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# THE ECONOMIC AND ENVIRONMENTAL IMPACT OF FEEDING A SCHOOL WITH RENEWABLE ENERGY

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**ABSTRACT**

One of the most serious problems of the twenty first century is global warming. Therefore, transformation plans for renewable energies have become a necessity not a luxury. Traditional ways of producing electrical energy is one of important source that cause greenhouse gases which contribute to global warming, so the best way to limit damage the environment is to use renewable resources, but it faces some challenges' such as its cost and the suitability climate conditions. In this paper we designed a renewable energy system based on wind and solar energy to feed al-kumishat high school in Gharyan city, Libya. We used r (Hybrid Optimization of Multiple Electric Renewables) HOMER program to design and simulate the system to study the technical, economic and environment impacts on the system. The study was conducted on a group of technical, economic factors and variables including three scenarios. The best scenarios are the third scenarios, which is capacity shortage is 10% of 25,527 Kwh/year electric load and peak load at 7.79 Kw. So we can reduce the mission of $Co_2$ gas in the atmosphere by about 25,093 kg per year. Also this scenario achieves the lowest level of COE by 0.432$ and a NPC by 55649$. This recommended system configuration includes a 0.938 Kw photo voltage array, three 3.3 Kw turbines and 13 Hoppecke of 1500 AH. Wind energy contributes 90.1% annually, which solar energy provides 9.92%. The system is estimated to have an Excess electricity of 60.5% .

## 1.0 Introduction

Climate change is considered one of the most pressing issues of our time, with one of its major causes being the burning of fossil fuels[1]. Therefore, it has become imperative, not just optionally, to transition to green energy to reduce carbon dioxide emissions and preserve humanity while enhancing the quality of life on this plant. reflecting heightened researcher interest in renewable energies over recent decades was conducted to estimate the CO2 emission factor for the entire energy industry sector in Libya using life-cycle assessment methodologyt. it was discovered that the total CO2 emissions amount to approximately 983 kg CO2 per (MWh). The results found exposed significant differences among CO2 emission factors listed in inventories approved by numerous environmental agencies across all categories. [2]. also designed a residential solar energy system, employing the HOMER program to assess feasibility. Their study demonstrated significant CO2 emission reductions and emphasized the environmental benefits of solar energy integration[3]. Similarly, optimized a hybrid renewable energy system for a governmental building in Tripoli, integrating 20 kW of solar energy, a 25 kW wind turbine, and 72 1500 amp-hour batteries, achieving a projected surplus electrical energy of 58.3% [4]. In Misurata utilized the HOMER program to design a hybrid renewable energy system for a school, highlighting the economic viability of solar and wind energy combinations with batteries and diesel generators. Their study underscored the varying utilization rates of renewable resources based on local availability[5]. In Libya, developed a renewable energy system for a mosque in Kufra, identifying solar energy combined with generators and batteries as the optimal configuration, with surplus energy available for other applications [6]. In India designed a residential solar energy system using PV*SOL software, emphasizing the effectiveness of solar energy in reducing carbon dioxide emissions and household energy consumption by approximately 41.09% [7]. applied the PV-Syst program to design solar energy systems for schools in Baghdad, showcasing benefits such as reduced strain on public networks, lowered CO2 emissions, and a project payback period of six years [8]. In Palestine optimized a solar energy system for Al-Dahiya Secondary School using the HOMER program, projecting significant energy production potential across schools in Palestine and annual surplus revenues of approximately 43 million USD [9]. implemented a grid-connected solar energy system for three schools in the West Bank of Palestine, achieving high system performance and a rapid payback period, in addition to environmental and economic benefits [10]. In Mexico designed solar energy systems to alleviate electrical loads in laboratories at the Autonomous International University of Mexico (UNAM), demonstrating cost savings and revenue generation through energy exports to the public grid. These studies collectively highlight the growing application of solar energy systems across diverse geographical and institutional contexts, emphasizing their environmental, economic, and technical advantages in reducing carbon emissions, enhancing energy efficiency, and promoting sustainabl[11].

## 2.0 Case Study

The education sector is one of the largest government sectors, comprising over 2 million students in approximately 4,775 schools with a staff of over 560,000 teachers and employees. With this magnitude, the energy consumption of the sector, though seasonal between September and May, with working hours from 8 AM to 2 PM, becomes apparent. This makes it easier to cover this load with renewable energies (solar and wind). Libya, with its high solar irradiance rates of about 7.5 kWh/m²/day and sunny hours ranging from 3000 to 3500 annually, and wind speeds ranging from 6 m/s to 7.5 m/s [12][13], can benefit from the surplus of this energy outside school hours to support the public grid. The Kameshat Secondary School was chosen as a model for the study as Figure 1, located in the village of Kumishat, east of Gharyan city, approximately 9 km away, at a latitude and longitude of 32° (8.1) and 13° (6.9), respectively, with an area of about 1900 square meters figure 1 .

Fig 1 located in the village of Kumishat, east of Gharyan city

The geographical nature of the area is mountainous, with a relatively rainy cold climate in winter and hot dry climate in summer. The school as Figure 2 consists of two corridors, each with four classrooms and a restroom, as well as four administrative rooms and a storage room, with two laboratories, one for computers and the other for chemistry. The school is surrounded by a large courtyard from all sides, including a basketball court. It can be classified as a medium-sized school, and its electricity loads were studied as follows: lighting loads were approximately 23.5 kilowatt-hours per day, while heating and cooling loads were around 18.8 kilowatt-hours per day, with the remaining loads specified in Table 2. Thus, the total school loads per day amount to 28.612 kilowatt-hours, with a peak load of 10.548 kilowatts.

Fig 2. The Kumishat Secondary School

## 3.0 Methodology

The HOMER Pro 3.14 software was used, developed by the National Renewable Energy Laboratory (NREL) in the United States[14]. It is considered one of the best simulation programs for renewable energy studies, combining strong engineering design with robust economic calculations and environmental studies. It has capabilities to simulate, study, and compare thousands of proposed systems, compare results, and select the best according to your inputs and preferences. The program simulates, designs and improves renewable energy systems, and analyzes the available systems to choose the best system from thousands of options. The program simulates the system and studies the economic costs of the system throughout the project lifespan, including construction, operation, maintenance, component replacement, fuel price, etc[15]. It also includes many economic variables that affect the construction process. It is also possible to conduct a sensitivity analysis for many variables that affect the system, such as fuel price, load size, reliability requirements, resource quality, etc. Solar and wind energy systems were chosen for their suitability to the study location. Batteries and power inverters were selected, and an off-grid system was chosen due to the lack of regulatory frameworks for such networks by the power company. Then the system was designed After collecting the remaining required information, such as the school's daily loads, climatic conditions data, and other technical and economic inputs, and t the simulation process and optimal design of the system in order to obtain the most accurate results.

## 4.0 load

Given that the study period in Libyan schools is between the months of September and May, the school's electrical loads are dominated by lighting loads of about 12.5 kilowatt hours per day, as shown in Table 1 and in Table 2 we see that it also contains some other electronic devices such as computers and printers with about One kilowatt-hour per day, while the heating loads of heaters are concentrated in the months of December and January at a value of 14 kilowatt-hours, as shown in Table 3. The total school electrical load is about 28.61 kwh/ day, with peak loads of 7.79 KWp.

**Table 1: Lighting Loads**

| Description | No. | Power (w) | Power (kw) | Operating Time | total Power (kwh/day) |
|---|---|---|---|---|---|
| **Classrooms** | **8** | **4*36** | **1.152** | **5 hours** | **5.760** |
| **Administrative offices** | **4** | **2*36** | **0.288** | **5 hours** | **1.440** |
| **Science laboratory** | **1** | **2*36** | **0.072** | **2 hours** | **0.144** |
| **Computer laboratory** | **1** | **2*36** | **0.072** | **1 hours** | **0.072** |
| **Restroom** | **1** | **2*36** | **0.072** | **6 hours** | **0.432** |
| **Bathrooms** | **2** | **2*36** | **0.144** | **2 hours** | **0.288** |
| **Indoor corridors** | **2** | **4*36** | **0.288** | **5 hours** | **1.440** |
| **Indoor courtyard** | **1** | **4*36** | **0.144** | **5 hours** | **0.720** |
| **Outdoor lighting** | **2** | **2*50** | **0.200** | **11 hours** | **2.200** |
| **Total Lighting Loads** | | | **2.432 Kw** | | **12.496 kwh/day** |

**Table 2: Light Loads**

| Description | Device | No. | Power kw | Operating Hours | Total |
|---|---|---|---|---|---|
| **Administrative offices** | **Photocopier** | **1** | **0.760** | **0.2hours** | **0.152 kwh** |
| **Administrative offices** | **Computers** | **1** | **0.100** | **1hours** | **0.100 kwh** |
| **Administrative offices** | **Printer** | **1** | **0.120** | **0.2hours** | **0.024 kwh** |
| **Administrative offices** | **Monitor** | **1** | **0.060** | **4hours** | **0.240 kwh** |
| **Computer laboratory** | **Computers** | **12** | **0.100** | **0.75hours** | **1.200 kwh** |
| **Water pump** | **pump** | **1** | **0.73** | **0.5 hours** | **0.365 kwh** |
| **Total Loads** | | | **1.870 Kw** | | **2.051 Kwh/day** |

**Table 3: Heating and Cooling Loads**

| Description | Device | No. | Power w | Operating Hours | Total |
|---|---|---|---|---|---|
| **Administrative offices** | **Air conditioner** | **2** | **1600** | **3 hours** | **9.6 kwh** |
| **Bathrooms** | **Water heater** | **1** | **1800** | **2.5 hours** | **4.5 kwh** |
| **Total Loads** | | | **3400 w** | | **14.1 Kwh/day** |

Figure 3 shows the electrical load profile of the school. A comprehensive survey of the school's electricity consumption facilitated the development of its load profile. It is noticeable that the demand increases significantly during the winter months, and this is primarily due to the fact that the study months in Libyan schools are usually from September to May. Also, loads are concentrated five days a week and from eight in the morning until two in the afternoon only, as is the case. The school consumes 28.61 kilowatt hours per day, accompanied by a peak demand of 7.79 kilowatts. With about 180 school days, 185 official holidays, and the summer months, we find that the annual load is 10,405 Kwh/y.

Name: School load

January Profile

| Hour | Load (kW) |
|---|---|
| 0 | 1.700 |
| 1 | 1.600 |
| 2 | 1.400 |
| 3 | 1.400 |
| 4 | 1.200 |
| 5 | 1.000 |
| 6 | 0.950 |
| 7 | 1.100 |
| 8 | 3.800 |
| 9 | 4.000 |
| 10 | 4.300 |

Time Step Size: **60** minutes

Random Variability
Day-to-day (%): 10
Timestep (%): 20

Peak Month: **February**

| Metric | Baseline | Scaled |
|---|---|---|
| Average (kWh/day) | 25.7 | 28.61 |
| Average(kW) | 1.07 | 1.19 |
| Peak (kW) | 7 | 7.79 |
| Load factor | .15 | .15 |

Load Type: ● AC ○ DC

☐ Efficiency (Advanced)
Efficiency multiplier: 1
Capital cost ($): 0
Lifetime (yr): 10

Scaled Annual Average (kWh/day): 28.61

Fig 3 Electrical loads throughout the year

The peak daily load is between eight in the morning and two in the afternoon in the period between September and May, when the weather is relatively moderate, which means dispensing with air conditioning loads. It is also possible to benefit from the energy available throughout the summer months and generated after working hours to support the public network if frameworks and legislation are available. This is required from the General Electricity Company Of Libya GECOL.

## 5.0 Renewable Energy resource

In this study, the meteorological data such as mean solar radiation, wind speed, and, temperature have obtained from the NASA database by using the area's coordinates (32°8.1N latitude and 13°6.9 E longitude).

### 5.1 Solar Resource

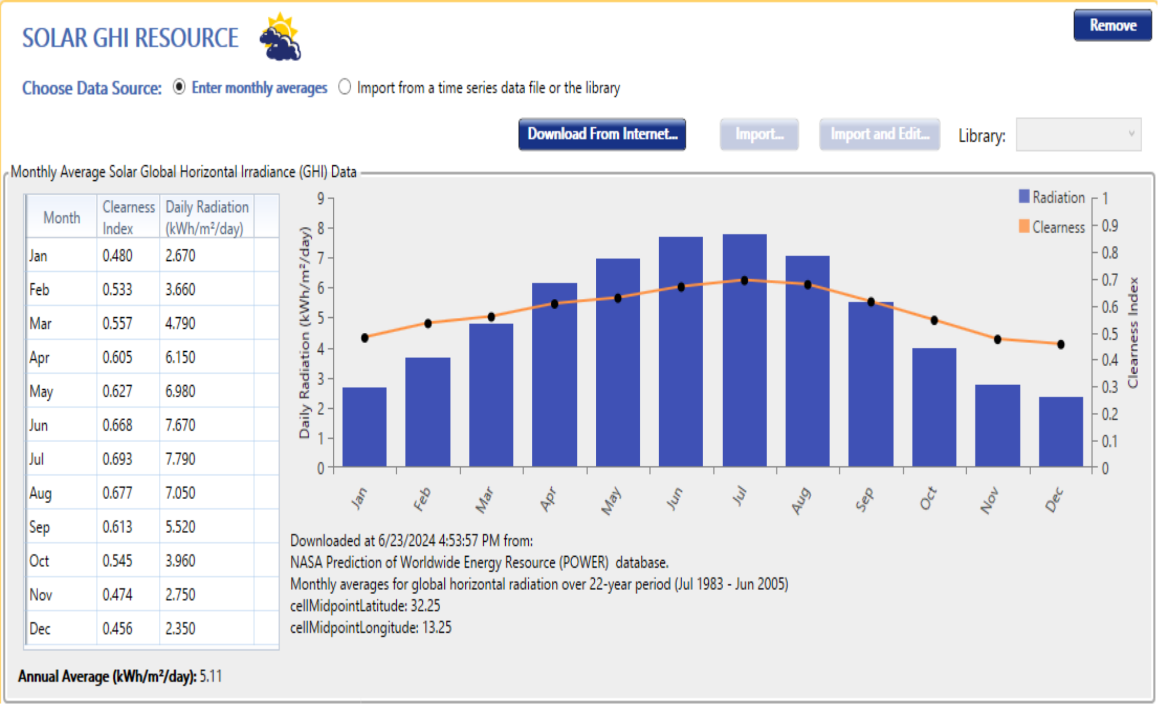
Utilizing the HOMER software, one can determine the solar radiation levels at a specific location by inputting its coordinates and importing solar irradiance data from a NASA database. Figure 4 illustrates the annual average daily solar radiation intensity at school. Particularly, daily solar radiation varies throughout the year: ranging from 2.67 to 3.66 kWh/m²/day in January, February, November, and December; increasing to 3.96 to 6.15 kWh/m²/day in March, April, September, and October; and peaking from 6.98 to 7.79 kWh/m²/day in May, June, July, and August. Consequently, the annual average solar radiation at school stands at 5.11 kWh/m²/day.

Table 4 : Electrical data for **Sun Power X-Series SPR-X21-335-BLK**

| Electrical Data | |
|---|---|
| **Nominal power** | **335 W** |

| | |
|---|---|
| **Power Tolerance** | **+5/-0%** |
| **Avg.Panel Efficiency** | **21.0%** |
| **Rated voltage (Vmpp)** | **57.3 V** |
| **Rated Current (Impp)** | **5.85 A** |
| **Open-Circuit Voltage (Voc)** | **67.9 V** |
| **Short-circuit Current (Isc)** | **6.23 A** |
| **Max. System Voltage** | **600 v UL & 1000 V IEC** |
| **Maximum Series Fuse** | **15 A** |
| **Power Temp Coef.** | **-0.29%/C$^o$** |
| **Voltage Temp Coef.** | **-167.4 mV/C$^o$** |
| **Current Temp Coef.** | **2.9 mA/C$^o$** |

The solar cells used in this study, PV type, are X21-335-BLK SUNPOWER**,** The PV system has a rated capacity of 0.335 kW. It operates with a temperature coefficient of -0.29 and is designed to perform optimally at a temperature of 43°C. The system boasts an efficiency of 21% as in Table 4 .Solar energy resource data plays a crucial role in this study as it facilitates the assessment of potential annual output from photovoltaic panels[16].



SOLAR GHI RESOURCE

Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Monthly Average Solar Global Horizontal Irradiance (GHI) Data

| Month | Clearness Index | Daily Radiation (kWh/m²/day) |
|---|---|---|
| Jan | 0.480 | 2.670 |
| Feb | 0.533 | 3.660 |
| Mar | 0.557 | 4.790 |
| Apr | 0.605 | 6.150 |
| May | 0.627 | 6.980 |
| Jun | 0.668 | 7.670 |
| Jul | 0.693 | 7.790 |
| Aug | 0.677 | 7.050 |
| Sep | 0.613 | 5.520 |
| Oct | 0.545 | 3.960 |
| Nov | 0.474 | 2.750 |
| Dec | 0.456 | 2.350 |

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NASA Prediction of Worldwide Energy Resource (POWER) database.
Monthly averages for global horizontal radiation over 22-year period (Jul 1983 - Jun 2005)
cellMidpointLatitude: 32.25
cellMidpointLongitude: 13.25

**Annual Average (kWh/m²/day):** 5.11

**Fig 4. Solar resource responses values for the location of the school**

Solar energy is considered one of the renewable sources that are inexhaustible. Libya is characterized by high solar radiation. the electrical Energy product from PV system $E_{PV}$ can be calaulated by eq. (1) [17]

$$E_{PV} = E_{array} * Loss_{sys} \ldots\ldots\ldots\ldots\ldots\ldots\text{(1)}$$

$$E_{array} = H * P_{DC} \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{(2)}$$

$$E_{array} = H * A * \eta_{pv} \text{………………..……}\textbf{(3)}$$

and by using eq.(2) ,(3) we have the final equation to calculate $E_{PV}$ :

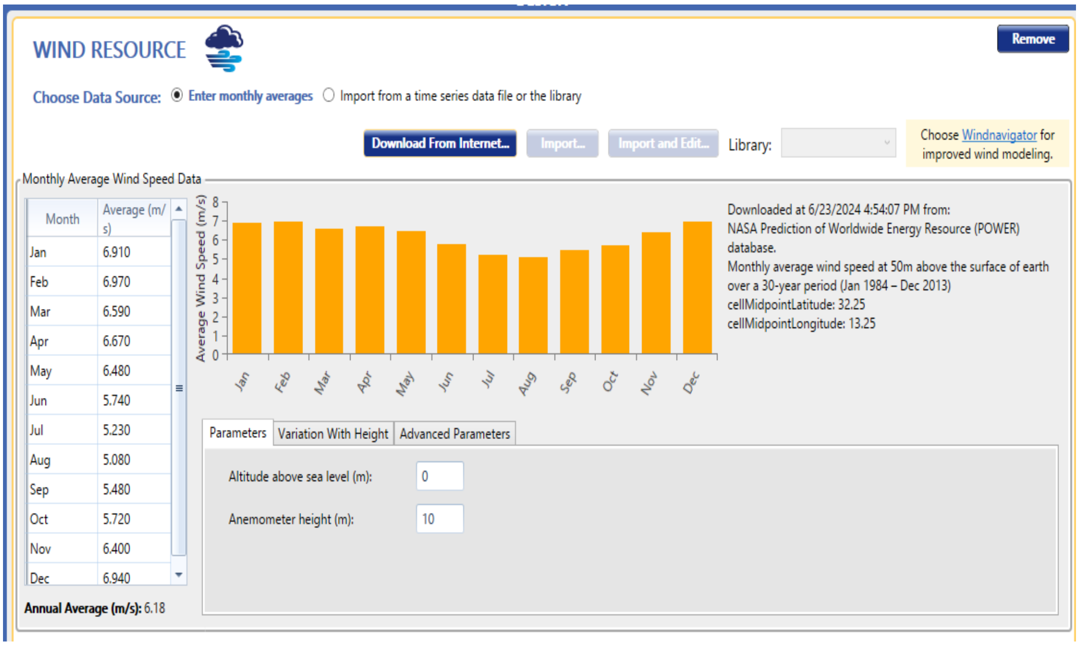
$$E_{PV} = H * P_{DC} * Loss_{sys} \text{……………..}\textbf{(4)}$$

Where:
H is effective global solar irradiance in kWh/m2, $\eta_{pv}$ is the efficiency of the PV on STC, $P_{DC}$is the rated power of PV array with commercial PV module at STC, A is the area of the PV module, $Loss_{sys}$ is total losses of the system, and $E_{array}$ is the electric energy of array.

### 5.2 wind resource

Wind resource data for the school was similarly acquired using the HOMER program to determine the appropriate wind turbine capacity for the system design. By inputting the coordinates of the study site and accessing the NASA database, monthly mean wind speed statistics were obtained to inform the selection and sizing of wind energy technologies.

The AWS HC 3.3 kW wind turbine has a rated capacity of 3.3 kW. Figure (5) illustrates the average monthly and annual wind speeds for school. The average wind speed varies from a low of 5.08 m/s in August to a peak of 6.94 m/s in December. Consequently, the approximate annual average wind speed at the school site is 6.18 m/s.



Choose Data Source: ● Enter monthly averages ○ Import from a time series data file or the library

Monthly Average Wind Speed Data

| Month | Average (m/s) |
|---|---|
| Jan | 6.910 |
| Feb | 6.970 |
| Mar | 6.590 |
| Apr | 6.670 |
| May | 6.480 |
| Jun | 5.740 |
| Jul | 5.230 |
| Aug | 5.080 |
| Sep | 5.480 |
| Oct | 5.720 |
| Nov | 6.400 |
| Dec | 6.940 |

**Annual Average (m/s):** 6.18

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NASA Prediction of Worldwide Energy Resource (POWER) database.
Monthly average wind speed at 50m above the surface of earth over a 30-year period (Jan 1984 – Dec 2013)
cellMidpointLatitude: 32.25
cellMidpointLongitude: 13.25

Altitude above sea level (m): 0
Anemometer height (m): 10

**Fig. 5. Wind resource inputs values for the location of the school.**

Several factors were carefully considered in the selection of the wind turbine capacity, including project location, site height restrictions, average wind speed, regulatory permissions, ease of installation and maintenance, initial capital costs, and the power curve characteristics. In order to maximize efficiency in low wind conditions, an **AWS HC 3.3 kW** wind turbine with specific emphasis on its rated power was chosen for the design. Figure 5 illustrates the power curve associated with the **AWS HC 3.3 kW** wind turbine.

After selecting the appropriate turbine, the wind speed is calculated at the height of the turbine based on the wind speed at the standard height here 10 meters using the eq. (5)

$$\frac{V_0}{V_a} = \left(\frac{Z_0}{Z_a}\right)^{\alpha} \text{……………………}(5)$$

$$\alpha = \frac{\ln(V_0) - \ln(V_a)}{\ln(Z_0) - \ln(Z_a)} \text{…………..}(6)$$

Where :

$V_0$ wind speed at standard level, $V_a$ wind speed at turbine level, $z_0$ the standard high, $z_a$ turbine high, $\alpha$ wind shear coefficient [11].

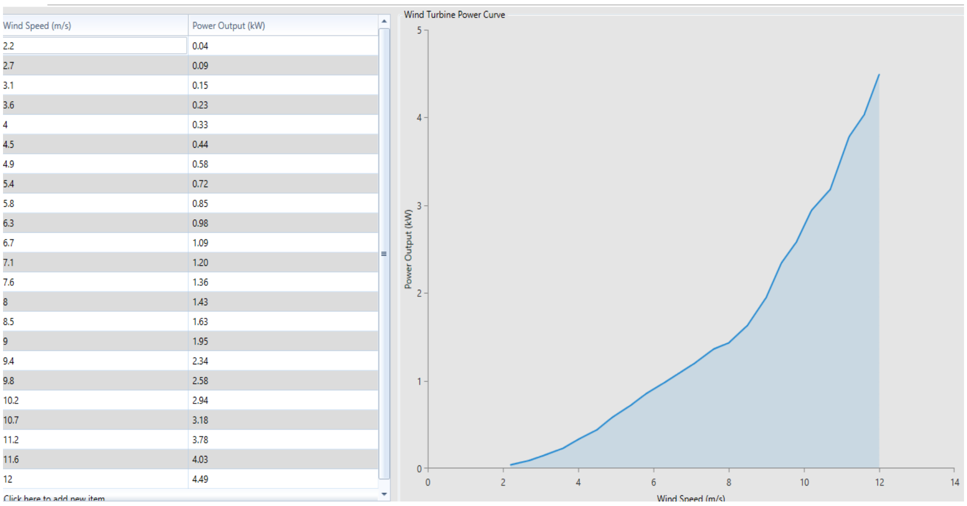
After deducing the wind speed at the height of the turbine used, the resulting power can be found from the power curve of the turbine used in Figure 6.

Using eq. (7), we can find the resulting power from the wind turbine at the actual air density[18].

$$P_{WT} = \left(\frac{\rho_a}{\rho_0}\right) * P_0 \text{……………..}(7)$$

Where :

$\rho_a$ actual dencity of air, $\rho_0$ air dencity at standard temperature and presure, $P_0$ wind turbine power at standard condution



| Wind Speed (m/s) | Power Output (kW) |
|---|---|
| 2.2 | 0.04 |
| 2.7 | 0.09 |
| 3.1 | 0.15 |
| 3.6 | 0.23 |
| 4 | 0.33 |
| 4.5 | 0.44 |
| 4.9 | 0.58 |
| 5.4 | 0.72 |
| 5.8 | 0.85 |
| 6.3 | 0.98 |
| 6.7 | 1.09 |
| 7.1 | 1.20 |
| 7.6 | 1.36 |
| 8 | 1.43 |
| 8.5 | 1.63 |
| 9 | 1.95 |
| 9.4 | 2.34 |
| 9.8 | 2.58 |
| 10.2 | 2.94 |
| 10.7 | 3.18 |
| 11.2 | 3.78 |
| 11.6 | 4.03 |
| 12 | 4.49 |

Fig6. (**AWS HC 3.3 kW**) Wind Turbine Power Curve .

Renewable energy sources like photovoltaic panels have variable performance on cloudy days, while energy production from wind turbines varies with wind speed. For that System constraints include maximum annual capacity shortages ranging from 1%, 5% and 10%.

### 5.3 Battery storage

A battery is important for the reliable and efficient operation of a renewable energy-based system. When the system's capacity is limited, the battery is used to store excess electricity and supply it to the load as needed.

In this study, Battery Hoppecke has been used with a nominal voltage of 2 V and a capacity of 3.59 kWh is working. It has a minimum state of charge (SoC) of 30% and a roundtrip efficiency of 86%. The chosen battery has a lifetime of 20 years.

### 5.4 converter

The converter is engineered to function bidirectional, serving as both a rectifier (AC to DC) and an inverter (DC to AC). Its primary role is to manage the flow of electricity between AC and DC bus components.

The inverter is specified with a 15-year lifespan and operates at 95% efficiency. Conversely, the relative capacity is 60% designed with 100% comparative capacity and also achieves 95% efficiency

## 6.0 . Economic Inputs

The selection of power system components is influenced by several critical factors, such as capital costs, operating and maintenance expenses, component efficiency, and lifespan. These attributes play pivotal roles in determining the suitability and performance of the chosen components. In the design of hybrid energy systems currently under consideration, potential energy supply options encompass wind turbines, solar photovoltaic (PV) arrays, battery banks, and converters. Each of these components possesses unique characteristics and cost structures that must be carefully evaluated and compared to ensure optimal system performance and cost-effectiveness. The following subsections will provide detailed descriptions of the qualities and pricing considerations associated with these system components.

**Table 5. Input to the HOMER software**

| Component | Capacity (kW) | Capital $ | Replacement ($/year) | O&M USD/year | Life Time (Year) | Reference |
|---|---|---|---|---|---|---|
| **Wind Turbine** | **3.3** | **6000** | **5300** | **20** | **20** | [19] |
| **PV** | **1** | **1771** | **1240** | **30** | **25** | [4] |
| **Converter** | **1** | **5000** | **4800** | **15** | **15** | [20] |
| **Battery Hoppecke** | **3.59** | **675** | **470** | **0** | **20** | [4] |

The cost of 3.3 kW wind turbines can vary significantly among manufacturers. To determine the specific cost of wind turbines suitable for meeting the site's load demand, it is essential to conduct a comparative analysis across different manufacturers. Factors influencing cost include turbine specifications, such as rotor diameter, tower height, and technology advancements, as well as additional costs for installation, maintenance, and any required infrastructure modifications. Gathering detailed quotations from various manufacturers will provide a comprehensive understanding of the investment required for implementing 3.3 kW wind turbines tailored to the site's specific energy needs.

The capital cost for the wind turbine amounts to $6,000, inclusive of a $5800 base price and 30 O & M costes. These financial considerations—capital costs, replacement costs, and O&M expenses are detailed in Table 5.

From the HOMER library, a 0.335kW monocrystalline silicon solar module was selected for integration into the system. These modules boast a lifespan of 25 years and operate with an efficiency of 21%. The specific attributes of the PV panels used in the system, as provided by the HOMER program, are summarized in Table 5. The anticipated installation cost for a 1 kW PV array system is projected to be $1771 USD, with O&M costs amounting to 1% of the total investment in solar panels[4].

## 7.0 . RESULTS AND DISCUSSION

Through performing hourly energy balance calculations throughout the year, Homer simulated the operation of the hybrid system proposed for the school. It compared the energy supply that the system could provide at each time step with the electrical demand for each time step. Then, energy flows to and from each component of the system were computed. Homer conducted these energy balance calculations for each considered system configuration. Subsequently, it determined the practicality of each configuration whether it could meet the electricity demand under specified conditions and calculated the installation and operational costs over the project's lifetime. This study considered three scenarios, and consists of photovoltaic system, wind turbine, battery, and inverter as shown in Figure 7 .

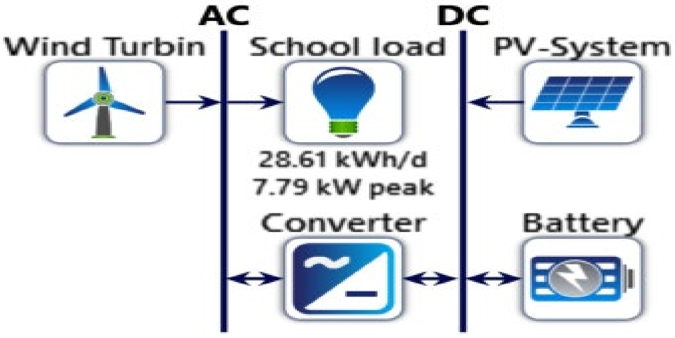
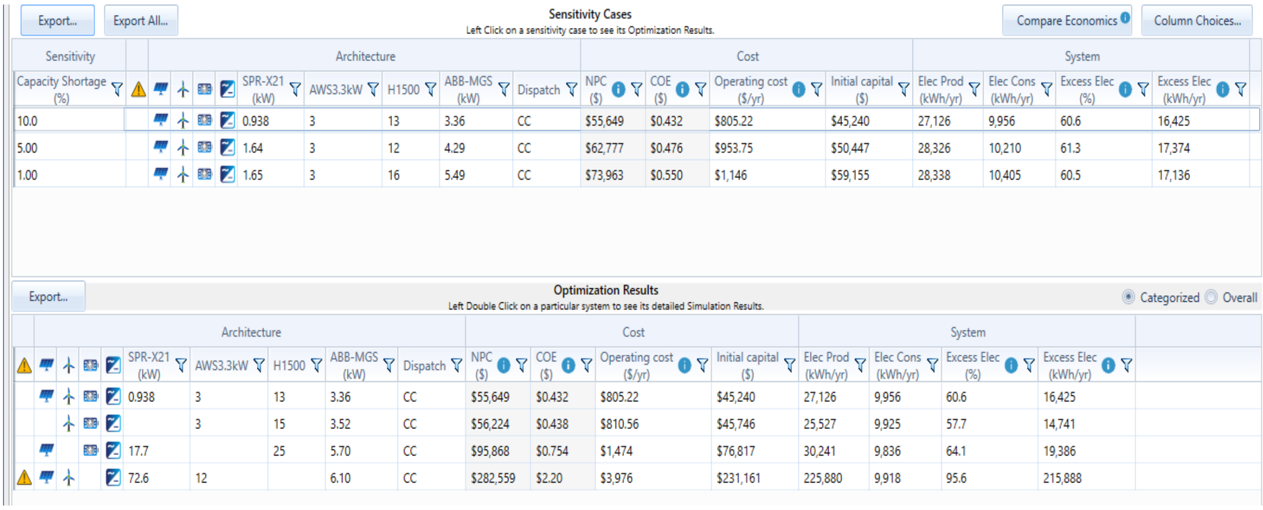


Fig.7.The structure of a stand-alone system for the community

and Sensitivity analysis was conducted considering capacity shortages of 1%, 5%, and 10%. These results are organized in ascending order based on NPC (Net Present Cost) and COE (Cost of Energy). The categorization Figure 8 displays the most cost-effective configurations of all component designs, while the complete optimization results encompass all NPC based system configurations that are financially viable. Among the configurations evaluated, the PV/Wind Turbine/Battery combination (Case I) emerges as the most cost-effective option.



Sensitivity Cases
Left Click on a sensitivity case to see its Optimization Results.

| Sensitivity | Architecture | | | | | Cost | | | | System | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacity Shortage (%) | SPR-X21 (kW) | AWS3.3kW | H1500 | ABB-MGS (kW) | Dispatch | NPC ($) | COE ($) | Operating cost ($/yr) | Initial capital ($) | Elec Prod (kWh/yr) | Elec Cons (kWh/yr) | Excess Elec (%) | Excess Elec (kWh/yr) |
| 10.0 | 0.938 | 3 | 13 | 3.36 | CC | $55,649 | $0.432 | $805.22 | $45,240 | 27,126 | 9,956 | 60.6 | 16,425 |
| 5.00 | 1.64 | 3 | 12 | 4.29 | CC | $62,777 | $0.476 | $953.75 | $50,447 | 28,326 | 10,210 | 61.3 | 17,374 |
| 1.00 | 1.65 | 3 | 16 | 5.49 | CC | $73,963 | $0.550 | $1,146 | $59,155 | 28,338 | 10,405 | 60.5 | 17,136 |

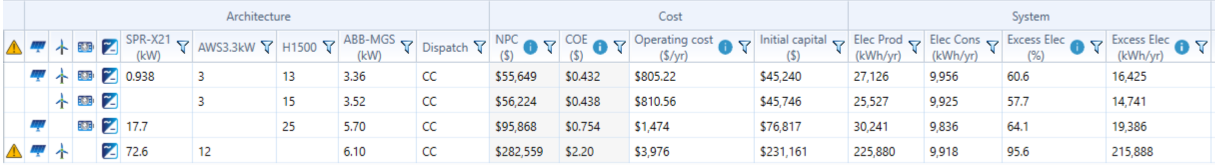
Optimization Results
Left Double Click on a particular system to see its detailed Simulation Results.

| Architecture | | | | | | Cost | | | | System | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ⚠ | SPR-X21 (kW) | AWS3.3kW | H1500 | ABB-MGS (kW) | Dispatch | NPC ($) | COE ($) | Operating cost ($/yr) | Initial capital ($) | Elec Prod (kWh/yr) | Elec Cons (kWh/yr) | Excess Elec (%) | Excess Elec (kWh/yr) |
| | 0.938 | 3 | 13 | 3.36 | CC | $55,649 | $0.432 | $805.22 | $45,240 | 27,126 | 9,956 | 60.6 | 16,425 |
| | | 3 | 15 | 3.52 | CC | $56,224 | $0.438 | $810.56 | $45,746 | 25,527 | 9,925 | 57.7 | 14,741 |
| | 17.7 | | 25 | 5.70 | CC | $95,868 | $0.754 | $1,474 | $76,817 | 30,241 | 9,836 | 64.1 | 19,386 |
| ⚠ | 72.6 | 12 | | 6.10 | CC | $282,559 | $2.20 | $3,976 | $231,161 | 225,880 | 9,918 | 95.6 | 215,888 |

Fig. 8. Sensitivity cases optimization results

Since the loads are concentrated in the fall, winter and spring seasons, while they are almost non-existent in the summer as in Fig 2, while solar radiation is concentrated in the summer and wind speed increases with the fall and winter seasons, and since the system is not connected to the public grid to benefit from the surplus generation during periods of no loads (since the school loads are only in the morning), and by choosing a relatively small wind turbine, which facilitates the process of generalizing the idea to the rest of the schools, we find that the best economic scenarios will depend more on wind energy than solar energy, as was the case in[21].

In the first scenario, which involves a 10% energy deficiency, the optimal solution consists of using 0.938 kW solar energy, the ideal solution has three of 3.3 kW wind turbines, 13 batteries of 1500 Ah , and a 3.36 kW converter. This system outperforms alternatives such as relying solely on a wind farm or solar power, as the following Figure shows.

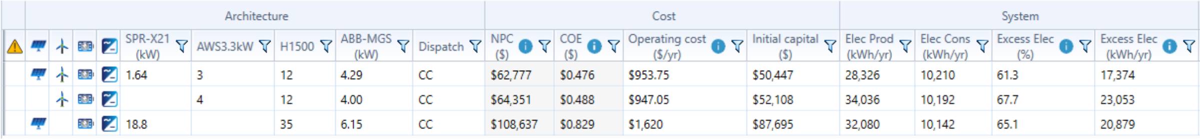


| Architecture | | | | | | Cost | | | | System | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ⚠ | SPR-X21 (kW) | AWS3.3kW | H1500 | ABB-MGS (kW) | Dispatch | NPC ($) | COE ($) | Operating cost ($/yr) | Initial capital ($) | Elec Prod (kWh/yr) | Elec Cons (kWh/yr) | Excess Elec (%) | Excess Elec (kWh/yr) |
| | 0.938 | 3 | 13 | 3.36 | CC | $55,649 | $0.432 | $805.22 | $45,240 | 27,126 | 9,956 | 60.6 | 16,425 |
| | | 3 | 15 | 3.52 | CC | $56,224 | $0.438 | $810.56 | $45,746 | 25,527 | 9,925 | 57.7 | 14,741 |
| | 17.7 | | 25 | 5.70 | CC | $95,868 | $0.754 | $1,474 | $76,817 | 30,241 | 9,836 | 64.1 | 19,386 |
| ⚠ | 72.6 | 12 | | 6.10 | CC | $282,559 | $2.20 | $3,976 | $231,161 | 225,880 | 9,918 | 95.6 | 215,888 |

Fig.9. Sensitivity first scenario

options underscores the significance of this scenario's superiority over other choisse in terms of NPC, COE, and Initial Capital, as confirmed through numerical comparisons.

In the second scenario, which features a 5% energy shortage rate, the optimal solution involves utilizing 1.46 kW of solar energy, three of 3.3 kW wind turbines, 12 batteries rated at 1500 Ah, and a 4.29 kW converter. This configuration shows superior to alternative options, such as relying solely on a wind farm or solar energy, as illustrated in the following Figure.

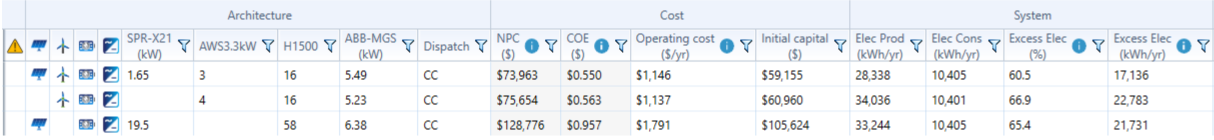


| | | | | | Architecture | | | | | Cost | | | | System | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ⚠ | | | | | SPR-X21 (kW) | AWS3.3kW | H1500 | ABB-MGS (kW) | Dispatch | NPC ($) | COE ($) | Operating cost ($/yr) | Initial capital ($) | Elec Prod (kWh/yr) | Elec Cons (kWh/yr) | Excess Elec (%) | Excess Elec (kWh/yr) |
| | ● | ● | ● | ● | 1.64 | 3 | 12 | 4.29 | CC | $62,777 | $0.476 | $953.75 | $50,447 | 28,326 | 10,210 | 61.3 | 17,374 |
| | | ● | ● | ● | | 4 | 12 | 4.00 | CC | $64,351 | $0.488 | $947.05 | $52,108 | 34,036 | 10,192 | 67.7 | 23,053 |
| | ● | | ● | ● | 18.8 | | 35 | 6.15 | CC | $108,637 | $0.829 | $1,620 | $87,695 | 32,080 | 10,142 | 65.1 | 20,879 |

Fig.10. Sensitivity second scenario

It is noted that this scenario surpasses Wind NPC, NPC, and Initial Capital, as demonstrated by a comparison of numerical values among the three scenarios, with the first scenario being the most economical.

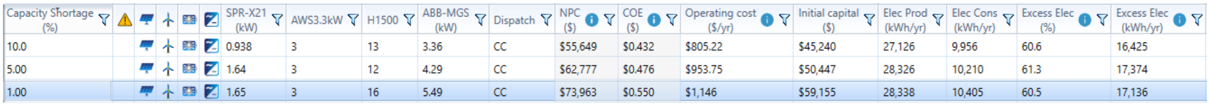
The third scenario, which features a 1% energy shortage rate, indicates that the optimal solution involves using 1.56 kW of photovoltaic (PV) energy, three 3.3 kW wind turbines, 16 batteries rated at 1500 Ah each, and a 5.49 kW converter. This configuration proves superior to other alternatives, such as relying solely on wind turbines or solar energy, as illustrated in the accompanying Figure 11.



| | | | | | Architecture | | | | | Cost | | | | System | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ⚠ | | | | | SPR-X21 (kW) | AWS3.3kW | H1500 | ABB-MGS (kW) | Dispatch | NPC ($) | COE ($) | Operating cost ($/yr) | Initial capital ($) | Elec Prod (kWh/yr) | Elec Cons (kWh/yr) | Excess Elec (%) | Excess Elec (kWh/yr) |
| | ● | ● | ● | ● | 1.65 | 3 | 16 | 5.49 | CC | $73,963 | $0.550 | $1,146 | $59,155 | 28,338 | 10,405 | 60.5 | 17,136 |
| | | ● | ● | ● | | 4 | 16 | 5.23 | CC | $75,654 | $0.563 | $1,137 | $60,960 | 34,036 | 10,401 | 66.9 | 22,783 |
| | ● | | ● | ● | 19.5 | | 58 | 6.38 | CC | $128,776 | $0.957 | $1,791 | $105,624 | 33,244 | 10,405 | 65.4 | 21,731 |

Fig.11. Sensitivity third scenario

It is observed that this scenario outperforms of other choise in terms of NPC, COE, and Initial Capital, as illustrated by a numerical comparison among the three scenarios, with the first scenario being the most cost-effective. Therfore, When comparing the best scenario among the three scenarios.



| Capacity Shortage (%) | ⚠ | | | | | SPR-X21 (kW) | AWS3.3kW | H1500 | ABB-MGS (kW) | Dispatch | NPC ($) | COE ($) | Operating cost ($/yr) | Initial capital ($) | Elec Prod (kWh/yr) | Elec Cons (kWh/yr) | Excess Elec (%) | Excess Elec (kWh/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.0 | | ● | ● | ● | ● | 0.938 | 3 | 13 | 3.36 | CC | $55,649 | $0.432 | $805.22 | $45,240 | 27,126 | 9,956 | 60.6 | 16,425 |
| 5.00 | | ● | ● | ● | ● | 1.64 | 3 | 12 | 4.29 | CC | $62,777 | $0.476 | $953.75 | $50,447 | 28,326 | 10,210 | 61.3 | 17,374 |
| 1.00 | | ● | ● | ● | ● | 1.65 | 3 | 16 | 5.49 | CC | $73,963 | $0.550 | $1,146 | $59,155 | 28,338 | 10,405 | 60.5 | 17,136 |

Fig.12. comparing the three scenarios

When comparing the three scenarios, the optimal choice is the option with a 10% energy deficit rate, which proves superior for economic productivity. This is evident when examining the data in Figure 12, where Option No. 1 incurred a total cost of approximately $55,649, compared to $627,770 and $73,963 for the second and third options, respectively. The lowest cost per kilowatt-hour was $0.432 for the first option, versus $0.476 and $0.550 for the other two options as [4].

For Option No. 1, the initial project cost was $45,240, while it was $50,447 and $59,155 for the second and third options, respectively. The optimal scenario with a 10% energy deficit produces around 27,126 kilowatt-hours annually and provides a surplus electrical production of 60%, equalling approximately 16,425 kilowatt-hours annually. This scenario also reduces carbon dioxide emissions (CO2) by 25,093 kg [2],[22]. If this approach were applied to primary education schools across Libya, it could potentially decrease the load on the General Electricity Company by about 49.684 GWh per year and reduce annual carbon dioxide emissions by approximately 119,819 tons, assuming complete conversion to renewable energies in these schools as [9].

## 8.0 CONCLUSION

The hybrid system offers a cost-effective solution for rural electrification in Gharyan city, Libya. Various system configurations combining PV, wind turbine (WT), battery storage, were evaluated during the modelling phase to identify the most suitable and economical options, while considering the environmental impacts of each design. According to the study results, the most cost-effective approach involves a PV/battery system with a capacity shortage is 10% of 25,527 Kwh/year electric load and peak load at 7.79 Kw, 13 battery cells, and a 6.57 kW converter, cost of energy (COE) of 0.432$ /kWh, a net present cost (NPC) of 55649 $, and an initial capital cost of 45240$, effectively reducing the mission of Co2 gas in the atmosphere by about 25,093 kg per year. Wind energy contributes 90.1% annually, while solar energy provides 9.92%. The system is expected to have an excess electricity of 60.5%.

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