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*RESEARCH ARTICLE - ENGINEERING*

# A HOMER-Aided Study for PV System Design and Cost Analysis for a College Campus in Baghdad

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**Abstract**

Due to the lack of electric power generation in Iraq and as a step forward to adopting a sustainable campus of the Electrical Engineering Technical College (EETC), Middle Technical University, in Baghdad, Iraq, and the critical demand for energy in our institutions, particularly educational institutions, this pilot study was proposed. The study aims to analyze the adoption of PV solar systems on the campus in the presence and absence of grid power and how that affects our design discussion in the matter of Net Present Cost (NPC), Cost of Energy (COE), Operation Cost, initial cost, power production, fuel consumption, and the annual net consumed energy from the grid. Forty-five different scenarios were analyzed for all possible cases. The existence of backup generators on the campus was also taken into consideration; G1-350kVA and G2-500kVA. The study has two stages. In the first stage, they used a walkthrough energy audit in the (EETC) to estimate the load profile of the campus, while in the second stage, they used HOMER Pro to analyze this data. The results show that adding an on-grid PV system to the campus grid can reduce the COE by 58%, and it is the best scenario when the grid is present, with an NPC, operation cost ($/yr), and initial capital ($) equal to $77,680, $1,460, and $59,018 respectively. When the grid was absent, the winning scenario was using a PV solar system with a 100-kWh lithium battery storage and a converter. Despite that scenario being the best solution, the produced energy cost is 372% higher than the grid energy cost (0.1 $/kWh) in Iraq, with an NPC, operation cost ($/yr.), and initial capital ($) equal to $337,291, $7,855, and 236878 respectively. Finally, both winning scenarios have no generator, and this will have a high impact on the campus environment.



Publisher: Middle Technical University

**Keywords**: Pilot Study; Hybrid System; Near Zero Energy Building; Lithium Storage Capacities; College Campus.

## 1. Introduction

There is no doubt that electrical power is a crucial requirement in all fields of life. Meanwhile, in the education sector electricity is mandatory due to its impact on developing countries. Unfortunately, Iraq lacks the produced electrical energy, and the power grid is unreliable, unstable, and scheduled. In the EETC and many other college campuses in Iraq and the world, many studies have been accomplished to adopt alternative sources of energy. In the same matter using a diesel generator as a backup power source is considered costly, noisy, and not environmentally friendly.

Scientists optimized that the most cost-effective arrangement consisted of solar cells and a battery energy storage device [1]. Technological viability of a diesel/PV/storage hybrid system for the Taiwanese island of Pratas using the HOMER program Different capital costs, fuel economy, COE, and NPC limitations are used to examine each power supply system [2]. HOMER Software is also used to identify the best hybrid renewable system and the lowest energy cost (COE) with the least NPC, along with reducing carbon emissions. The sensitivity analysis of the recommended system along with the energy scheme based on the renewable energy system [3].

In terms of renewable energy, the system is planned by the site's wind potential, solar radiation, and temperature; the study of the load profile throughout the year; system capacity; and the ability to draw power from the grid as necessary [4-6]. The design of an optimal standalone power supply system for a small, remote off-grid village in Western Australia is the main topic of this study. Different systems are taken into consideration to increase the cost of power supply and offer the most cost-effective solution for this town. With the help of HOMER software, data on various energy storage techniques, including a hybrid system to a diesel-generator-based alternative, wind generators, photovoltaic

| **Nomenclature & Symbols** | | | |
|---|---|---|---|
| HOMER-Pro | Hybrid Optimization Model for Electrical Regeneration | COE | Cost-of-Energy |
| NASA | National Aeronautics and Space Administration | NPC | Net Present Cost |
| NREL | National Renewable Energy Laboratory | HRES | Hybrid Renewable Energy Source |
| EETC | Electrical Engineering Technical College | CWEA | Campus Walkthrough Energy Audit |
| ξ | The Enhancement Percentage | | |

systems, and batteries, are analyzed [7]. In the work of [8], Homer Pro and PVsyst software have been used to analyze the performance of solar photovoltaic systems. For hybrid renewable energy systems, Homer Pro provides an economic and sensitivity analysis. Rooftop on-grid systems have been examined using simulation in [9].

Similarly, in [10], the benefits of HOMER for the economic analysis of a designed system have been discussed. The system shows the economic viability of the designed system concerning the available resources and the type of load assumed. A hybrid power system uses backup batteries and diesel generators with quick responses as it faces reliability and stability issues due to the intermittent nature of renewable energy sources. The power system must be sustainable at all costs to support the required load. Hybrid system modeling involves multiple approaches, such as programmable algorithms and compact software tools to design stand-alone or grid-connected systems with real-time data [11]. HOMER Pro software is a popular tool for energy planning and optimization [12]. HOMER Pro's main types of analysis are simulation, optimization, and sensitivity analysis [13].

However, renewable energy sources are many, and their availabilities vary based on site to site. In Iraq wind is speed enough and its direction is not seasonally fixed. But Iraq has very efficient sun radiation that can use to produce energy economically. ON-grid is a very economical solution due to its low cost; no backup energy storage is required, and it can solve a huge problem, but as we mentioned before the grid is unstable and it is difficult to synchronize the inverter when the grid is shut down. We attempt to synchronize it with the generator, but it was not an easy task due to many technical difficulties, one of which is that the used generator on the campus cannot be remotely controlled.

This article adopts a pilot study to compare using the hybrid solar system with; two backup lithium battery storage (100kWh &1MWh), the two existing diesel generators (350 kVA & 500 kVA), and a PV Solar system (Schneider Electric 540). They are sensitivity analysis, optimization, and simulation. Numerous power combinations, including those involving generators, utility loads, PV arrays, and battery backup. Estimates the cost of the power system under consideration across its entire life cycle. The viability of the power system is determined by its cost, which covers installation and operation.

This study aims to analyze the adoption of PV solar systems on the campus in the presence and absence of grid power, and how that affects our design discussion, in the matter of Net Present Cost (NPC), Cost of Energy (COE), Operation Cost, initial cost, power production, fuel consumption, and the annual net consumed energy from the grid. Forty-five different scenarios were analyzed for all possible cases. The existence of backup generators on the campus was also taken into consideration, G1-360kVA and G2-500kVA. In the first stage of this study, we adopt a walkthrough energy audit in the (EETC), to estimate the load profile of the campus, while in the second stage, we used HOMER Pro to analyze these data.

The rest of this article includes section 1, which presents a brief about HOMER Pro software, while section 2 shows the adopted methodology. In section 3 the results that show initial cost, COE, and NPC are presented. Moreover, the last section includes the article's conclusion.

## 2. HOMER in Brief

HOMER software makes it easier to construct renewable energy sources, and distributed generation systems for a variety of applications, in both ON-grid and OFF-grid. The system's configuration is based on what elements should be included in the system design, and the used quantities and sizes of each component. Evaluation of the numerous potential system configurations is facilitated by HOMER's optimization and sensitivity analysis techniques.

- Fundamental abilities (Simulation, Optimization, Sensitivity Analysis).
- Simulation: HOMER is fundamentally a simulation model. HOMER simulates the operation of a system by making energy balance calculations at each time step (interval) of the year. HOMER determines whether a configuration is feasible and estimates the cost of installing and operating the system over the lifetime of the project. When figuring out how much a system costs, costs like capital, replacement, operation and maintenance, fuel, and interest are taken into account.
- Optimization: There are two optimization algorithms in HOMER Pro. All of the feasible system configurations specified by the search space are simulated by the original grid search algorithm. The new HOMER Optimizer looks for the least expensive system using a unique, derivative-free algorithm. Following that, HOMER presents a list of configurations that you can use to contrast different system design options, sorted by net present cost (also known as life-cycle cost).
- Sensitivity analysis: When you define sensitivity variables as inputs, HOMER performs the optimization procedure for every one of those variables. With the help of this optional phase, you may model the impacts of variables that are beyond your control, such as wind speed, fuel costs, etc., and observe how the ideal system changes as a consequence. Steps in the use of HOMER Software shows in Fig. 1.

## 3. Methodology

Based on the proposed methodology presented in the flowchart, see Fig. 2, which shows the strategy adopted in the article methodology in steps. In the first step, we did a campus walkthrough energy audit. In this audit, we survey all the campus buildings for consumed energy, building area, roof area, load profile, energy loss, heated and cooling area, and more. Eight existing buildings are surveyed as well as presented in the next subsection. The total campus load profile will be generated in the second step. This campus load profile is mandatory for the next step where we will use it for our design.

In step three, project location, resources, local weather, and sensitive analysis values input will be gathered, as well as the adopted components like generators, PV, batteries, and converters. These adopted components are selected based on the selected site and the expectation of effective renewable energy sources. The budget is very important and will be analyzed in the next step. The last step is to simulate all these data in HOMER Pro software to get data analysis and discussion to calculate the initial cost, NPC, and COE. Unfortunately, the power grid in Iraq is unreliable and not stable. For that reason, we adopt two tracks here. In the first track, we will analyze the system with the presence of grid power, while in the second track, we will consider the absence of grid power. In the next subsection, we will explain all our input data and components.

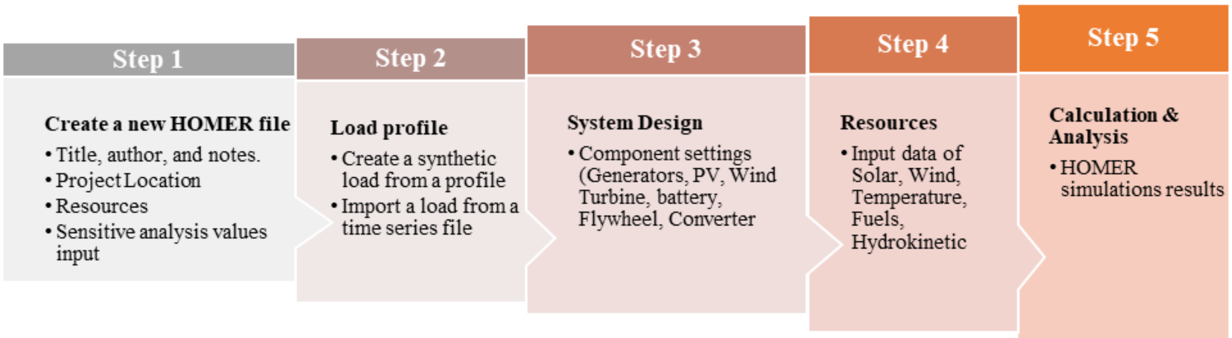



Fig. 1. Steps Homer Software

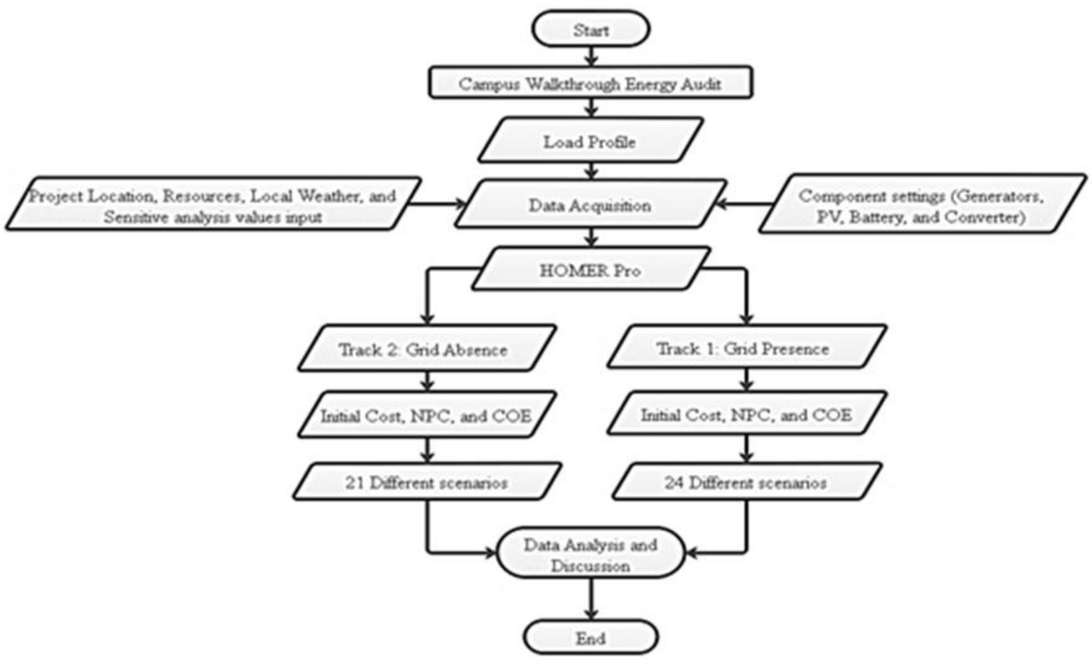



Fig. 2. Methodology Flowchart

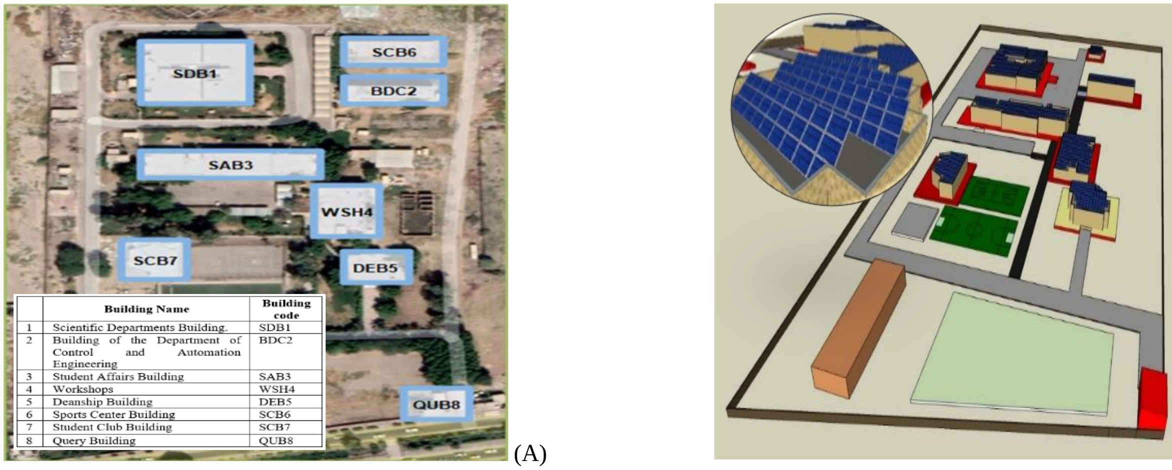
*3.1. Campus walkthrough energy audit (CWEA)*

EECT is one of the sixteen college campuses belonging to the MTU in Iraq. It is in Baghdad, Dora District at 33°15.5'N and 44°23.8'E. The CWEA was included for all the main buildings on the campus, as shown in Fig. 3a. Then the campus was drawn using Sketch-up software, as shown in Fig. 3b. This audit included the following:

- Measuring the consumed energy by each building.
- Identify the load types as heating, cooling, lighting, office, and other load types.
- I point out the main energy losses in each building and how to reduce them.
- Measure the total building area, the occupied area, and the roof area.
- Identify the main sunlight obstacles and the possible areas to install the PV panels.
- Identify the possible location of the inverters and the distribution of the PV panels.

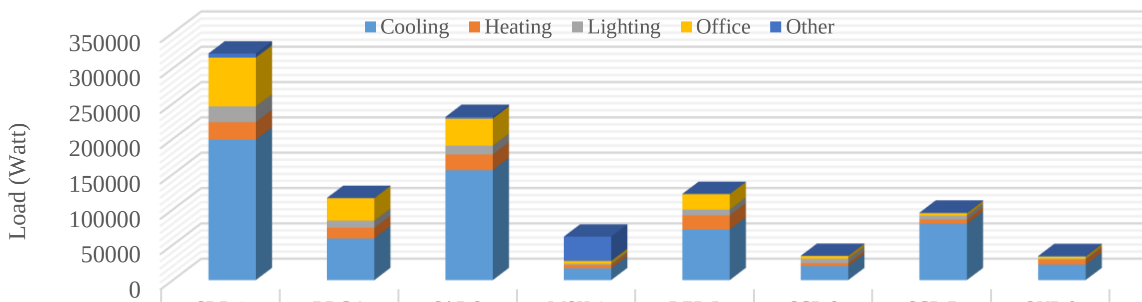
*3.2. Load profile results*

As a result of the CWEA, the loads' detailed information based on the load types is shown in Fig. 4. According to this study's findings, the audit shows that cooling energy is the most consumed and is equal to 66% of the annual total load. While the second highest load is office appliances, which is equal to 15%, followed by heating equal to 9%, then lighting equal to 6%, and the other appliances, which include all the laboratory equipment, is equal to 4%, (see Fig. 5).



(A) (B)

Fig. 3. Location of the study area A) Campus Layout, and B) Sketch-up Drawing




| | SDB 1 | BDC 2 | SAB 3 | WSH 4 | DEB 5 | SCB 6 | SCB 7 | QUB 8 |
|---|---|---|---|---|---|---|---|---|
| Other | 5740 | 370 | 2370 | 34490 | 370 | 370 | 740 | 740 |
| Office | 69090 | 31760 | 38315 | 3820 | 21825 | 3760 | 3590 | 3100 |
| Lighting | 22220 | 10230 | 12485 | 1760 | 8195 | 6380 | 5390 | 1430 |
| Heating | 25000 | 15000 | 22000 | 5000 | 20000 | 4000 | 6000 | 7000 |
| Cooling | 198800 | 59000 | 155900 | 16500 | 71700 | 20000 | 79800 | 21900 |

Fig. 4. Loads Estimation for Different Campus Buildings [14]

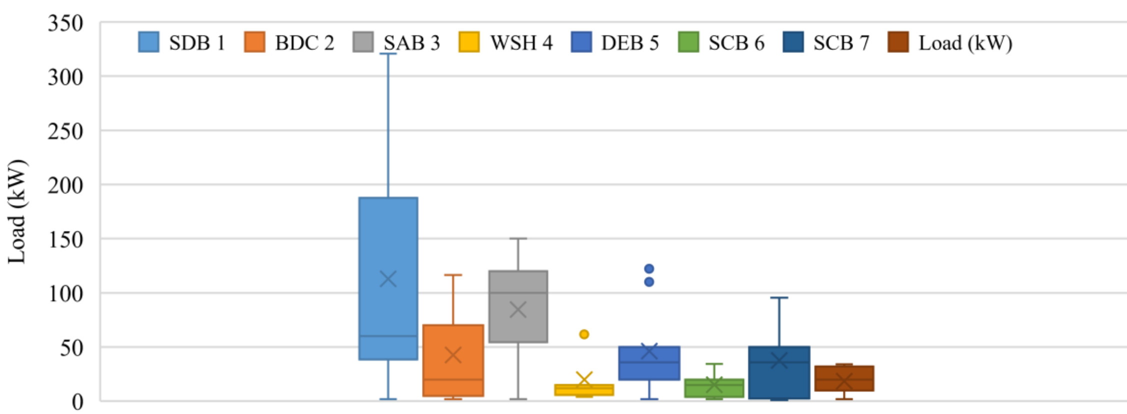



Fig. 5. Annual Loads Estimation for Different Campus Buildings

*3.3. Site Weather Conditions*

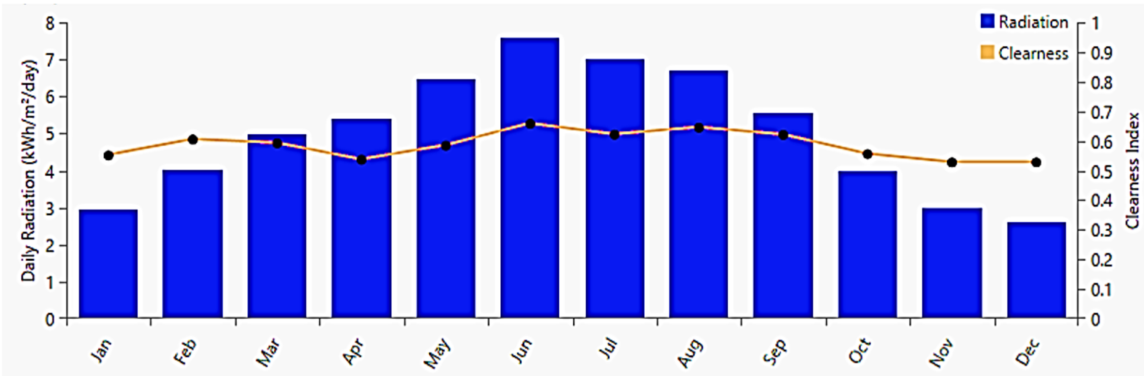
In this section, we will describe the two main weather conditions that affect the performance of the PV system: the Solar GHI Resource and the temperature.

3.3.1. Solar GHI Resource

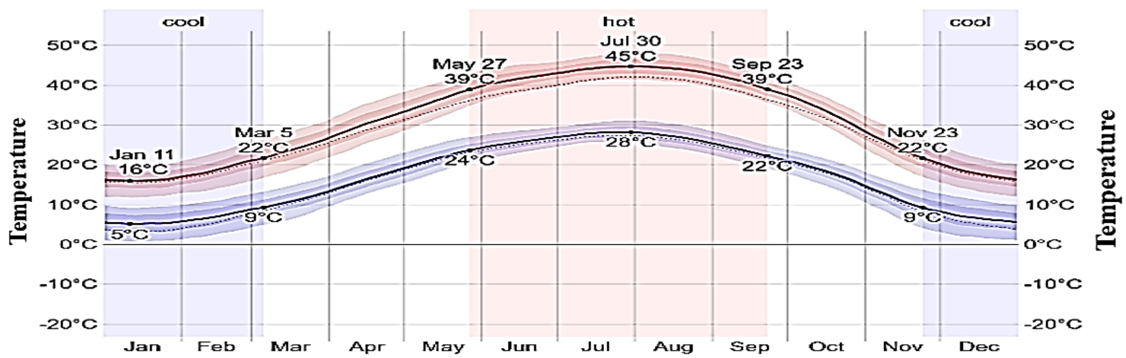
The average monthly values of solar energy data in the EETC are shown in Fig. 6. A., the minimum solar radiation reaches 2.62 kWh/m²/day in December, while the maximum solar radiation reaches 7.65 kWh/m²/day, and 7 kWh/m²/day in June and July. An annual average scale of 5.02 kWh/m$^2$/day is considered permissive.

3.3.2. Temperature Resource:

The site temperature in Fig. 6. B shows that the minimum temperature is less than 5 °C in winter (December and January), while more than 45 °C in summer (June, July, and August). According to the presented temperature data, the environment is harsh and not PV-friendly in the summertime, but most of that time is a vacation period for students and academics.




(A)




(B)

Fig. 6. (A) Solar GHI Resource Data and Graph, (B) Monthly Average Temperature Data [15]

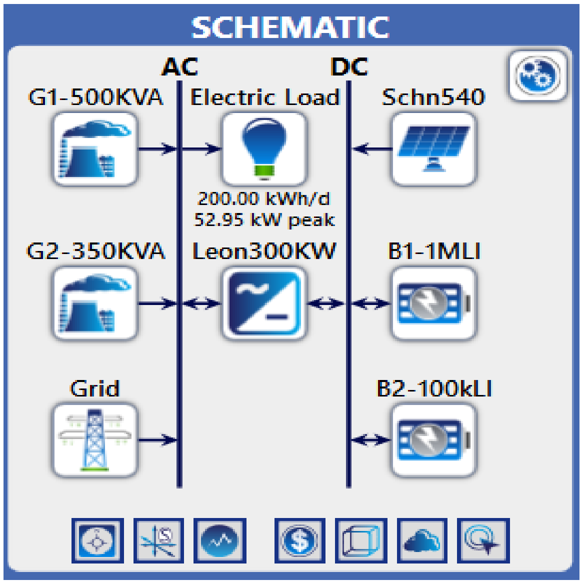
*3.4. Project Component Setting*

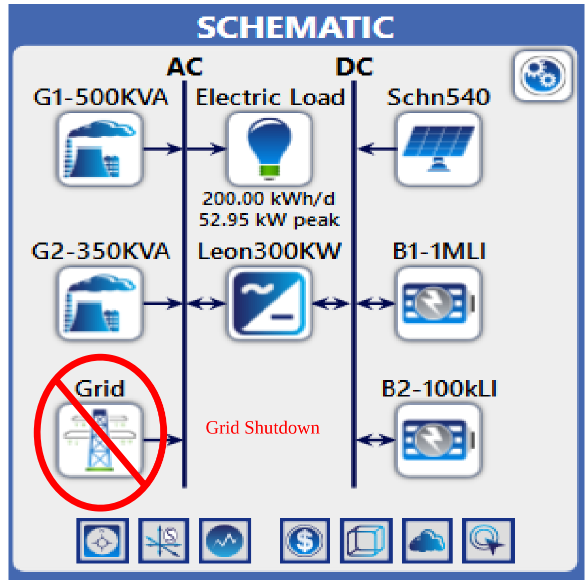
The components of both two proposed hybrid solar systems are shown in Fig. 7 A and B. The systems are grid-tied, with backup generators and lithium batteries. Configuring the system after choosing the mentioned components, their initial cost, operation and maintenance cost, replacement cost, and the lifetime of each component below is a brief description of these components:

- Diesel Generators: Currently, there are two diesel generators. The first generator, G1, is a Caterpillar-Model DE550E0 with a capacity of 500kVA, and the second generator, G2, is a Perkins-Model 2300Series with a capacity of 350kVA. Both generators are not able to handle the total peak load in the summertime in the period of the final exam of the summer semester, and usually, the operator has to disconnect some loads. G1 has an initial cost of $56,000.00, replacement costs of $56,000.00, and an operating life of 90,000 hours. While G2's initial cost is $45,000.00, replacement costs are $45,000.00, and operating life is 15,000 hrs. Finally, the diesel cost per liter is assumed to be (0.5 $/L).
- Solar PV Panels: Schneider ConextCoreXC 540kWp with Generic PV, whose estimated lifetime is 25 years, is the model chosen from the HOMER library. It is estimated that the installation will cost $900.00 per kW according to local market prices, which cover the cost of the panel, the wiring, and the mounting hardware.
- Converter: The Leonics MTP-4117H 300KW Converter has a capital and replacement cost of $600/kW. Its efficiency is around 96%, and its lifetime is approximately 10 years.
- Battery system: Two types of battery capacity have been chosen from the HOMER library. The first type is a generic (100kWh Li-Ion) model, which has a 90% efficiency. Initial costs are estimated at $70,000 per set. The second type is a generic (1MWh Li-Ion) with a 90% efficiency. The initial price is estimated to be $700,000.00 per set.
- Grid System: When there are limited renewable energy resources to support the system and meet load demand, the grid system is used; the cost is set at $0.10 per kWh.

**4. Results and Discussion**

As shown in Fig. 7. A. all of the data in this section of the article was entered into HOMER PRO. Two AC and DC buses are connected to the AC and DC components. On the AC bus, the two generators, the load, the grid, and the converter are connected. While on the DC bus, the PV panels and the two storage batteries are connected. In the first track test, we connect the smart grid with a net meter. The net meter was set to sell the energy as in Iraq at 0.1$/kWh and buy it at 0.8 $/kWh. Unfortunately, in Iraq, we have not used a smart meter yet, but the electricity ministry plans to use it soon. In the second track, we recalculate the same configuration but with the absence of a grid to calculate the COE, as shown in Fig. 7. B. The load profile was uploaded as a table to the HOMER Pro according to our audit report as shown in Fig. 8. The histogram in Fig. 9 represents the loads frequently appearing and it is produced by HOMER Pro, as is the monthly load profile in Fig. 10.




(A) (B)

Fig. 7. (A) ON-grid solar PV system with backup battery 100KWh, (B) ON-grid solar PV system with backup battery 1MWh

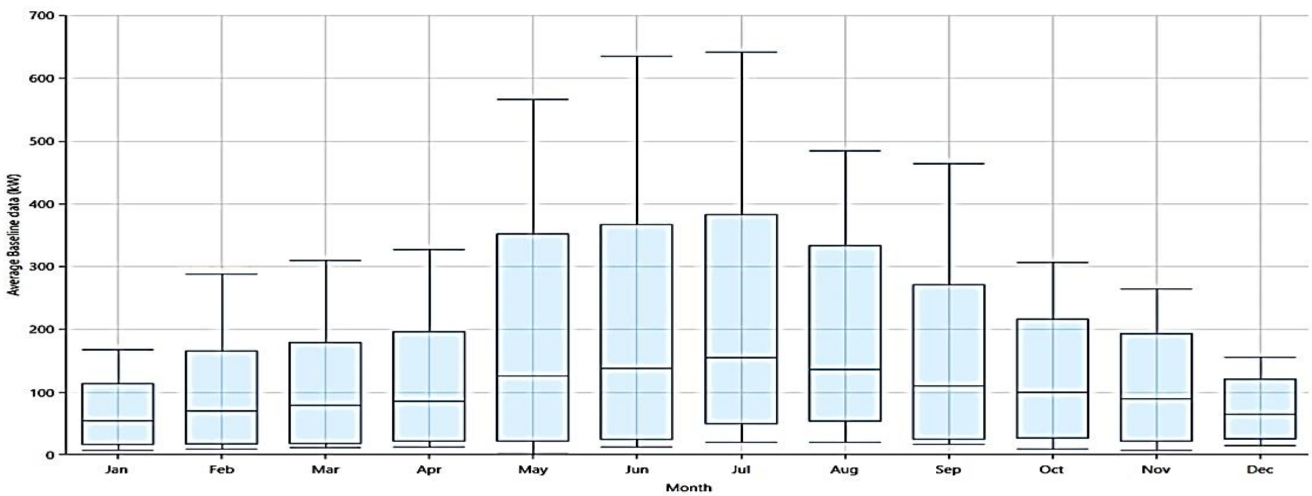



Fig. 8. Baseline data Monthly Averages

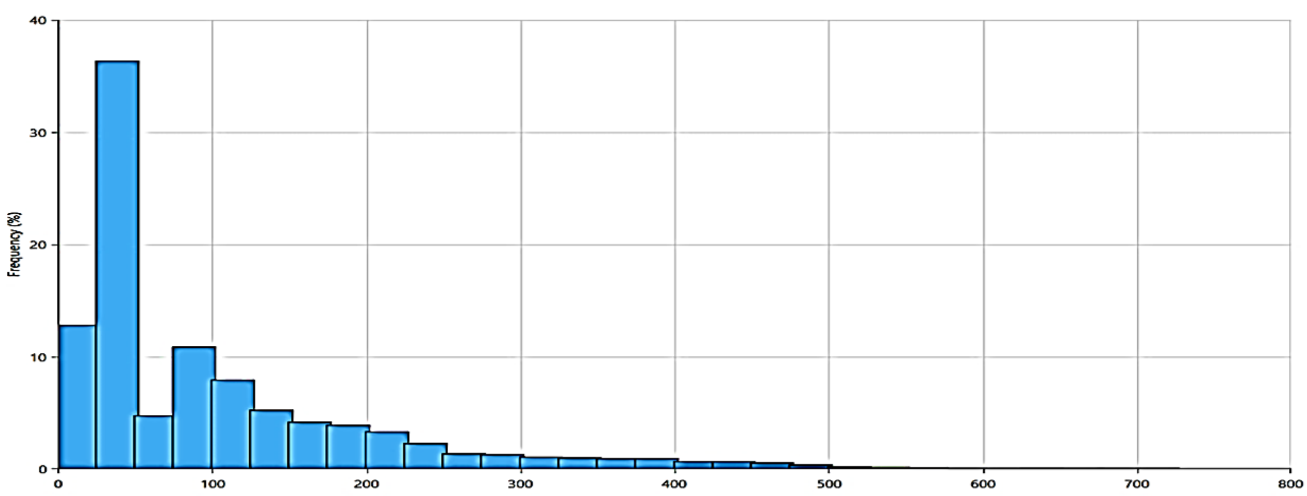



Fig. 9. Baseline data histogram

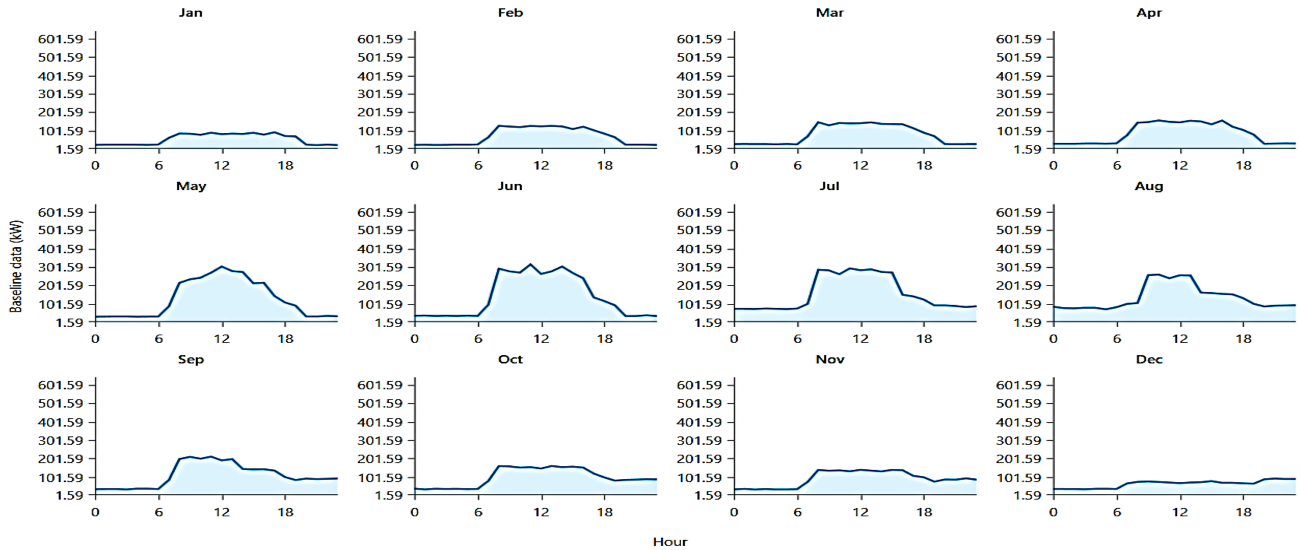



Fig. 10. Baseline Monthly Load Profile

### *4.1. Grid presence system analysis*

In this analysis, twenty-four different scenarios were adopted as listed in Table 1. In each scenario, HOMER calculates the NPC, COE, operation cost, and initial capital in USD. The produced energy and the consumed fuel by each generator are listed too. The data also presents the capital cost and the energy produced by the PV panels. Finally, in the matter of the grid, the results present the annual purchased, sold, and net energy. After listing the data for the lowest COE, the first scenario was the winner, as well as explained in detail.

- This scenario includes using PV panels, an on-grid converter, and a smart grid.
- In the matter of the COE, this scenario has only $0.058 which is 58% less than the grid power cost.
- It has the lowest NPC over 25 years, but its initial cost is only $59,018.
- The annual purchased energy (31802 kWh/year) is less than the sold energy (31777 kWh/year), which leads us toward near-zero energy building.
- Due to its high cost and impact on the environment, no generator is required in this scenario and all the others. But it will be present on the next track when the grid is absent.

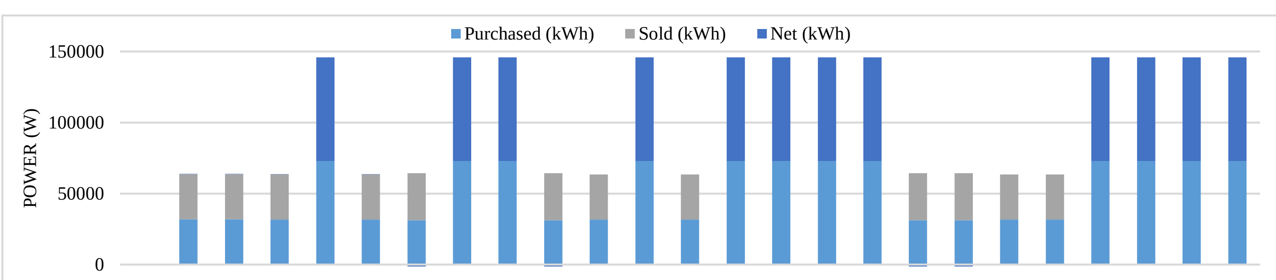
Moreover, Fig. 11. A shows the annual purchases, sold, and net energy. Many scenarios like S1, S2, S3, S5, S12, S19, and S20 show a near-zero net, but S1 has the lowest NPC and initial cost. Some scenarios show a negative net value, which means an income for the campus, but a high initial cost will be required. In Fig. 11. B, the COE, and NPC were shown. According to HOMER, the NPC is defined as: “The net present cost (or life-cycle cost) of a component is the present value of all the costs of installing and operating the component over the lifetime of the project, minus the present value of all the revenues that it earns over the lifetime of the project.”. Finally, in Fig. 11. C, the initial capital in $ and the operation cost in $/year were presented for all the scenarios.

Table 1. Grid Presence Results

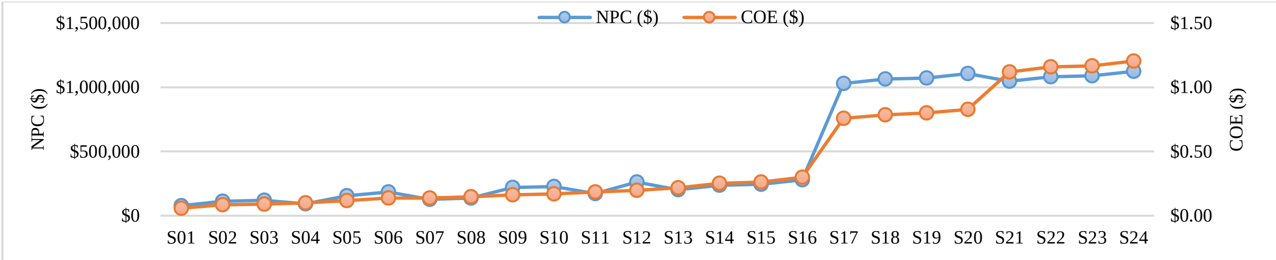
| Architecture | | | | | | | | Cost | | | | G1-500KVA | | G2-350KVA | | Schn 540 | | Grid Energy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S* | PV | G1 | G2 | B1 | B2 | G* | C* | NPC ($) | COE ($) | Oper. cost ($/yr) | Initial capital ($) | Prod.(kWh) | Fuel (L) | Prod.(kWh) | Fuel (L) | Capital Cost ($) | Prod. (kWh/yr) | Purchased (kWh) | Sold (kWh) | Net (kWh) |
| S01 | PV | | | | | G | C | $77,680 | $0.058 | $1,460 | $59,018 | | | | | 41305 | 81580 | 31802 | 31777 | 25 |
| S02 | PV | | G2 | | | G | C | $112,457 | $0.084 | $660 | $104,018 | | | 0 | 0 | 41305 | 81580 | 31802 | 31777 | 25 |
| S03 | PV | G1 | | | | G | C | $120,962 | $0.090 | $459 | $115,089 | 0 | 0 | | | 41532 | 82029 | 31756 | 31715 | 42 |
| S04 | | | | | | G | | $93,319 | $0.100 | $7,300 | $0 | | | | | | | 73000 | 0 | 73000 |
| S05 | PV | G1 | G2 | | | G | C | $155,739 | $0.116 | $340 | $160,089 | 0 | 0 | 0 | 0 | 41532 | 82029 | 31756 | 31715 | 42 |
| S06 | PV | | | | B2 | G | C | $184,300 | $0.136 | $4,207 | $130,517 | | | | | 42478 | 83897 | 31338 | 33096 | -1758 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S07 | | | G2 | | | G | | $128,096 | $0.137 | $6,500 | $45,000 | | | 0 | 0 | | | 73000 | 0 | 73000 |
| S08 | | G1 | | | | G | | $136,597 | $0.146 | $6,305 | $56,000 | 0 | 0 | | | | | 73000 | 0 | 73000 |
| S09 | PV | | G2 | | B2 | G | C | $219,077 | $0.162 | $3,408 | $175,517 | | | 0 | 0 | 42478 | 83897 | 31338 | 33096 | -1758 |
| S10 | PV | G1 | | | B2 | G | C | $227,561 | $0.170 | $3,298 | $185,408 | 0 | 0 | | | 42081 | 83113 | 31626 | 31742 | -116 |
| S11 | | G1 | G2 | | | G | | $171,374 | $0.184 | $5,505 | $101,000 | 0 | 0 | 0 | 0 | | | 73000 | 0 | 73000 |
| S12 | PV | G1 | G2 | | B2 | G | C | $262,325 | $0.196 | $2,504 | $230,314 | 0 | 0 | 0 | 0 | 41965 | 82884 | 31659 | 31698 | -39 |
| S13 | | | | | B2 | G | C | $201,628 | $0.216 | $10,219 | $71,000 | | | | | | | 73000 | 0 | 73000 |
| S14 | | | G2 | | B2 | G | C | $236,405 | $0.253 | $9,419 | $116,000 | | | 0 | 0 | | | 73000 | 0 | 73000 |
| S15 | | G1 | | | B2 | G | C | $244,906 | $0.262 | $9,223 | $127,000 | 0 | 0 | | | | | 73000 | 0 | 73000 |
| S16 | | G1 | G2 | | B2 | G | C | $279,683 | $0.300 | $8,424 | $172,000 | 0 | 0 | 0 | 0 | | | 73000 | 0 | 73000 |
| S17 | PV | | | B1 | | G | C | $1,028,247 | $0.758 | $20,944 | $760,517 | | | | | 42478 | 83897 | 31338 | 33096 | -1758 |
| S18 | PV | | G2 | B1 | | G | C | $1,063,025 | $0.784 | $20,144 | $805,517 | | | 0 | 0 | 42478 | 83897 | 31338 | 33096 | -1758 |
| S19 | PV | G1 | | B1 | | G | C | $1,071,508 | $0.800 | $20,034 | $815,408 | 0 | 0 | | | 42081 | 83113 | 31626 | 31742 | -116 |
| S20 | PV | G1 | G2 | B1 | | G | C | $1,106,272 | $0.827 | $19,241 | $860,314 | 0 | 0 | 0 | 0 | 41965 | 82884 | 31659 | 31698 | -39 |
| S21 | | | | B1 | | G | C | $1,045,575 | $1.120 | $26,955 | $701,000 | | | | | | | 73000 | 0 | 73000 |
| S22 | | | G2 | B1 | | G | C | $1,080,352 | $1.158 | $26,155 | $746,000 | | | 0 | 0 | | | 73000 | 0 | 73000 |
| S23 | | G1 | | B1 | | G | C | $1,088,853 | $1.167 | $25,960 | $757,000 | 0 | 0 | | | | | 73000 | 0 | 73000 |
| S24 | | G1 | G2 | B1 | | G | C | $1,123,630 | $1.204 | $25,160 | $802,000 | 0 | 0 | 0 | 0 | | | 73000 | 0 | 73000 |

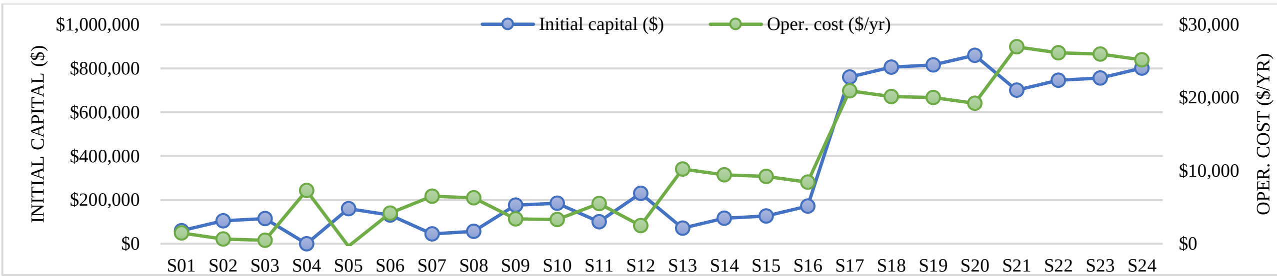
*Where S: Scenario, PV: Photovoltaic, G1: Generator 1, G2: Generator 2, G: Grid, and C: Converter*




(A)




(B)




(C)

Fig. 11. Grid presence Analysis

*4.2. Grid absent system analysis*

In this track, twenty-one scenarios were adopted in the absence of the grid, as shown in Table 2. Here we also calculate the NPC, COE, operation cost, and initial capital in USD. The produced energy and the consumed fuel by each generator are listed too. The data also presents the capital cost and the energy produced by the PV panels. Finally, on the matter of the grid, the results show that the annual purchases, sold, and net energy are zero due to the absence of the grid. After listing the data for the lowest COE, the first scenario was the winner, as well as explained in detail.

- This scenario includes using PV panels, a converter, and 100kWh of lithium battery storage.
- It has the lowest COE of $0.372, which is 641% higher than the cost in Track 1.
- In this scenario, no generator is used.
- As a comparison with the winner from track1, this scenario has a higher NPC, COE, operation cost, and initial capital as listed in Table 3.

Fig. 12. A and B show the produced energy by the generators and the fuel consumption for all the scenarios. The current fuel cost in Iraq is $0.66 for diesel on July 6, 2022. In Fig. 12. C, the PV-produced energy in kWh and its capital cost in USD are shown. In Fig. 12. D, NPC, and the COE in USD are shown, and finally, in Fig. 12. E, we present the initial capital and the operation cost.

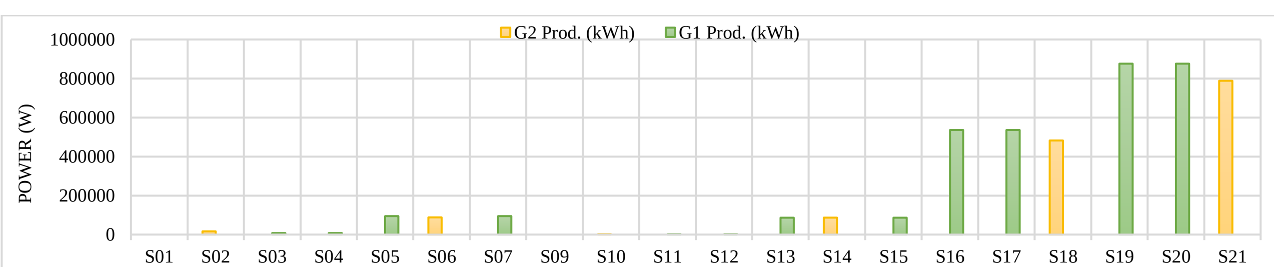
Table 2. Grid Absence Results

| Architecture | | | | | | | Cost | | | | G1-500KVA | | G2-350KVA | | Schn 540 | | Grid Energy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S* | PV | G1 | G2 | B1 | B2 | C* | NPC ($) | COE ($) | Oper. cost ($/yr) | Initial capital ($) | Prod. (kWh) | Fuel (L) | Prod. (kWh) | Fuel (L) | Capital Cost ($) | Prod. (kWh/yr) | Purchased (kWh) | Sold (kWh) | Net (kWh) |
| S01 | PV | | | | B2 | C | $337,291 | $0.372 | $7,855 | 236878 | | | | | 73042 | 144262 | 0 | 0 | 0 |
| S02 | PV | | G2 | | B2 | C | $397,236 | $0.426 | $12,664 | 235345 | | | 16560 | 5759 | 73161 | 144498 | 0 | 0 | 0 |
| S03 | PV | G1 | | | B2 | C | $418,773 | $0.449 | $9,607 | 295958 | 7600 | 2408 | | | 68532 | 135354 | 0 | 0 | 0 |
| S04 | PV | G1 | G2 | | B2 | C | $453,810 | $0.486 | $8,814 | 341132 | 7600 | 2408 | 0 | 0 | 68603 | 135495 | 0 | 0 | 0 |
| S05 | | G1 | | | B2 | C | $754,779 | $0.809 | $44,666 | 183800 | 94549 | 29854 | | | | | 0 | 0 | 0 |
| S06 | | | G2 | | B2 | C | $769,554 | $0.825 | $46,731 | 172173 | | | 88130 | 30317 | | | 0 | 0 | 0 |
| S07 | | G1 | G2 | | B2 | C | $789,556 | $0.846 | $43,866 | 228800 | 94549 | 29854 | 0 | 0 | | | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S09 | PV | | | B1 | C | $1,040,629 | $1.147 | $21,208 | 769521 | | | | | 50797 | 100327 | 0 | 0 | 0 |
| S10 | PV | | G2 | B1 | C | $1,106,637 | $1.186 | $21,648 | 829903 | | | 1628 | 566 | 55383 | 109386 | 0 | 0 | 0 |
| S11 | PV | G1 | | B1 | C | $1,114,577 | $1.194 | $21,367 | 841440 | 1500 | 475 | | | 55435 | 109488 | 0 | 0 | 0 |
| S12 | PV | G1 | G2 | B1 | C | $1,149,354 | $1.232 | $20,567 | 886440 | 1500 | 475 | 0 | 0 | 55435 | 109488 | 0 | 0 | 0 |
| S13 | | G1 | | B1 | C | $1,439,097 | $1.542 | $48,068 | 824624 | 86404 | 26558 | | | | | 0 | 0 | 0 |
| S14 | | | G2 | B1 | C | $1,460,815 | $1.565 | $49,783 | 824420 | | | 86802 | 27982 | | | 0 | 0 | 0 |
| S15 | | G1 | G2 | B1 | C | $1,473,874 | $1.579 | $47,269 | 869624 | 86404 | 26558 | 0 | 0 | | | 0 | 0 | 0 |
| S16 | PV | G1 | | | C | $2,665,512 | $2.856 | $172,305 | 462875 | 535900 | 169777 | | | 376875 | 744353 | 0 | 0 | 0 |
| S17 | PV | G1 | G2 | | C | $2,700,289 | $2.894 | $171,505 | 507875 | 535900 | 169777 | 0 | 0 | 376875 | 744353 | 0 | 0 | 0 |
| S18 | PV | | G2 | | C | $2,807,326 | $3.008 | $184,259 | 451875 | | | 482310 | 167737 | 376875 | 744353 | 0 | 0 | 0 |
| S19 | | G1 | | | | $3,557,586 | $3.812 | $273,918 | 56000 | 876000 | 277524 | | | | | 0 | 0 | 0 |
| S20 | | G1 | G2 | | | $3,592,364 | $3.850 | $273,118 | 101000 | 876000 | 277524 | 0 | 0 | | | 0 | 0 | 0 |
| S21 | | | G2 | | | $3,796,748 | $4.069 | $293,487 | 45000 | | | 788400 | 274188 | | | 0 | 0 | 0 |

Table 3. Comparison between Track 1 and Track 2

| | Specifications | Track$_{1W}$ | Track$_{2W}$ | ξ |
|---|---|---|---|---|
| Cost | NPC ($) | $77,680 | $337,291 | -334% |
| | CoE ($) | $0.058 | $0.372 | -541% |
| | Oper. cost ($/yr) | $1,460 | $7,855 | -438% |
| | Initial capital ($) | $59,018 | 236878 | -301% |
| G1-500KVA | Prod. (kWh) | NA | NA | NA |
| | Fuel (L) | NA | NA | NA |
| G2-350KVA | Prod. (kWh) | NA | NA | NA |
| | Fuel (L) | NA | NA | NA |
| Schn 540 | Capital Cost ($) | 41305 | 73042 | -77% |
| | Prod. (kWh/yr) | 81580 | 144262 | ↑77% |
| Grid Energy | Purchased (kWh) | 31802 | 0 | 100% |
| | Sold (kWh) | 31777 | 0 | 100% |
| | Net (kWh) | 25 | 0 | 100% |



(A)

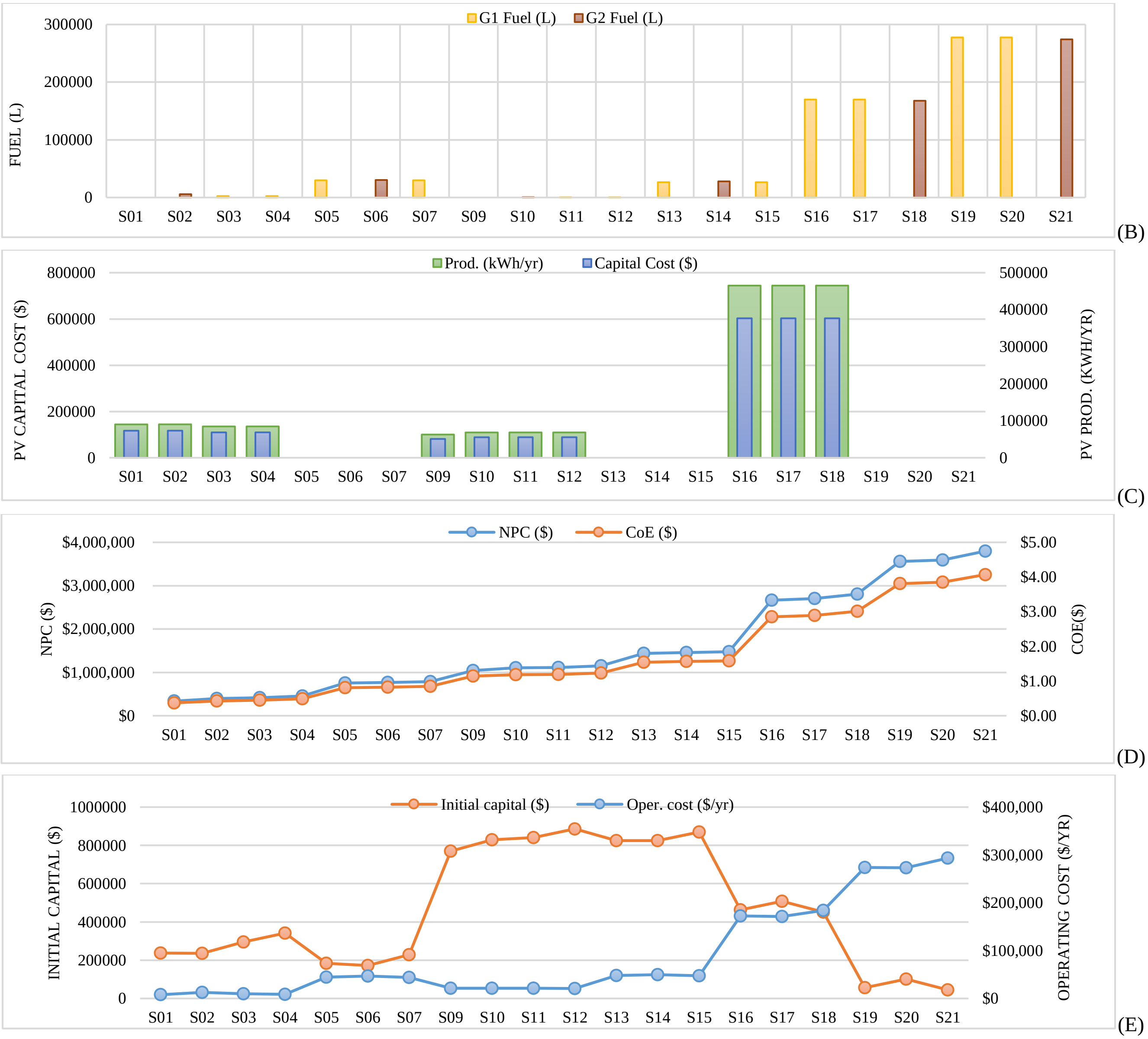



Fig. 12. Grid Absence Analysis, (A) Generators Power, (B) Generators Fuel Consumption, (C) the PV produced energy & their capital cost, (D) Net present cost & Cost of Energy, and (E) The initial capital and the operation cost

### *4.3. Grid Uncertainty Analysis*

A comparison has been made between the Winner scenarios (Track $_{1W}$ & Track $_{2W}$) from Track $_1$ & Track $_2$ as listed in in Track $_{1W}$.

- The initial capital in Track $_{2W}$ is 301% worse than in Track $_{1W}$.
- In both Track $_{1W}$ and Track $_{2W}$, no generators are used.
- All the Track2 scenarios had no grid, and this included Track $_{2W}$ which had no purchased energy from the grid as well as sold or net energy.
- PV Capital Cost in the Track $_{2W}$) is 77% worse than the Track $_{1W}$.
- PV power production in Track $_{2W}$ is 77% greater than in Track $_{1W}$.

To enhance the reliability of our power grid in Iraq, we will compare the winner scenarios from Track 1 and Track 2 for all the possibilities of the grid power absence. In this matter, we will consider adopting using grid annual availability from 0% up to 100% as in Table 4. Here it is required to consider the worst-case scenario where there is no grid, which led us to design based on data from Track 2. The results show that, while the grid availability varies from (0 -100%), the NPC is varied from \$77,680 to \$337,291, the CoE is varied from \$0.058 to \$0.372, the operation cost is varied from 1,460\$/yr to \$7,855 \$/yr. while the Initial capital is varied from \$59,018 to \$236,878. Normally the grid availability on the campus is varied from 40%-60, so we can consider that.

The comparison includes the percentage of enhancement between Track 1 & 2 if any. The Enhancement Percentage (ξ) is calculated based on (1):

$$\xi = \frac{\text{Track}_{1W} - \text{Track}_{2W}}{\text{Track}_{1W}} \times 100\% \quad (1)$$

We can conclude the results as the following:

- The NPC in Track $_{2W}$ is 334% worse than in Track $_{1W}$.
- The COE in Track $_{2W}$ is 541% worse than in Track $_{1W}$.
- The operation cost in Track $_{2W}$ is 438% worse than in Track $_{1W}$.
- The initial capital in Track $_{2W}$ is 301% worse than in Track $_{1W}$.
- In both Track $_{1W}$ and Track $_{2W,}$ no generators are used.
- All the Track$_2$ scenarios had no grid, and this included Track $_{2W}$ which had no purchased energy from the grid as well as sold or net energy.
- PV Capital Cost in the Track $_{2W}$) is 77% worse than the Track $_{1W}$.
- PV power production in Track $_{2W}$ is 77% greater than in Track $_{1W}$.

To enhance the reliability of our power grid in Iraq, we will compare the winner scenarios from Track 1 and Track 2 for all the possibilities of the grid power absence. In this matter, we will consider adopting using grid annual availability from 0% up to 100% as in Table 4. Here it is required to consider the worst-case scenario where there is no grid, which led us to design based on data from Track 2. The results show that, while the grid availability varies from (0 -100%), the NPC is varied from $77,680 to $337,291, the CoE is varied from $0.058 to $0.372, the operation cost is varied from 1,460$/yr to $7,855 $/yr. while the Initial capital is varied from $59,018 to $236,878. Normally the grid availability on the campus is varied from 40%-60, so we can consider that.

Table 4. Grid annual availability possibilities

| | Grid annual availability | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0% | 10% | 20% | 30% | 40% | 50% | 60% | 70% | 80% | 90% | 100% |
| NPC ($) | $77,680 | $103,641 | $129,602 | $155,563 | $181,524 | $207,486 | $233,447 | $259,408 | $285,369 | $311,330 | $337,291 |
| CoE ($) | $0.058 | $0.089 | $0.121 | $0.152 | $0.184 | $0.215 | $0.246 | $0.278 | $0.309 | $0.341 | $0.372 |
| Oper. cost ($/yr) | $1,460 | $2,100 | $2,739 | $3,379 | $4,018 | $4,658 | $5,297 | $5,937 | $6,576 | $7,216 | $7,855 |
| Initial capital ($) | $59,018 | $76,804 | $94,590 | $112,376 | $130,162 | $147,948 | $165,734 | $183,520 | $201,306 | $219,092 | $236,878 |

## 5. Conclusion

These results show the economic and reliable contribution of adopting a solar PV system at an educational institute based on their load profile. The result shows that the on-grid hybrid system has a high impact on the grid in terms of the cost of energy, especially when there is a usable area. The engineering implication of this study is represented by an energy audit of the campus to produce a solid design based on real data. This research will facilitate the future steps to adopting a near-zero energy campus. As summarized in the study, forty-five different scenarios were analyzed to select only two based on energy costs and other costs. The limitation of this study is that it is based on a specific location that has a specific number of renewable energy sources, specific weather conditions, and a specific load profile. Different scenarios may be applied to different circumstances. As a forward-looking change, putting a solar system on the college campus that is connected to the grid will have a big effect on the Iraqi grid and lower the cost of the solar system because it won't need storage.

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