## Monthly and yearly energy flows

Figure 6 shows the amount of energy produced by the renewable energy components (PV and WT) on a monthly basis. For the photovoltaic array, the summer months (April–August) provide the most energy due to the high incident solar irradiance, and the winter months produce the least energy due to the lower incident solar irradiance (September–March). The annual energy output of the photovoltaic array is expected to be 14,169 kWh. For the IND turbine, energy generation varies according to wind speed. The annual energy production by the WT system is estimated to be 15,976 kWh. The annual energy generated by BT to meet the electrical demand is around 949 kWh/year.

**Table 4:** Daily energy flow (kWh).

| Day | AC Load | PV | WT | From Grid | Fed Grid | BT |
|---|---|---|---|---|---|---|
| May 01, 2021 | 17.54 | 41.16 | 70.14 | 1.53 | 93.64 | 3.54 |
| June 01, 2021 | 35.52 | 62.63 | 78.29 | 0.76 | 104.96 | 2.68 |

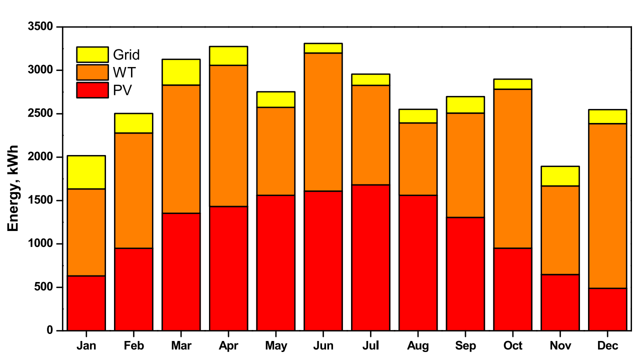


**Figure 6:** Monthly energy flow distribution.

Figure 7 shows the calculated monthly amount of energy taken from the grid and fed back to the grid each month. Which is the annual energy taken from the grid, estimated to be 2384 kWh/year, and the annual energy fed to the grid, estimated to be 23,036 kW/year.

Figure 8a,b show the variation btween the electrical load and PV power (a) and the electrical load and WT power in (b).

Figure 9a and b shows the annual generated by the HRES components. The PV array generated 14,169 kWh/year with a percentage of 44%, the WT system 15,655 kWh/year with a percentage of 48%, BT 235 kWh/year with a percentage of 1%, and energy taken from the grid 2384 kWh/year with a percentage of 7%.

# Economic prosepective

The economic productivity of the entire system is evaluated and the economic feasibility of grid expansion is offered. The best on-grid HRES has the cheapest NPC of $5142 and a acceptable COE of $0.05/kWh, with an initial cost of $11,800 and an annual operating cost of $488/year, respectively. The best hybrid system cost summary is shown in Tables 5 and 6. The highest capital investment is $5000 for the converter, followed by wind turbines at $3,600, photovoltaic panels at $3,000, and $200 for batteries.

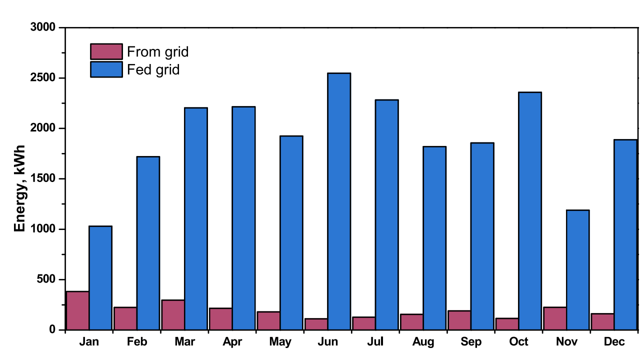


**Figure 7:** Monthly energy taken from the grid and fed back to the grid.

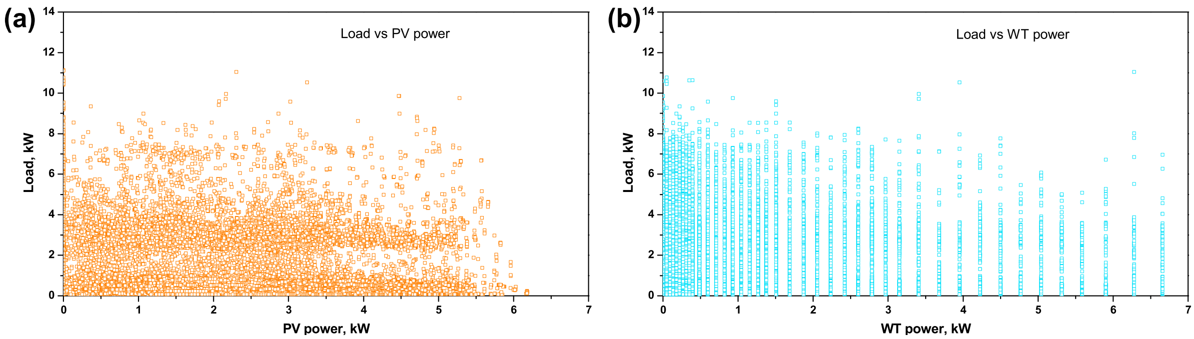


Figure 8: Profiles of electrical load and PV power (a), electrical load and WT power (b).

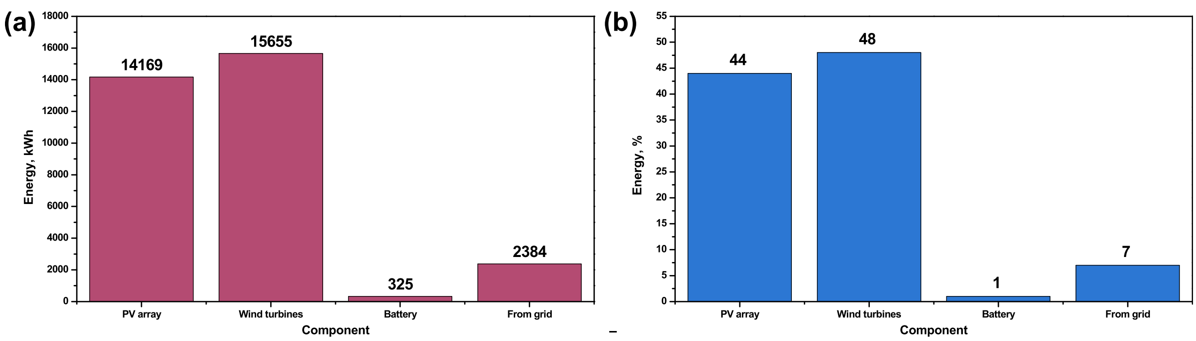


Figure 9: Annual energy generated by the HRES component in kWh (a), percentage in (b).

Table 5: The proposed HRES annual cost.

| Component | Capital ($/yr) | Replacement ($/yr) | O&M ($/yr) | Salvage ($/yr) | Total ($/yr) |
|---|---|---|---|---|---|
| PV | −262 | 0 | −200 | 0 | −462 |
| WT | −314 | 0 | −120 | 0 | −434 |
| Grid | 0 | 0 | 1239 | 0 | 1239 |
| BT | −17 | −232 | −10 | 5 | −254 |
| Converter | −436 | −182 | −10 | 91 | −537 |
| System | −1029 | −413 | 899 | 95 | −448 |

Table 6: The optimized HRES NPC.

| Component | Capital ($) | Replacement ($) | O&M ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|
| PV | −3000 | 0 | −2294 | 0 | −5294 |
| WT | −3600 | 0 | −1376 | 0 | −4976 |
| Grid | 0 | 0 | 14,207 | 0 | 14,207 |
| BT | −200 | −2656 | −115 | 54 | −2917 |
| Converter | −5000 | −2086 | −115 | 1039 | −6162 |
| System | −11,800 | −4,743 | 10,308 | 1093 | −5142 |

## Conclusions

Reliable and sustainable energy supply is viewed as a critical aspect in the promotion of regional social and economic development as well as an essential component in ensuring a high standard of living for people. Furthermore, with social progress, outlying social production patterns span across locations and may persist for an extended period of time. The use of renewable energy sources is emphasized as a viable alternative option for on-grid renewable energy delivery. Due to the intermittent and unpredictable nature of renewable energy sources, backup components are included in renewable energy systems to increase system dependability and minimize system size. Batteries are often utilized as backup components and are employed because of the difficulties of electrification, transportation, etc. This article discusses a technique for sizing an on-grid photovoltaic/wind/battery hybrid renewable energy system for electrifying the Engineering College's deanery building at the University of Diyala in Iraq. Each component of the hybrid renewable energy system was mathematically modelled. Their input was supplied by the GA algorithm with actual data on solar radiation, temperature, wind speed, and load demand. The proposed on-grid HRES consists of 9.0 kWp of photovoltaic panels, 23 10 kW wind turbines, a 200 A battery and a 25 kW converter, with an NPC and COE of $5142 and $0.05/kWh, respectively. As a consequence of the foregoing findings, it is determined that the proposed system is economically feasible to provide high-quality electricity and meet load demand while also achieving social and environmental advantages.

Feasibility study of an integrated HRPG for sustainable concurrent power generation to meet electrical load requirement. The innovation of research study carried out is integrating the hybrid renewable system components into optimised one. Presented system optimise power flows and the peak-power can effectively be delivery to meet the load requirement. As a consequence, oversizing system components is avoided, decreasing system costs and decreasing emission effects.

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