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Original Article

A Cost-Benefit Study of A PV Rooftop System In Comparison To Energy Sources Including The National Grid And A Diesel Generator In Erbil City

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ABSTRACT

Prolonged power outages significantly affect the development of all economic sectors in the Kurdistan Region. On-site energy generation utilizing diesel generators is twice as costly as prevailing fuel rates for the residential, industrial, and commercial sectors when compared to the price. The Iraqi Kurdistan area has significant solar energy capacity; however, its energy supply predominantly relies on conventional fossil fuels. This study aims to compare energy consumption cost from various sources, assess the feasibility and propose adoption strategies for rooftop solar photovoltaic systems in the Raparin neighborhood of Erbil and residential homes. Using Hybrid Optimization of Multiple Energy Resources (HOMER Pro) software, the study analyzes and compares identical energy consumption based on local diesel generators (DG) and national electrical sources, including the Public national grid, the Prepaid national power grid, and the Runaki national grid (Runaki project) system for projects with a 25-year lifespan. The study examines the electrical load profiles of 704 watts and 1408 watts, with an overall energy consumption of 16.9 kWh/day and 33.79 kWh/day, respectively, across seven scenarios of electrical power sources. The comparison of net present cost (NPC) and cost of energy (COE) revealed that the optimum scenarios are a combination of photovoltaic (PV) rooftop systems. The energy consumption through Prepaid metering of national grid power sources incurs an enormous NPC, while the diesel generator exhibits a high COE.

Keywords: PV Rooftop Solar System, Diesel Generator, HOMER Pro, NPC, COE, Erbil City.

1 Introduction

The global population has significantly increased energy consumption in developed and developing countries in recent decades, and the cost and use of energy have presented problems for governments. Most appliances nowadays are electrically powered, constituting the principal energy source [1]. The majority of energy supplies in the Kurdistan area are derived from non-renewable sources, specifically gasoline and natural gas, which significantly affect the environment [2-4] The Erbil province's supervisory and monitoring committee has recorded data on over 2500 private (DG) installed in Erbil city's central neighborhoods, supplying electricity to surrounding households during outages of the national grid electricity, with most having capacities that vary between 75 KVA to 1325 KVA. As a sustainable energy source, the photovoltaic system has recently garnered heightened interest. Numerous studies have assessed the capacity of photovoltaic systems to produce power through cost analysis, yearly revenue, and carbon footprints for certain areas [5,6]. Utilizing diverse energy sources in hybrid energy systems improves power supply stability and dependability, reducing the impact of weather fluctuations and ensuring a steady electrical supply even when an individual energy source is not functioning at optimal capacity [7,8]. Numerous research studies on hybrid energy systems demonstrate significant potential to decrease dependence on fossil fuels and greenhouse gas emissions. These technologies further ensure a dependable and uninterrupted electrical supply, yielding considerable economic benefits [9,10]. The use of renewable and clean energy has expanded significantly in recent decades, with a consistent rise in the share of renewable resources within the global energy supply [11]. Moreover, the prices associated with residential photovoltaic rooftop applications have decreased significantly in recent years. Cost reductions have led to substantial expansion in worldwide residential photovoltaic capacity [12]. Figure 1 shows that the International Renewable Energy Agency (IRENA) predicts an increase in solar PV power installations over the next decades, reaching a total capacity of 2,840 giga watt (GW) by 2030 and 8,519 GW by 2050, a significant increase from 2018. By 2050, 60% of global solar photovoltaic capacity will be utility-scale, with the remaining 40% distributed through rooftop installations.

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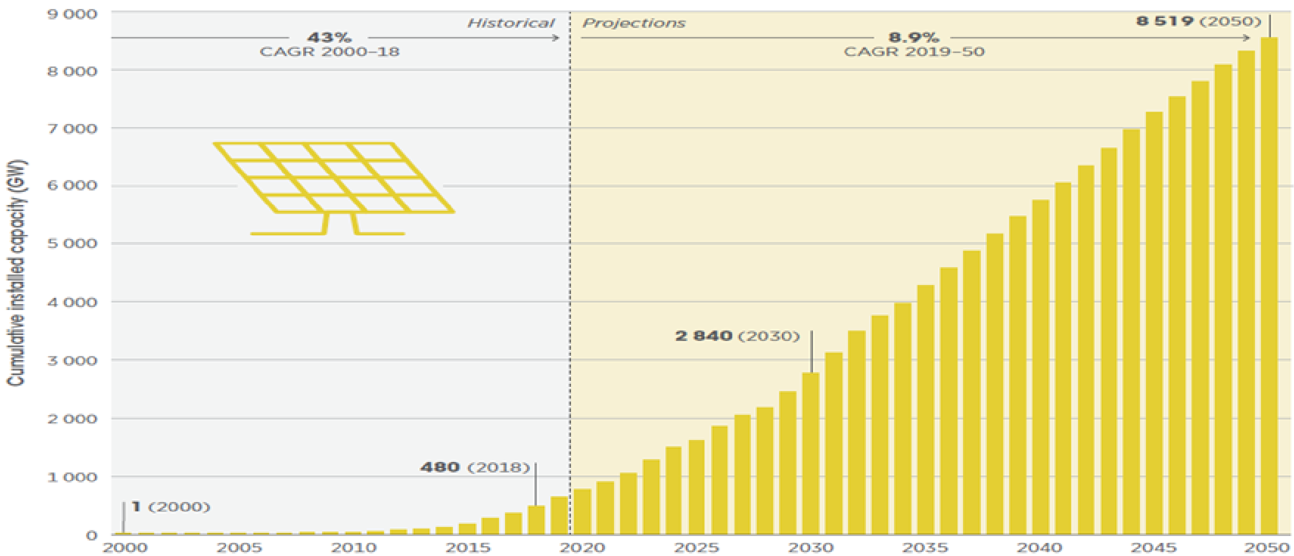

Figure 1: The total solar PV capacity is projected to expand six times by 2030, exhibiting a compound annual growth rate (CAGR) of around 9% until 2050 [13].

In the Kurdistan region (KRG), the daily irradiation, concerning global horizontal irradiation (GHI), varied from 4.4 to 5.6 kWh/m². These findings provide a useful database and offer critical assistance for decision-makers, energy developers, and investors to determine optimal sites for solar energy initiatives and enhance renewable energy generation [14]. In Erbil city, households are provided with electricity from some sources to ensure a 24-hour electrical supply: supply lines from the local diesel generators with the Public national grid, the national grid through a Prepaid system, and the Runaki project. The energy consumption, kilowatt-hours (kWh) of the source has different prices. The Erbil Province is situated in northern Iraq, the geographical coordinates range from 36° 12' 11" to 36° 15' 10" north latitude and from 44° 12' 11" to 44° 15' 10" east longitude [15]. The tilt angle is the critical parameter modified according to the latitude of the location to optimize solar energy absorption 16] Proposed an economical method for providing electricity to a government building in Baqubah, Iraq, utilizing two energy systems: a diesel generator with a grid and a photovoltaic system in addition to the grid. Solar energy is advocated for its reduced cost and support for grid electricity. The research study showed that photovoltaic panels are an essential alternative for diminishing dependence on diesel generators and enhancing solar energy utilization during daytime hours [17]. The research indicated that rooftop solar systems serve as a financially viable substitute for adjacent diesel generators, providing a levelized cost of energy [18]. The study examined the competition between renewable and conventional energy sources, their economic development, the demand for solar energy, and the annual reduction in costs, indicating that the solar panel system can be deployed in Iraq at a competitive cost relative to conventional energy [19]. The research examined many Publications, demonstrating that the photovoltaic system is more economically advantageous than alternative energy sources [20].

This study uses the HOMER Pro software to show a cost-effective comparison method. The study evaluates and (NPC) and (COE) for a project with a 25-year lifespan with assuming the capacity shortage for all systems is neglected. This is achieved by affecting a rooftop PV system, no tracking with a residential building's daily electrical consumption in the neighborhood of Erbil city as a case study, the system includes a diesel generator, the Public national grid, 24-hour electricity source that is Prepaid by the national grid, and Runaki projects, that provide electricity 24 hours a day.

2 Methods and Materials

The economic comparison of multi-source electrical energy in this study focuses on different sources with the same consumed units to design a photovoltaic system and operate it in different scenarios. HOMER Pro software is an advanced tool for the design and optimization of microgrids and distributed energy systems [21]. This modeling program models hybrid systems that integrate diverse energy sources, including solar photovoltaic, wind turbines, biogas generators, and other electrical sources. It assesses the techno-economic performance of various configurations, including NPC and COE [22]. Figure 2 illustrates the streamlined flowchart of the system. HOMER Pro is the benchmark for microgrid design and optimization, using extensive expertise in distributed power systems that incorporate fossil fuel generation, storage, and renewable energy sources [23]. Furthermore, it impacts NPC and levelized cost of energy (LCOE) by computing annualized costs; hence, it emphasizes the expenses related to certain components. HOMER Pro provides other essential applications in addition to its fundamental functionality. It enhances hybrid systems by evaluating various combinations of energy sources and storage to reduce costs while satisfying demand [24,25].

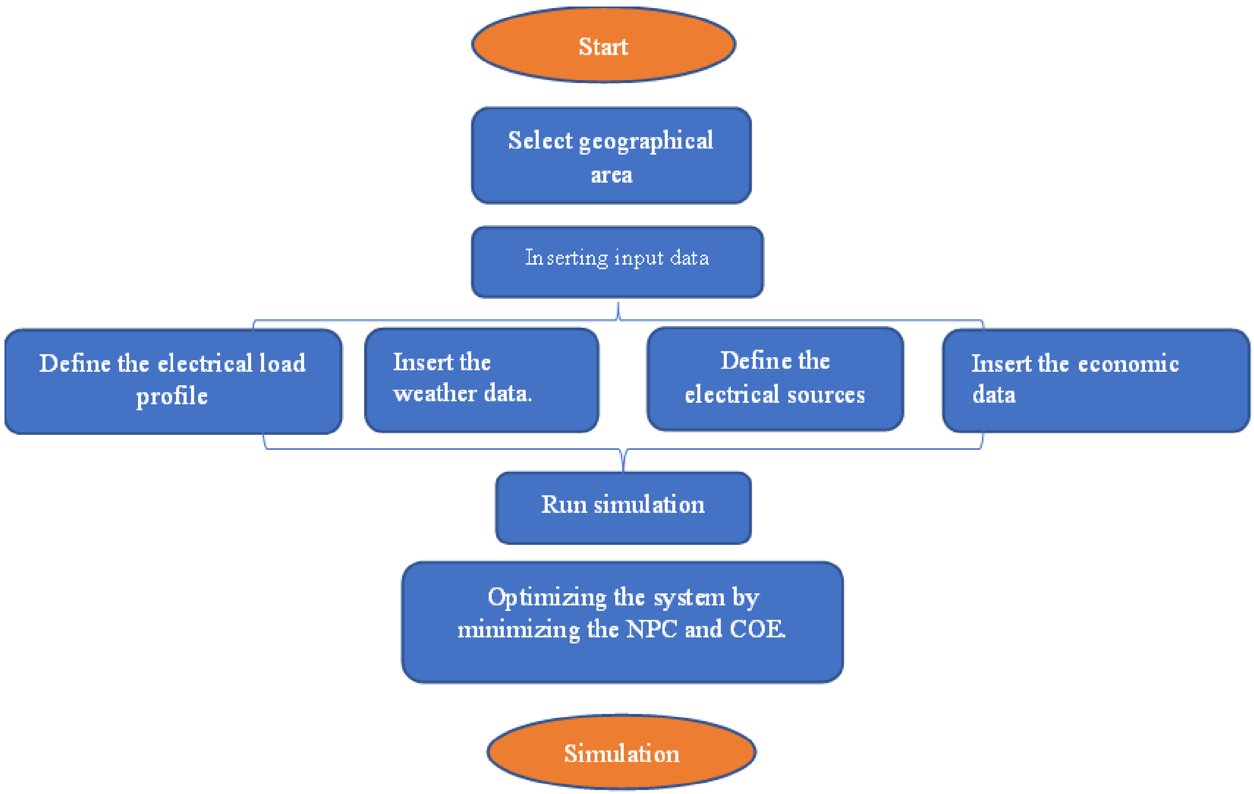

Figure 2: Analyze the framework of systems.

2. 1 Site Selection and Data Collection

This research analyzes residential buildings in the Raparin region in Erbil city, situated at 36°12.6°N and 44°2.5°E, serving as a typical sample for assessing daily energy usage from various electrical sources. Figure 3 displays the geographical location of the research area. HOMER Pro facilitates decision-making by modeling scenarios; hence, it assists in identifying cost-efficient and sustainable energy solutions.

Figure 3: The geographical location of the research area in Erbil City.

The residential complex has 270 houses, each with a different average current consumption from the local diesel generator (400 KVA). According to data gathered in 2024 in the Raparin district of Erbil city. Table 1 presents the specifics of the obtained data. Moreover, Families obtained energy (kWh) from the Public national electrical grid to provide a continuous 24-hour electricity supply with the diesel generator. In Erbil, electricity prices from the public grid are billed based on energy usage (Iraqi Dinar (IQD)/kWh), whereas local diesel generators pay fees according to the maximum current selected for a customer (IQD/Amp). According to the data obtained from the Kurdistan Region's Ministry of Electricity in Erbil, there are 11 KV feeders (891 feeders) each identified by a distinct name for identification and emergency management. The Raparin neighborhood is supplied by the (Bakoor-3, feeder) in the national electrical system. The data collected in 2024 showed that the residents consumed an annual average (ampere/day) amount of daily power from the diesel generator for 12.5 hours per day and the Public national electrical grid for 11.5 hours per day. Table 2 displays the average monthly hourly power supply from the national grid (Feeder Bakoor 3) and the diesel generator for the year 2024.

Table 1: Number of residences and amperage range acquired from the local diesel generator.

No. of households	The daily ampere values purchased from the diesel generator	The total daily ampere values purchased from the diesel generator
2	2	4
50	3	150
146	4	584
57	6	342
10	8	80
5	10	50
270		1210 Total ampere

Table 2: The operational hours for the National Grid (Feeder bakoor - 3) and the diesel generator are scheduled for the year 2024.

Date	Average daily operational hours of the Public national electricity grid (Feeder Bakoor 3)	Diesel generator (average daily operational hours)
January	8.5	15.5
February	9	15
March	10	14
April	14	10
May	14	10
June	12	12
July	10.5	13.5
August	11	13
September	12	12
October	15	9
November	14	10
December	8	16
Average	11.5	12.5

This study employed 4 and 8 amperes sourced from the diesel generator for the household loads. A 400kVA, 380V, 50Hz, diesel generator supplies the consumers. The voltage at households is approximately 220V, and the power factor is assumed to be 0.8. The diesel generator operated 4561 hours in 2024. The HOMER Pro program calculates kilowatts for a load and kilowatt hours for energy consumption in the generated load profiles, determined using a voltage of 220 volts and a current of 4 amperes (146 households) and 8 amperes (10 households). The power received by these two groups, according to equation 1, are 704 watts and 1408 watts, respectively, for inputting the load profiles into HOMER Pro software.

$$Power\ [\ kW\ ] = Voltage\ [\ V] * Ampere\ [\ A\ ] * Power\ factor \qquad (1)$$

2. 1. 1 Electrical Energy Prices

The cost of electrical energy in Erbil varies and is expressed in IQD/kWh, whereas the diesel generator is priced in IQD/ampere for one hour of operation. The Ministry of Electricity determines the cost of energy, whereas the Erbil province establishes the ampere cost of diesel generators. Table 3 presents the unit pricing for various electrical power sources.

Table 3: Displays the unit costs for several electrical power sources.

Electrical sources	Energy consumption (kWh)/month	(IQD) /kWh
Public (Normal) national grid	1-450	18
	451-900	24
	901-1500	42
	1501-2100	72
	2101-3000	90
	3001-5000	180
	over (5001)	240
Prepaid system (national grid)	All	156
Runaki project (national grid)	1- 400	72
	401- 800	108
	801-1200	175
	1201 - 1600	265
	1600+	350
Local diesel generator	All	232.63

2. 1. 2 Solar Power System Current Market Devices

The Kurdistan Regional Government's Marketing Department states that the pricing of renewable energy sources and associated equipment varies based on the system's size and brand. Table 4 illustrates the cost of the solar power system equipment.

Table 4: *Solar power system equipment price.*

Item	Description	Estimated Price (IQD)
PV Panel size (750W)	N-type-Monocrystalline, 132 cells, IP68, bifacial	Around 140,000
Hybrid Inverter size (2.5kW)	Suitable for small-scale residential systems	Around 250,000 to 750,000
Hybrid Inverter (4.5kW)	Suitable for medium systems	Around 450,000 to 1,000,000
Lead Acid Battery (2.41 kWh)	Commonly used for backup energy, (12V, 201 Ah),	Around 225000 to 260000

2. 2 System Load Profiles

This paper includes several scenarios, each characterized by a distinct load profile.

2. 2. 1 Diesel Generator and National Grid Load Profile

The diesel generator has a peak load of 0.704 kW and 1.408 kW, with an average daily energy usage of 8.8 kWh/day and 17.6

kWh/day, respectively, over 12.5 hours annually. Additionally, the national grid requires 0.704 kW and 1.408 kW for peak demand and 8.1 kWh/day and 16.19 kWh/day, respectively, for an annual average of 11.5 hours. Figures 4, 5, 6, and 7 illustrate the load profiles for the diesel generator and the Public national grid for 0.704 kW and 1.408 kW, respectively.

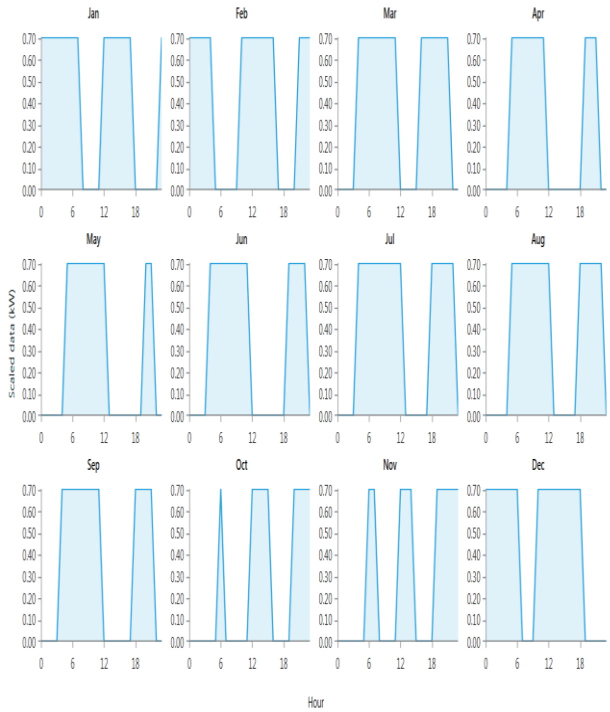

Figure 4: Diesel generator seasonal load profile (0.704kW).

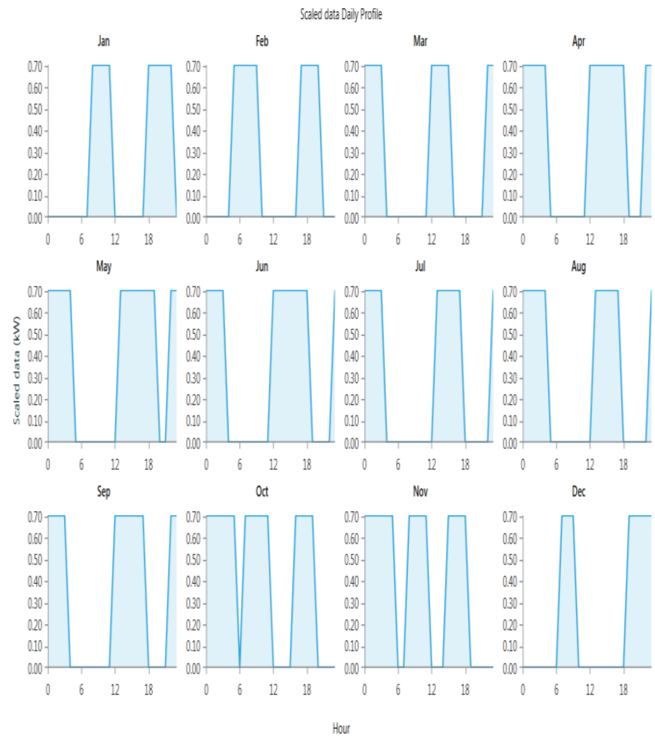

Figure 5: Public national grid seasonal load profile (0.704kW).

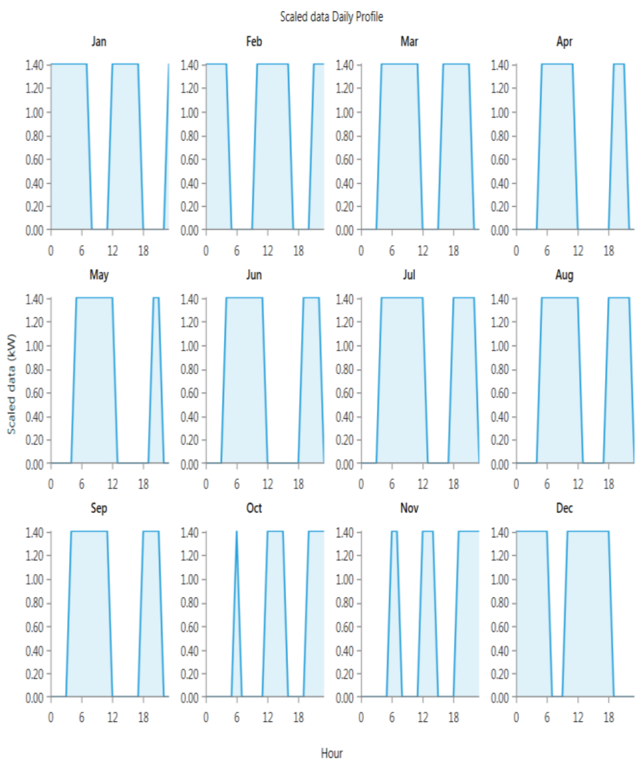

Figure 6: Diesel generator seasonal load profile (1.408 kW).

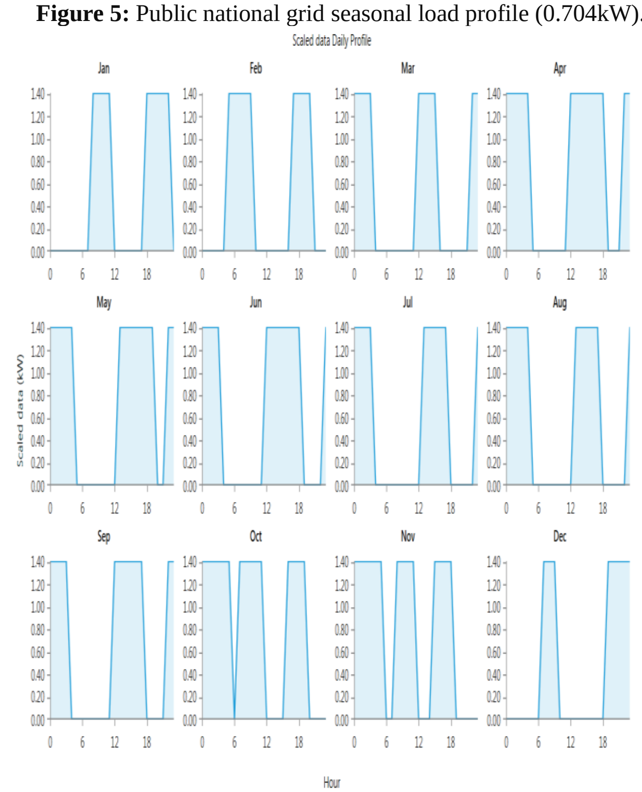

Figure 7: Public national grid seasonal load profile (1.408kW).

In this scenario, assumed that households consistently acquire 0.704 kW and 1.408 kW from the Prepaid and Runaki project national grid for 24 hours each day, and the energy consumption becomes 16.9 kWh/day and 33.79 kWh/day. Figures 8 and 9 show the seasonal load profile for residential properties connected to the Prepaid and Runaki project national grid.

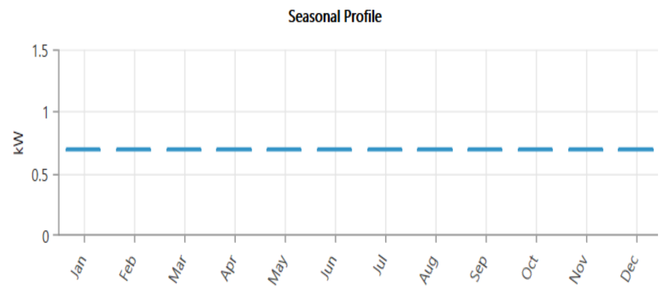

Figure 8: Seasonal load profile (0.704 kW).

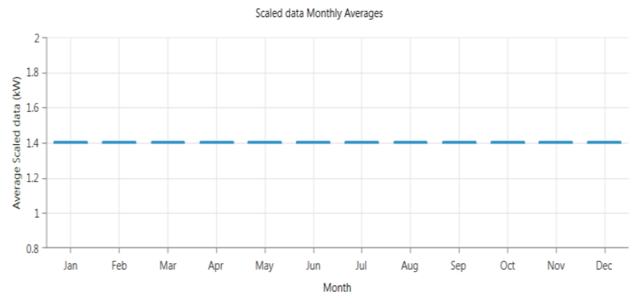

Figure 9: Seasonal load profile (1.408 kW).

2. 3 Resources

To execute the simulation, data on renewable energy resources, including solar radiation, the clearness index and temperature, must be obtained at designated places. The NASA Surface Meteorology and Sun Energy database was utilized to obtain data on sun irradiation for the chosen site from NASA Prediction of Worldwide Energy Resource [28]. The output of the solar photovoltaic system is significantly influenced by sun radiation and clearness index values. Increased solar radiation enhances the potential energy yield of photovoltaic systems. Conversely, the clearness index, which signifies air transparency, influences the effectiveness of photovoltaic systems by altering the quantity of sunlight that reaches the solar panels.

Figure 10 depicts the annual total solar radiation at the specified region, together with the clearness index. Also, the efficiency of solar photovoltaic systems is directly affected by variations in temperature. As temperatures rise, the efficiency of photovoltaic modules diminishes owing to increased internal resistance. Figure 11 depicts the daily temperature profile at the location, with an average temperature of 18.19 °C. In addition, increased wind speeds can augment the cooling of solar panels, thus enhancing their efficiency [29].

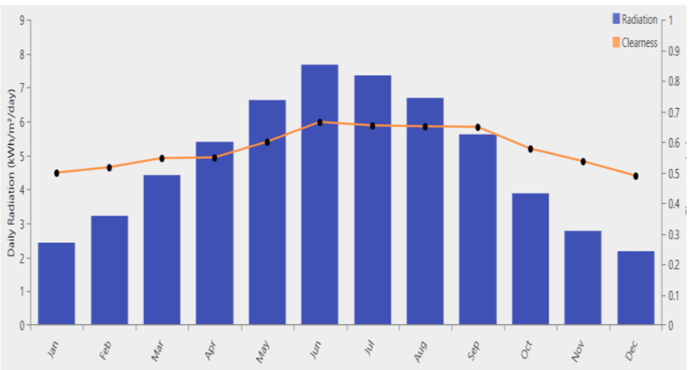

Figure 10: Solar (GHI (kWh/m²/day)) and clarity index for the location.

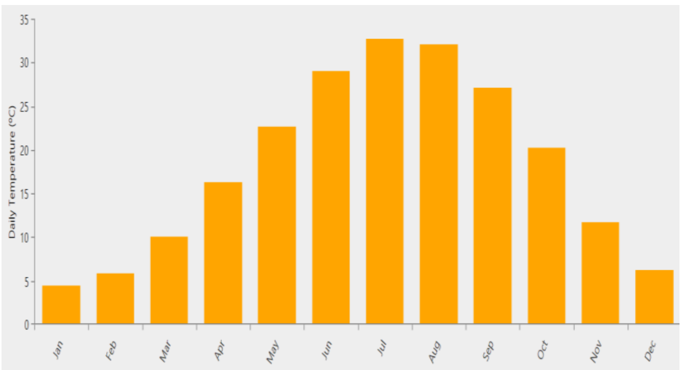

Figure 11: Average monthly temperature for the location.

2. 4 Equipment System Analysis Input Data

Table 5 shows different information about the costs of power sources and equipment, like photovoltaic solar systems, and the energy use (IQD/kWh) for each electrical source, including diesel generators and national electrical grids, in HOMER Pro software.

Table 5: Displays item prices and lifetime.

Item	Capacity	Initial capital and installation cost (IQD)	Replacement Cost (IQD)	O&M cost	Lifetime (years)
PV panel	0.750 kW	180,000	180,000	0	25
Hybrid inverter	2.5 kW	450,000	380,000	15,000 (IQD/year)	5
Hybrid inverter	4.5 kW	900,000	760,000	25000 (IQD/year)	5
Lead-acid battery	12V,201AH, 2500 Life cycle at 0.5 Depth of discharge (DOD)	260,000	200000	1000 (IQD/year)	5

Neighborhood diesel generator	Auto size (kW)	0	0	(232.63/kWh)	--------
National grid (Public)	(1-450 kWh)	0	0	(18 IQD/kWh)	--------
	(451- 900 kWh)	0	0	(24 IQD/kWh)	
National grid (Prepaid)	1kWh	0	0	(156 IQD/kWh)	--------
National grid (Runaki)	(1-400 kWh)	0	0	(72 IQD/kWh)	
	(401-800 kWh)	0	0	(108 IQD/kWh)	--------
	(801-1200 kWh)	0	0	(175 IQD/kWh)	--------

2. 5 Economic Parameters

2. 5. 1 Net Present Cost (NPC)

The NPC of the component includes the present purchase price, installation costs, operational expenses, and maintenance expenditures during its lifespan. IC represents the initial cost, IO&M denotes the operation and maintenance cost, and IR signifies the replacement cost [30]. Equation 2 represents the NPC.

$$NPC = IC + IO\,\&\,M + IR \tag{2}$$

2. 5. 2 Cost of Energy (COE)

The (COE) is defined as the essential cost to generate a certain amount of energy. The outcome is based on the location, geographical region, governmental regulations, fuel costs, and other factors. The sum can be represented as a ratio of the total annual cost [30]. In Equation 3, NPC represents the net present cost, and E served represents the total electrical load provided (kWh/year).

$$COE = \frac{NPC\ [IQD]}{Eserved\ [kWh]} \tag{3}$$

2. 5. 3 Levelized Cost of Energy (LCOE)

The (LCOE) is the average cost per of electricity, often expressed in (kWh), generated by a power-producing system, such as solar panels, Grid sources, and diesel generators, during its operational lifespan, inclusive of any related costs [30].

$$L\,COE = \frac{Total\ life\ time\ cost}{Total\ life\ time\ energy\ production} \tag{4}$$

2. 6 Solar PV System Sizing

To determine an appropriate size for minimizing the diesel generator and other electricity sources, [31] showed that system size is an essential phase in the design of photovoltaic (PV) systems, since it determines the capacity required to satisfy energy requirements. In residential settings, it is crucial to determine the total daily electrical demand of the building to ensure that the photovoltaic system effectively and dependably satisfies the household's energy requirements. It is generally accepted to account for 20%–30 % losses within the system, necessitating that the module be sufficiently sized to compensate for these losses. The size of the PV module is multiplied by the system losses to determine the actual need, which is shown in equation 5, and the number of PV panels is determined by equation 6. The hybrid solar systems require battery backup storage. Equation 7, determines the battery capacity. The size of the inverter depends on the PV power output and the desired AC power deliverable by the overall system. The rated power of the inverter should be equal to or greater than the output PV array for this system. The optimal tilt angle for the photovoltaic arrays should be around 36.12°, with the modules oriented towards the south. The Iraqi Kurdistan area possesses significant potential for solar energy implementation, with an average rate of 5.245 kWh/m2 [2]. Table 6 represents the PV system size of each load profile connected to the HOMER Pro software. To compare the photovoltaic systems with the Prepaid grid and the Runaki national grid, the capacity of the photovoltaic system was established at half of the electrical load profile, as shown in table 6.

$$PV\ module\ size\ [kW] = \frac{Daily\ energy\ consumption\ [\frac{kWh}{day}]}{Peak\ Sun\ Hour\ (PSH)} * system\ losses \tag{5}$$

$$Number\ of\ PV\ module = \frac{PV\ array\ capacity[kW]}{PV\ panel\ capacity\ [kW]} \tag{6}$$

$$Battery\ bank\ capacity\ [Ah] = \frac{Daily\ energy\ consumption\ [Wh]}{system\ voltage\ [V] * DOD * efficieny} \tag{7}$$

$$Battery\ number = \frac{Battery\ bank\ capacity\ [Ah]}{Battery\ capacity\ [Ah]} \tag{8}$$

Table 6: PV system size design of different load profiles for replacing the DG, Prepaid system, and Runaki project.

Name	**(0.704 kW *12.5 hr),8.8 kWh for replacing a diesel generator**	**(1.408 kW*12.5 hr), 17.6 kWh for replacing a diesel generator**	**16.9 kWh for Prepaid and the Runaki project**	**33.79 kWh for Prepaid and the Runaki project**
Capacity size of PV System	2.25 kW	4.5 kW	2.25 kW	4.5 kW
No. of PV panels	3	6	3	6
Battery capacity size	14.5 kWh	29 kWh	--------	-------
Battery No.	6	12	--------	-------
Inverter capacity size	2.5 kW	4.5 kW	2.5 kW	4.5 kW

2. 6. 1 Photovoltaic Solar Panel Output Source

Equation 9 can be used by HOMER Software to ascertain the power production from the solar photovoltaic system [22,32], where:

Ppv : represents the power output of the PV system.
Ypv : denotes the rated capacity of the PV array.
f_{pv} : signifies the PV derating factor. The variable G_T represents incident solar radiation.
$G_{T,STC}$: The variable for incoming solar radiation under typical test conditions is defined as 1 kW/m².
α_P : represents the temperature coefficient for maximum power.
T_c : denotes the operating temperature of the photovoltaic (PV) cell.
$T_{C,STC}$ indicates the reference condition temperature of a PV cell ($T_{C,STC}$ = 25°C).

$$Ppv = Ypv\, f_{pv} \left(\frac{G_T}{G_{T,STC}}\right) [1 + \alpha_P(T_c - T_{C,STC})] \tag{9}$$

This equation allows HOMER Pro to simulate the performance of the PV system under diverse climatic circumstances, facilitating the optimization of system designs based on accurate performance predictions. The above information allows for a more precise modeling of the energy-generating capacity of the solar PV system, which is essential for establishing the ideal design and maintaining system dependability within the proposed microgrid.

2. 7 Study Simulation Scenarios

Scenario 1, illustrates that the major AC loads of 8.8 kWh/day and 17.6 kWh/day are directly connected to and supplied by the diesel generator, devoid of any renewable energy resources, as seen in Figure 12 and Figure 13 respectively.

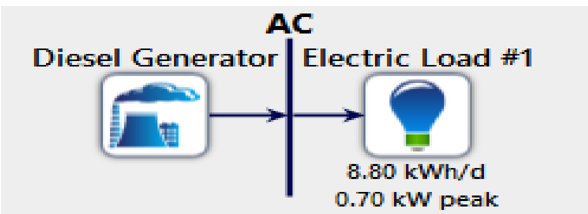

Figure 12: Scenario 1, diesel generator simulation system.

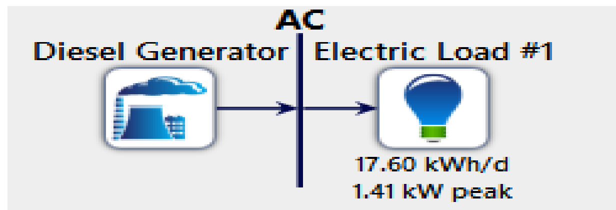

Figure 13: Scenario 1, diesel generator simulation system.

In scenario 2, the loads of 8.1 kWh/day and 16.19 kWh/day are directly linked to and supplied by the Public national grid, devoid of any renewable energy sources. This Scenario aims to complete the first scenario for obtaining 24 hours of electricity, as seen in Figure 14 and Figure 15, respectively. The cost of one kilowatt-hour is showed in Table 5.

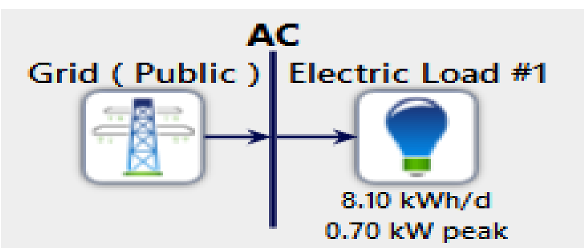

Figure 14: Scenario 2, Public national grid simulation 8.1kWh/day.

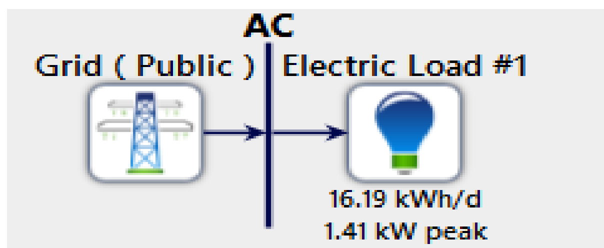

Figure 15: Scenario 2, Public national grid for 16.19 kWh/day

In scenario 3, the primary energy use of 16.9 kWh/day and 33.79 kWh/day, respectively, are sourced only from the national grid (Prepaid system) and does not incorporate any photovoltaic solar system, as seen in Figure 16 and 17. The price of one kilowatt-hour obtained from the national grid is 156 IQD/kWh. This technique applies to small city populations in Erbil, which receive 24 hours of energy every day from the national grid. The price of the increase in energy consumption is linear.

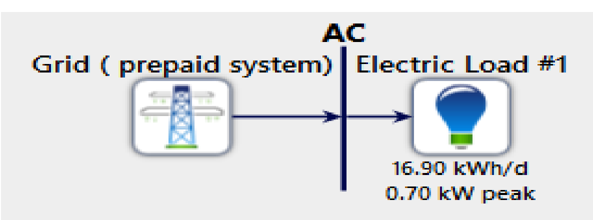

Figure 16: Scenario 3, Prepaid national grid for 16.9 kWh/day.

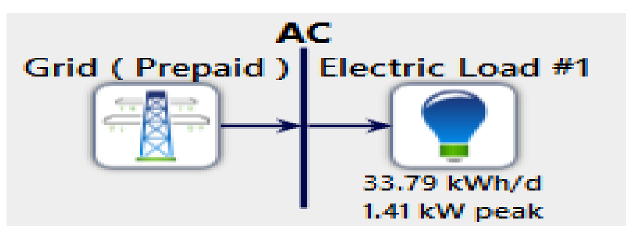

Figure 17: Scenario 3, Prepaid national grid for 33.79 kWh/day.

In scenario 4, the primary energy consumption of 16.9 kWh/day and 33.79 kWh/day, respectively are exclusively derived from the national grid (Runaki projects) and excludes any photovoltaic solar system or diesel generator, as seen in Figures 18 and 19, respectively. The cost of one kilowatt-hour from the national grid depends based on energy use; The cost of energy consumption is included in Table 5. This system is applicable to some neighborhoods in Erbil that receive a continuous electricity supply from the national grid for 24 hours daily. The price does not rise linearly but instead corresponds with the amount of energy consumption.

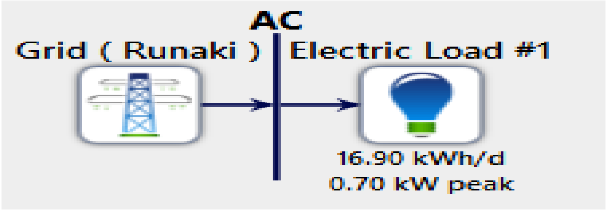

Figure 18: Scenario 4, Runaki national grid for 16.9 kWh/day.

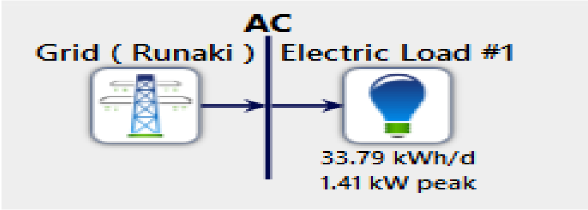

Figure 19: Scenario 4, Runaki national grid for 33.79 kWh/day.

In scenario 5, the principal AC load of 16.9 kWh/day is directly associated with the Public traditional national grid, a 2.25 kW photovoltaic solar array, and 14.5 kWh and 29 kWh lead-acid batteries for each load profile, respectively, for times of need when the depth of discharge is 0.5. The hybrid solar system is integrated with the Public national grid to replace the diesel generator. Figures 20 and 21, respectively, illustrate the simulation framework.

In scenario 6, the electricity consumption of 16.9 kWh/day and 33.79 kWh/day is linked to the Prepaid system utilizing the national grid, as previously referenced in scenario 3. The system is augmented by a 2.5 kW solar panel system through a hybrid inverter. The hybrid solar system is connected to the national grid to minimize energy expenditures and net present value costs. The Prepaid system offers continuous, 24-hour electricity, eliminating the necessity for battery storage backup when renewable energy is incorporated. Figures 22 and 23, respectively, present the simulation framework.

In scenario 7, the primary energy use of 16.9 kWh/day and 33.79 kWh/day are associated with the Runaki project, which utilizes the national grid; this is scenario 4, which was mentioned before; but in scenario 7, the system was supplemented and augmented by a 2.5 kW solar panel system via a hybrid inverter, the hybrid solar system is linked to the national grid to compare with scenario 4 about COE and NPC. Figures 24 and 25, respectively, illustrate the simulation framework.

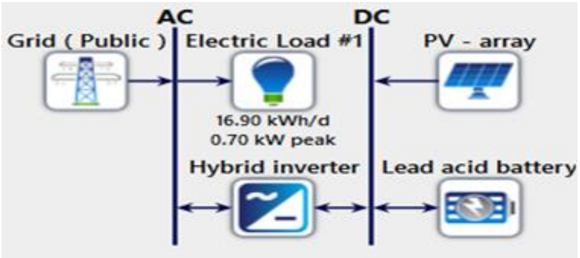

Figure 20: Scenario 5, Public national grid with a hybrid solar system simulation for 16.9 kWh/day.

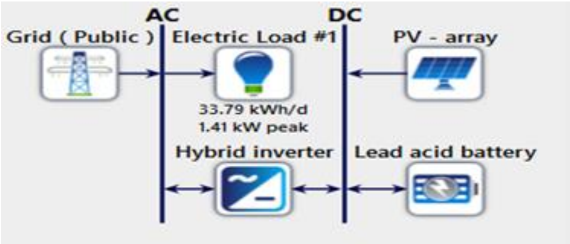

Figure 21: Scenario 5, Public national grid with a hybrid solar system simulation for 33.79 kWh/day.

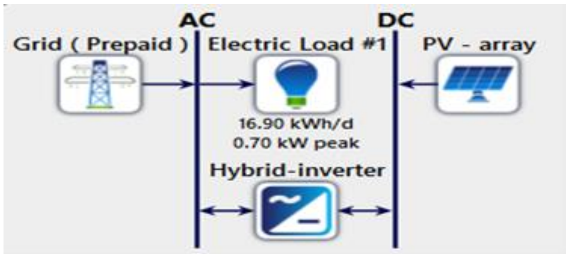

Figure 22: Scenario 6, Prepaid system from the national grid with a solar power system simulation for 16.9 kWh/day.

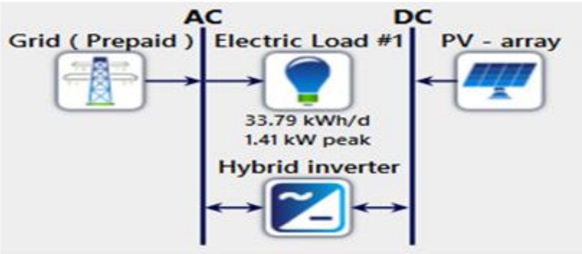

Figure 23: Scenario 6, Prepaid system from the national grid with a solar power system simulation for 33.79 kWh/day.

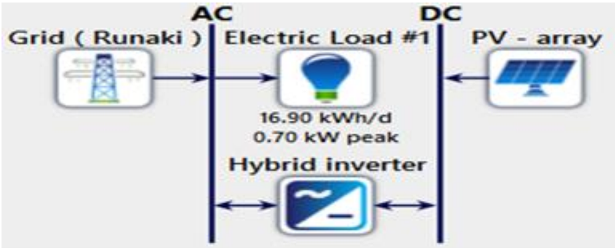

Figure 24: Scenario 7, Runaki project from the national grid with a power solar system simulation for 16.9 kWh/day.

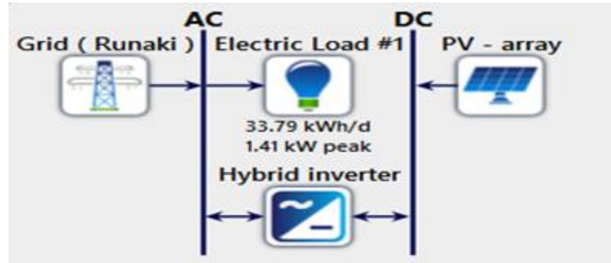

Figure 25: Scenario 7, Runaki project from the national grid with a solar power system simulation for 33.79 kWh/day.

3 Results and Discussions

In scenario 1, the generator cost includes the installation, operation, maintenance, and fuel costs of all system components; however, electricity is provided by a local diesel generator in the vicinity, and individual residences are not liable for capital expenditures, replacements, or fuel costs. Instead, they suffer charges based on their actual consumption, measured by the number of hours of operation for each ampere utilized. The diesel generator operated for 4561 hours in 2024. The diesel generator system is automatically sized and selected by HOMER Pro software based on the load profiles. Table 7 presents the results for scenario 1, and Figures 26 and 27 present detailed results for each load profile. Also, Figures 28 and 29 show the total energy production for a year.

Table 7: Presents the result of scenario 1, for a 25-year lifetime project.

Diesel generator source	Load profiles	Diesel generator energy production (kWh/year)	NPC (IQD)	COE (IQD)
Scenario 1	0.704 kW, 8.8 kWh	3212	18,679,960	232.63
	1.408 kW, 17.6 kWh	6424	37,360,060	232.63

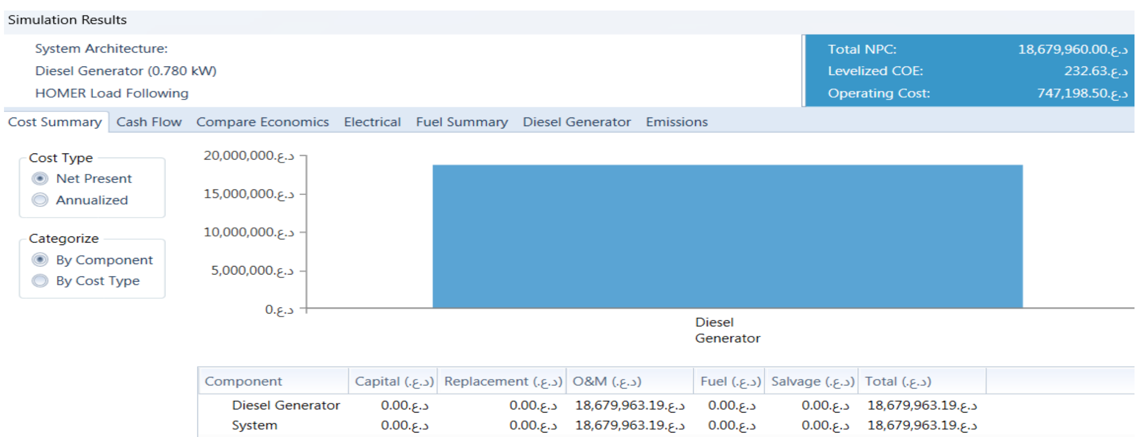

Figure 26: Scenario 1, diesel generator NPC and COE System Simulation Results for (8.8 kWh/day).

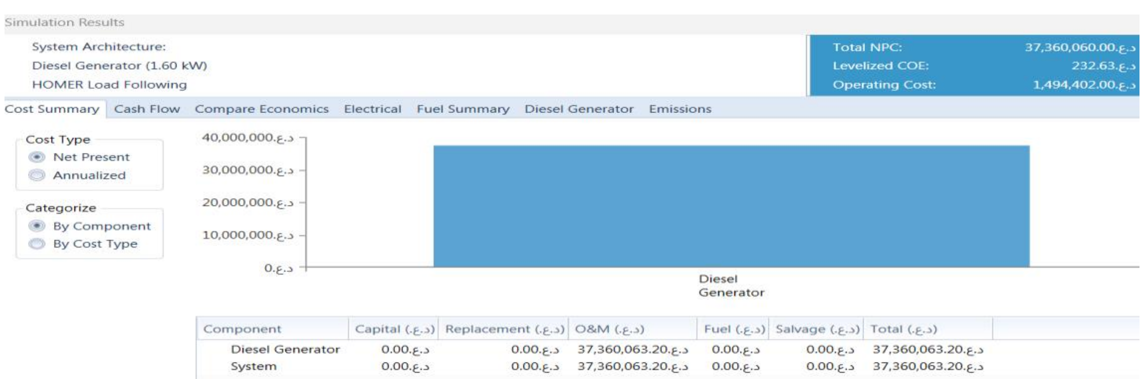

Figure 27: Scenario 1, diesel generator NPC and COE System Simulation Results for (17.6 kWh/day).

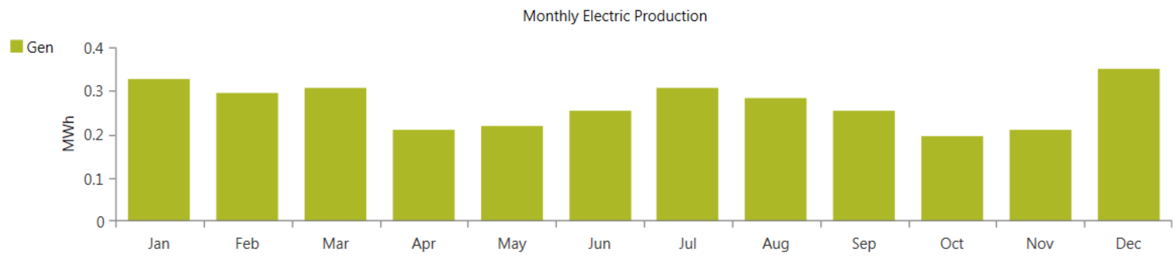

Figure 28: Scenario 1, diesel generator system monthly electrical production simulation results for (8.8 kWh/day).

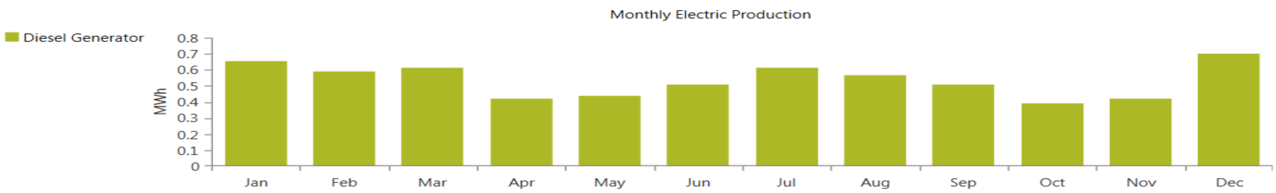

Figure 29: Scenario 1, diesel generator system monthly electrical production simulation results for (17.6 kWh/day).

In scenario 2, the principal AC load of 8.1 kWh/day and 16.19 kWh/day completely relies on the Public national grid, devoid of any renewable energy sources. The power cost from the grid is 18 IQD/kWh for monthly usage ranging from 1 kWh to 450 kWh, and 24 IQD/kWh for monthly usage ranging from 451 kWh to 900 kWh. Table 8 presents the results for scenario 2, and Figures 30 and 31 depict the outcome for the NPC and COE for each load profile; also, Figures 32 and 33 show the total energy production for a year. The total NPC and COE for both scenarios 1 and 2, for obtaining 24-hour electricity, are shown in Table 9.

Table 8: Presents the results of scenario 2, for a 25-year lifetime.

Public national grid	**Load profiles**	**Public national grid (kWh/year)**	**NPC (IQD)**	**COE (IQD)**
Scenario 2	0.704 kW, 8.1 kWh	2956	1,330,425	18
	1.408 kW, 16.19 kWh	5910	2,733,074	18.5

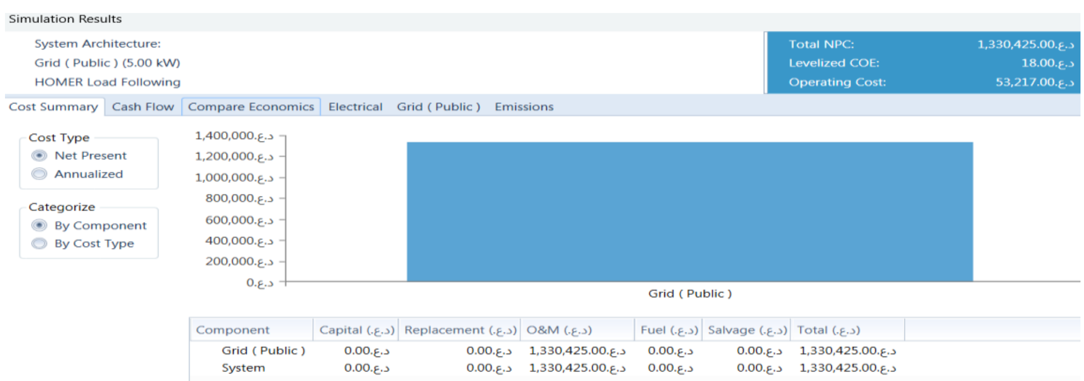

Figure 30: Scenario 2. Public national grid NPC and COE system simulation results for (8.1 kWh/day).

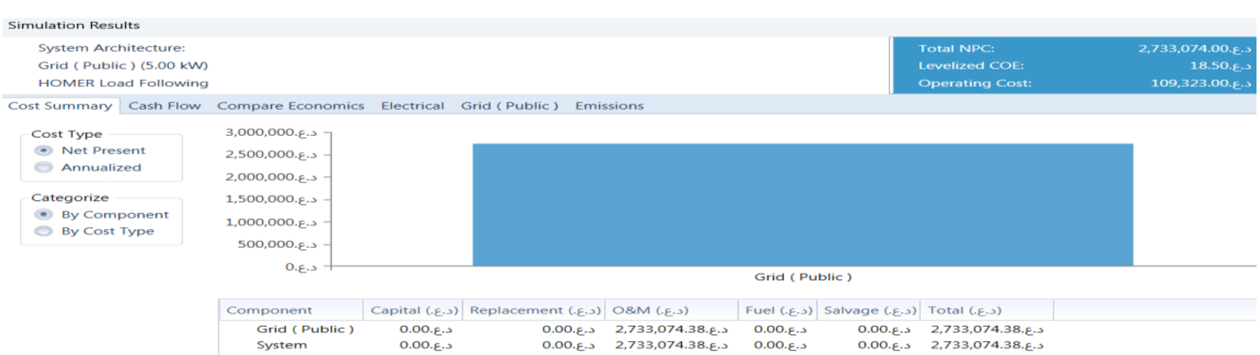

Figure 31: Scenario 2. Public national grid NPC and COE system simulation results for (16.19 kWh/day).

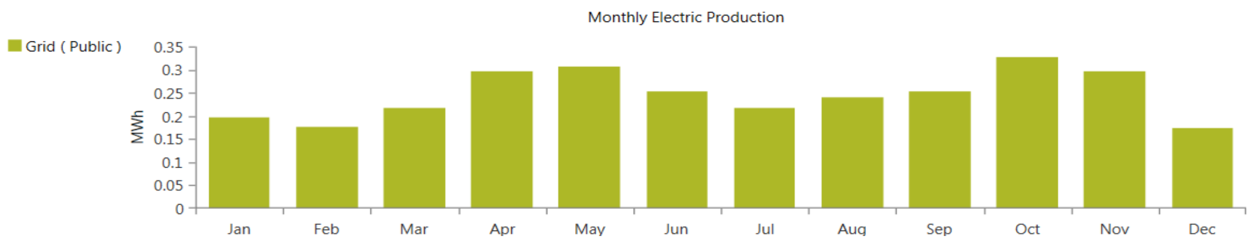

Figure 32: Scenario 2, Public national grid system monthly electrical production simulation results for (8.1 kWh/day).

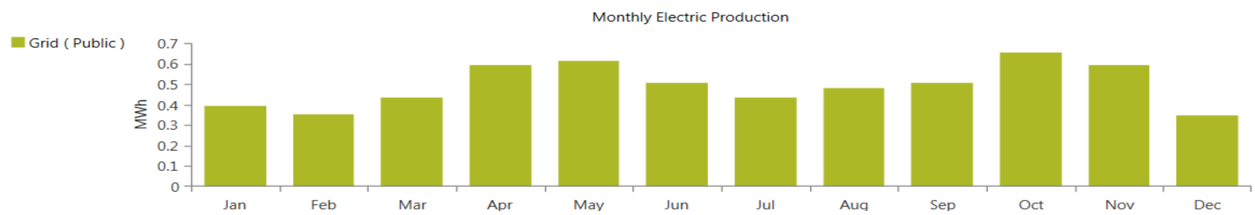

Figure 33: Scenario 2, Public national grid system monthly electrical production simulation results for (16.19 kWh/day).

Table 9: NPC and COE for diesel generator and Public national grid for a 25-year lifetime project.

Scenarios	Load profiles	Public national grid (kWh/year)	NPC (IQD)	COE (IQD)
Scenario 1 (DG)+ Scenario 2 (Public national grid)	0.704 kW,16.9 kWh	6168	20,010, 385	129.76
	1.408 kW,33.79 kWh	12333	40,093,134	130

In scenario 3, the primary load profiles are 0.704 kW/day and 1.408 kW/day, resulting in a consumption of 16.9 kWh/day and 33.79 kWh/day, respectively. The electricity depends on the Prepaid national grid, which has an energy cost of 156 IQD /kWh. Figures 34 to 37 depict the outcome in scenario 3. The Prepaid national grid provides 24 hours of electricity. The result is indicated in Table 10.

Table 10: Scenario 3, NPC and COE for the Prepaid national grid for a 25-year lifetime project.

Public national grid	Load profiles	Public national grid (kWh/year)	NPC (IQD)	COE (IQD)
Scenario 3	0.704 kW, 16.9 kWh	6168	24,057,150	156
	1.408 kW, 33.79 kWh	12333	48,100,060	156

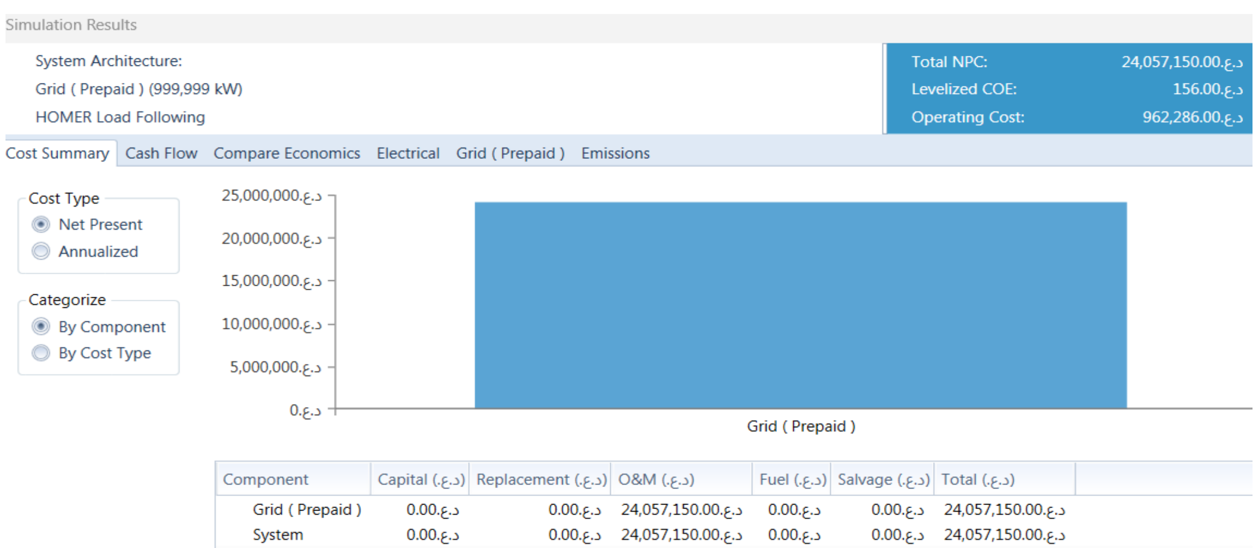

Figure 34: Scenario 3, Prepaid national grid NPC and COE system simulation results for (0.704 kW, 16.9 kWh/day).

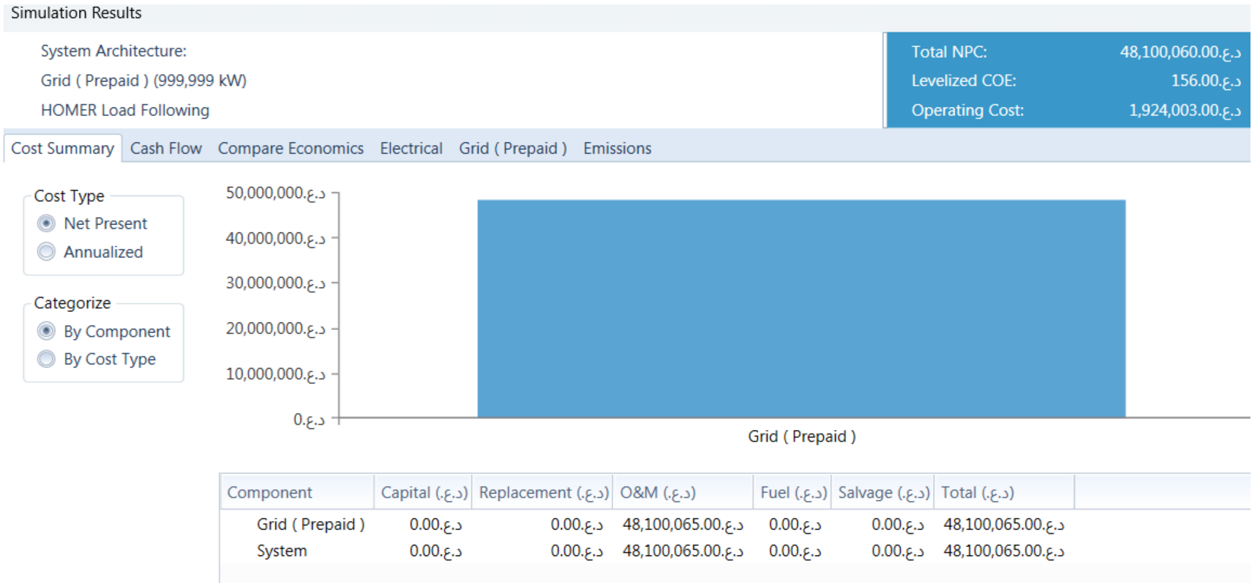

Figure 35: Scenario 3, Prepaid national grid NPC and COE system simulation results for (1.408 kW, 33.79 kWh/day).

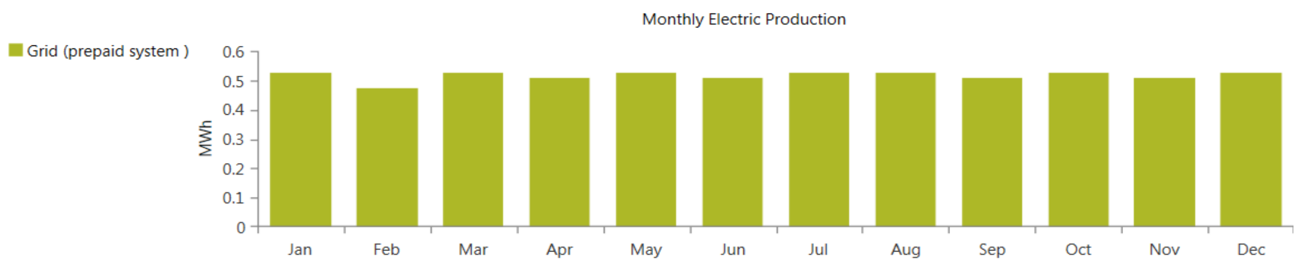

Figure 36: Scenario 3, Prepaid national grid system monthly electrical production simulation results for (0.704 kW,16.9 kWh/day).

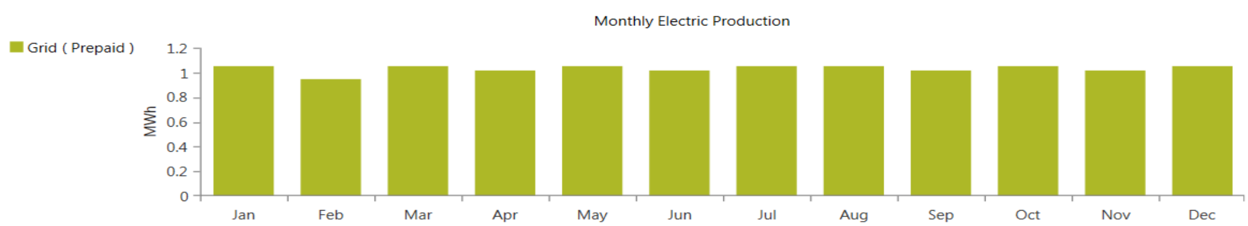

Figure 37: Scenario 3, Prepaid national grid system monthly electrical production simulation results for (1.408kW, 33.79 kWh/day).

In scenario 4, the main load profiles are 0.704 kW and 1.408 kW, resulting in a consumption of 16.9 kWh/day and 33.79 kWh/day, respectively. The electricity is sourced from the Runaki project on the national grid. Outcome of scenario 4, concerning the power supply. The Runaki project from the national grid provides continuous energy for 24 hours. The result is indicated in Table 11. Figures 38 to 41 depict the outcome in scenario 4.

Table 11: NPC and COE for the Runaki national grid for a 25-year lifetime project.

Runaki Project	Load profiles	Public national grid (kWh/year)	NPC (IQD)	COE (IQD)
Scenario 4	0.704 kW,16.9 kWh	6168	12,333,920	79.98
	1.408 kW,33.79 kWh	12333	33,555,960	108.83

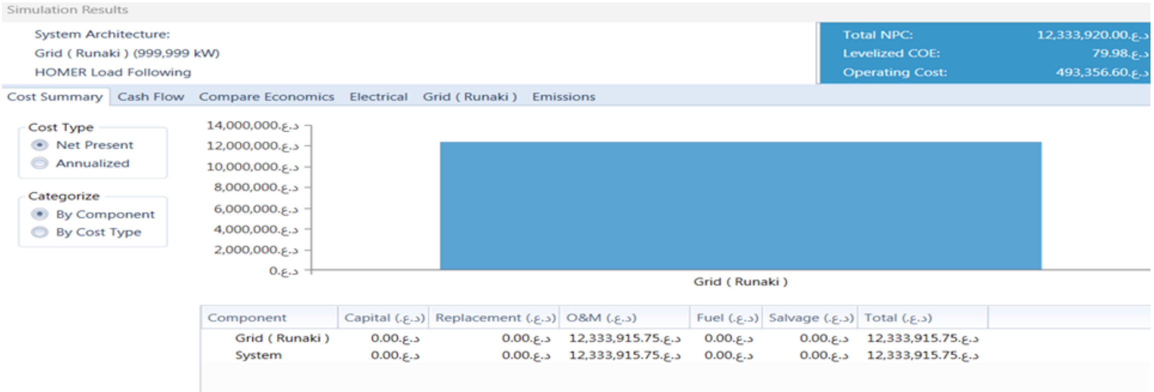

Figure 38: Scenario 4, Runaki project of the national grid NPC and COE system simulation results for (0.704 kW,16.9 kWh/day).

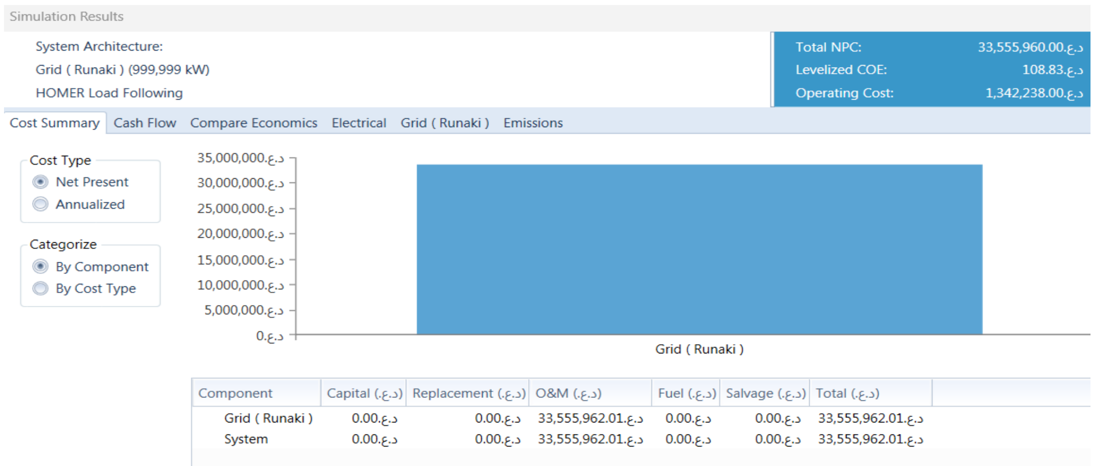

Figure 39: Scenario 4, Runaki project of the national grid NPC and COE system simulation results (1.408 kW, 33.79 kWh/day).

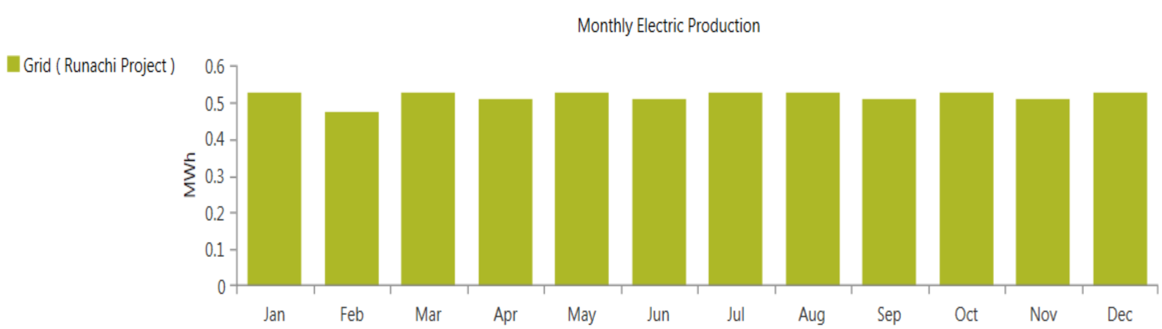

Figure 40: Scenario 4, total system electrical production for (0.704 kW,16.9 kWh/day).

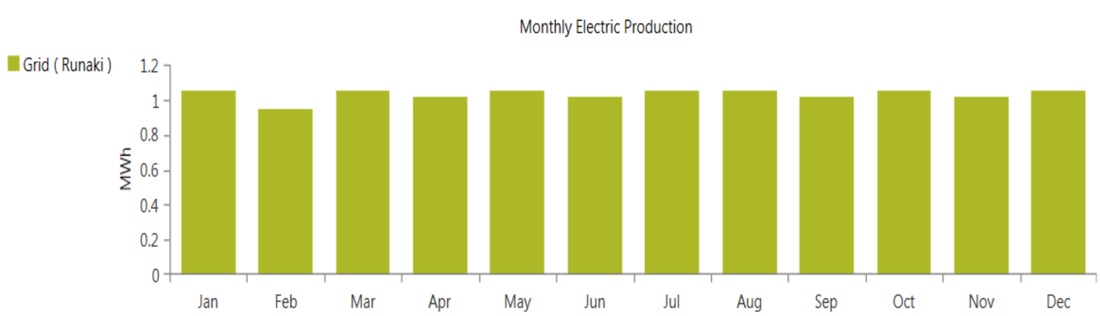

Figure 41: Scenario 4, total system electrical production for (1.408 kW, 33.79 kWh/day).

In scenario 5, when added, the PV solar system replaced the diesel generator and was connected to the Public national grid. The system's performance was compared to the total NPC and COE of the previous system. The result is indicated in Table 12 for a 25-year life span. Figures 42 and 43 indicate the details of the system, whereas Figures 44 and 45 present the monthly electrical output of the two power generation systems.

Table 12: Comparison of scenario 1 and scenario 2, with scenario 5, according to NPC and COE for a 25-year lifetime project.

Electrical load profile	Scenario 1 (DG) + Scenario 2 (Public grid)		Scenario 5 (Public Grid + PV system)	
	NPC(IQD)	COE(IQD)	NPC(IQD)	COE(IQD)
0.704 kW, 16.9 kWh	20,010, 385	129.76	10,723,270	69.54
1.408 kW, 33.79 kWh	40,093,134	130	21,393,710	69.38

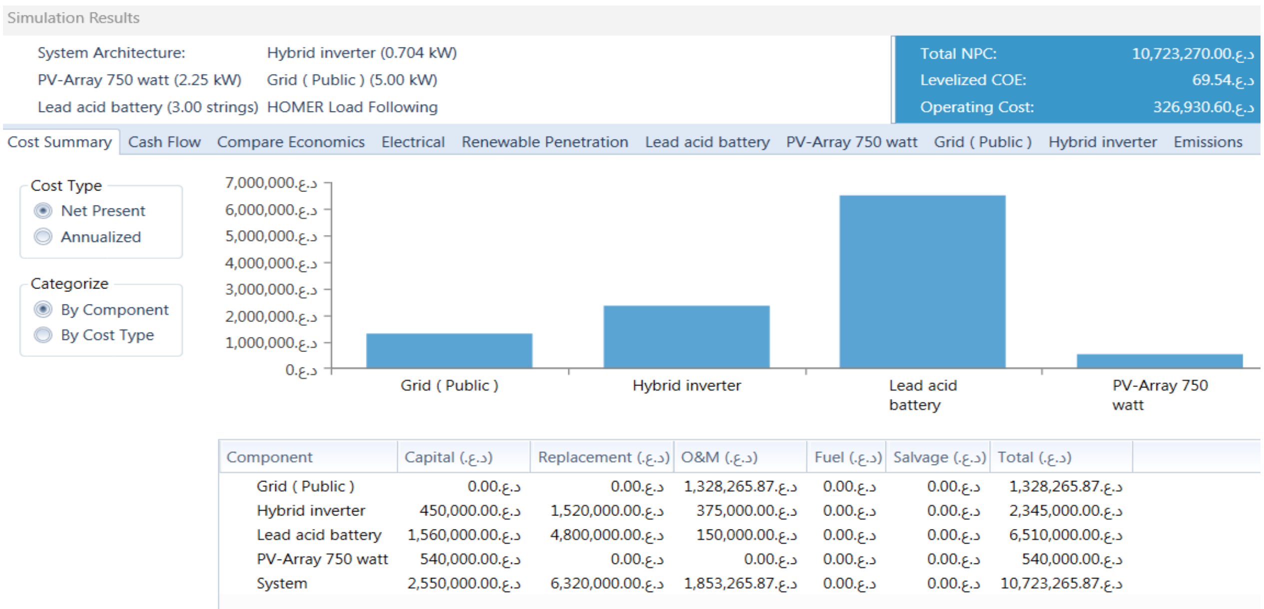

Figure 42: Scenario 5, total system component cost for (0.704 kW,16.9 kWh/day).

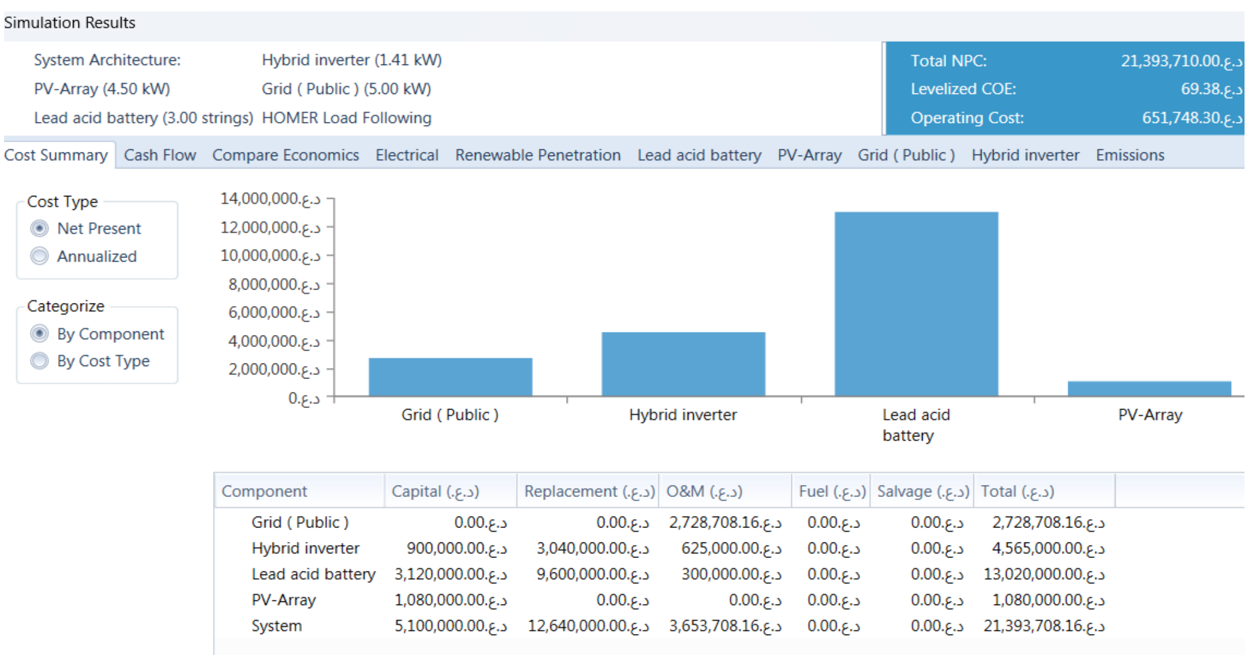

Figure 43: Scenario 5, total system component cost for (1.408 kW,33.79 kWh/day).

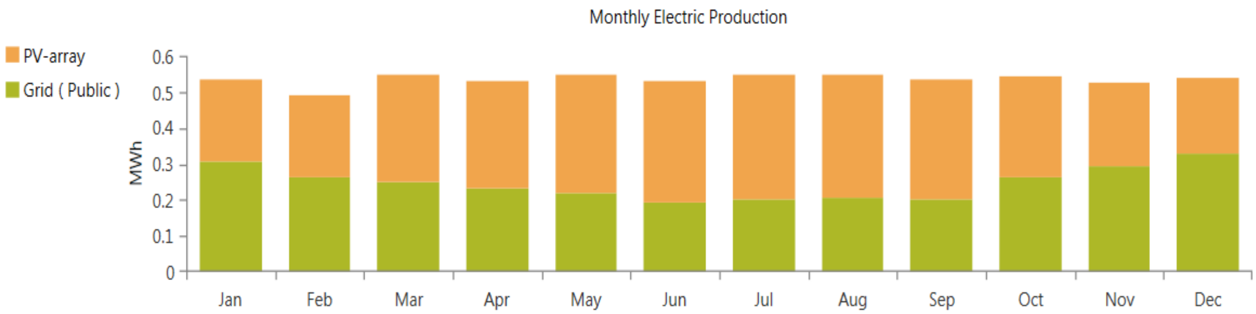

Figure 44: Scenario 5, total system electrical production for (0.704 kW, 16.9 kWh/day).

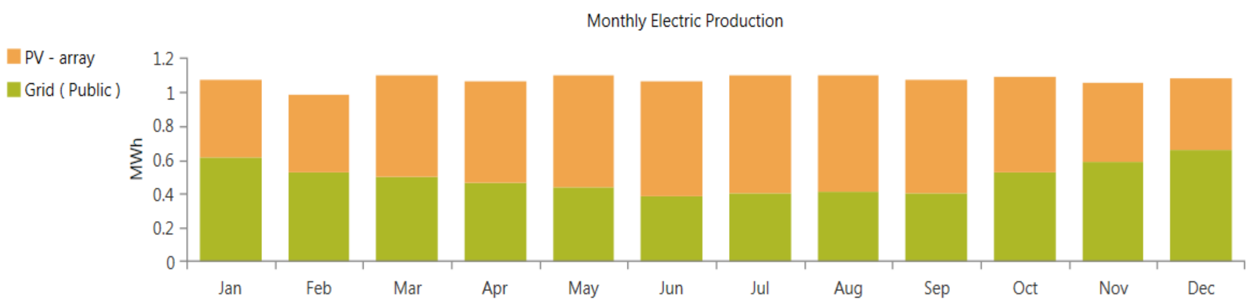

Figure 45: Scenario 5, total system electrical production for (1.408 kW,33.79 kWh/day).

In scenario 6, the PV solar system was integrated with the Prepaid national grid. The system's performance was evaluated against the aggregate NPC and COE of the previous system (scenario 3). The result is indicated in Table 13 for a 25-year lifespan. Figures 46 and 47 indicate the details of the system, whereas Figures 48 to 49 present the monthly electrical output.

Table 13: Comparison of scenario 3 with scenario 6, according to NPC and COE for a 25-year lifetime project.

Electrical load profile	**Electrical load profile**		**Electrical load profile**	
	NPC (IQD)	**COE (IQD)**	**NPC (IQD)**	**COE (IQD)**
0.704 kW, 16.9 kWh	24,057,150	156	18,428,570	100.8
1.408 kW, 33.79 kWh	48,100,060	156	36,721,340	100.44

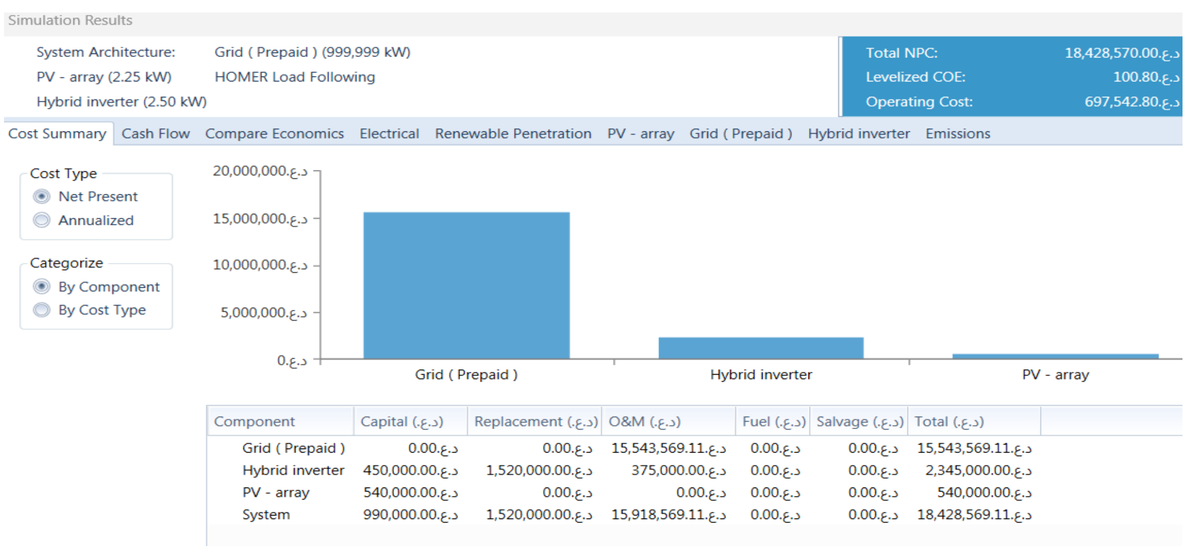

Figure 46: Scenario 6, total system component cost for (0.704 kW, 16.9 kWh/day).

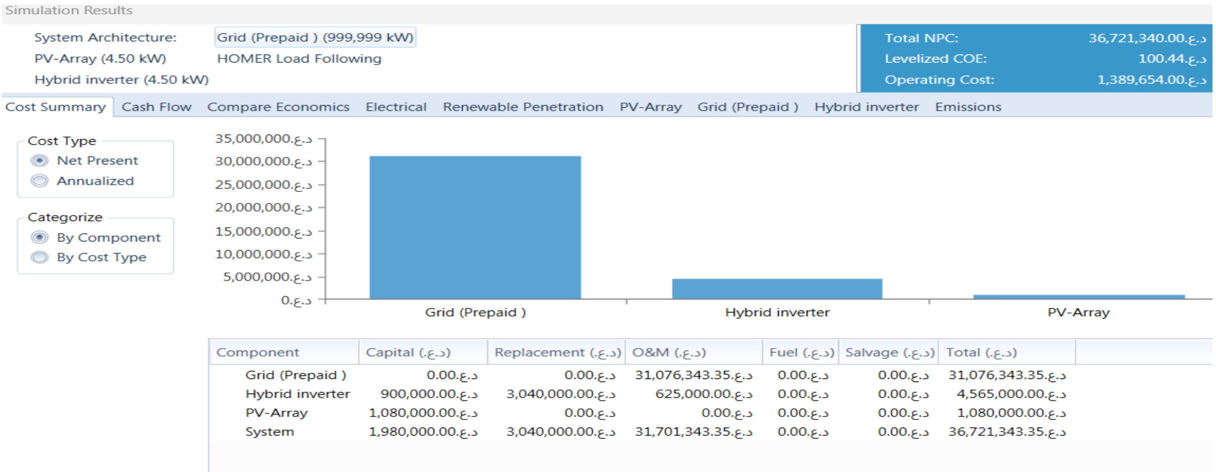

Figure 47: Scenario 6, total system component cost for (1.408 kW, 33.79 kWh/day).

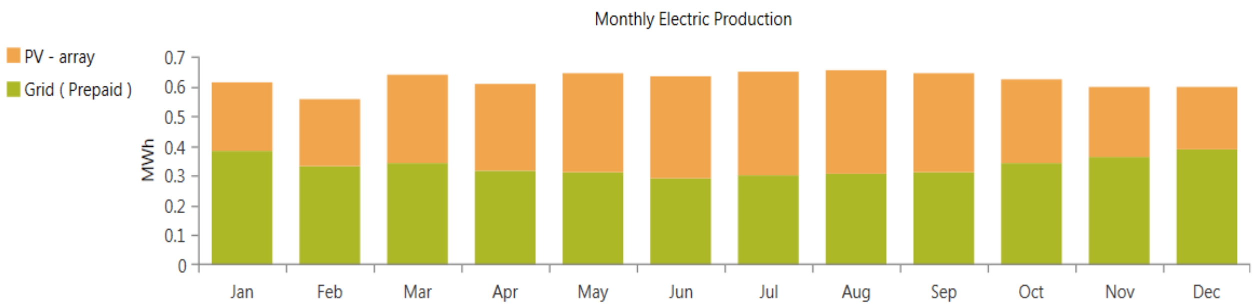

Figure 48: Scenario 6, monthly electrical production of the two electrical source systems for (0.704 kW, 16.9 kWh/day).

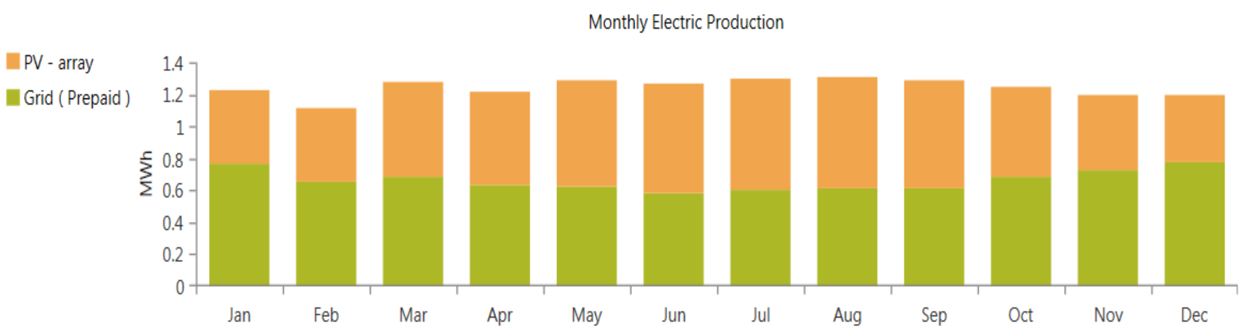

Figure 49: Scenario 6, monthly electrical production of the system for (1.408 kW, 33.79 kWh/day).

In scenario 7, the PV solar system was integrated with the Runaki national grid. The system's performance was evaluated against the aggregate NPC and COE of the previous system (Scenario 4). The result is indicated in Table 14 for a 25-year lifespan. Figures 50 and 51 delineate the specifics of the system, whereas Figures 52 and 53 present the monthly electrical output of the two power generation systems. The Runaki project system provides continuous electricity, avoiding the need for battery storage backup when combining renewable energy.

Table 14: Comparison of scenario 4 with scenario 6, according to NPC and COE for a 25-year lifetime.

Electrical load profile	Electrical load profile		Scenario 4 (Runki national grid)	
	NPC (IQD)	COE (IQD)	NPC (IQD)	COE (IQD)
0.704 kW, 16.9 kWh	12,333,920	79.98	10,058,960	55.02
1.408 kW, 33.79 kWh	33,555,960	108.83	22,836,590	62.46

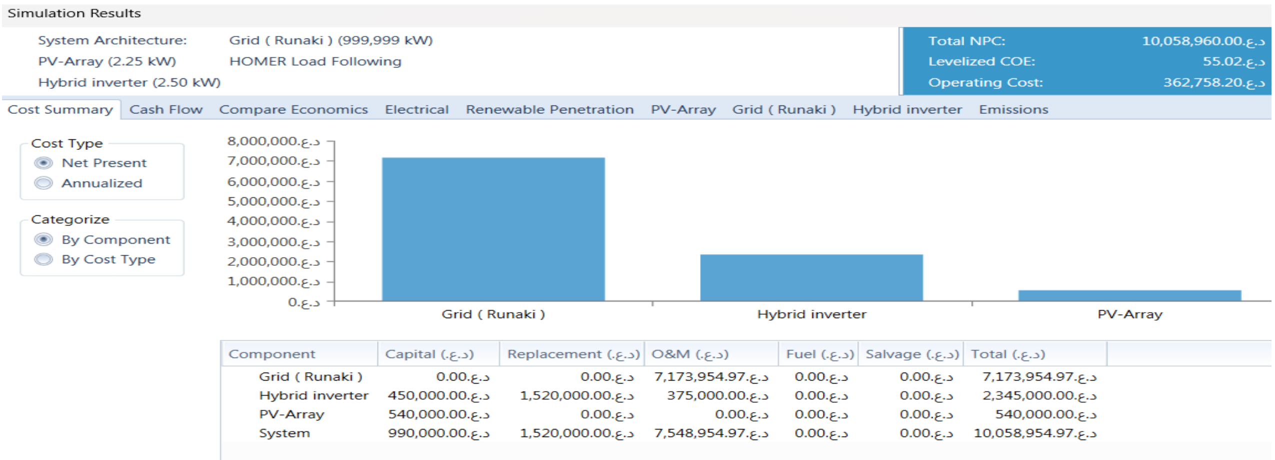

Figure 50: Scenario 7, total system component cost for (0.704 kW, 16.9 kWh/day).

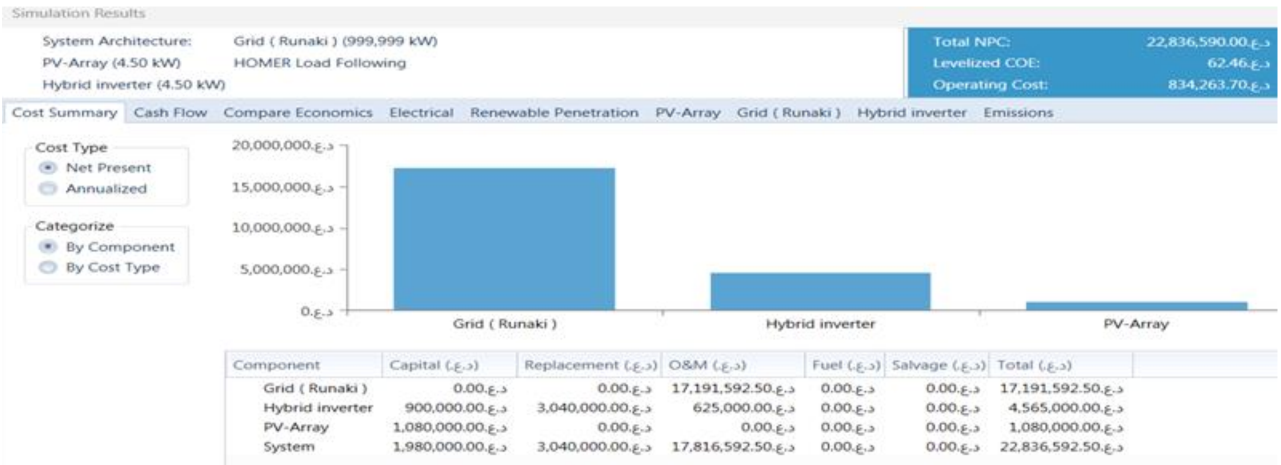

Figure 51: Scenario 7, total system component cost for (1.408 kW,33.79 kWh/day).

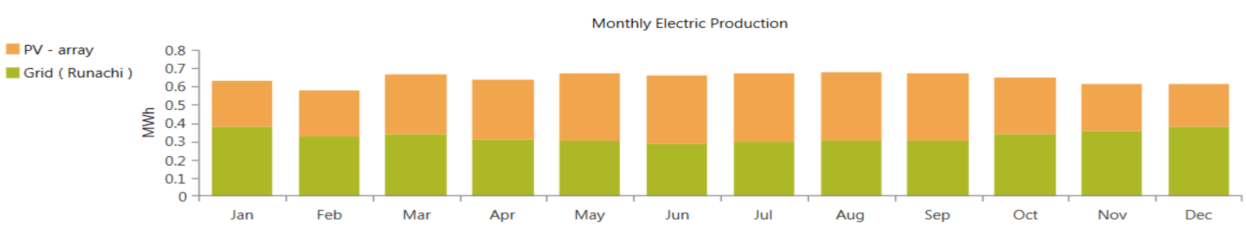

Figure 52: Scenario 7, the monthly electrical output of the two power generation systems for (0.704 kW, 16.9 kWh/day).

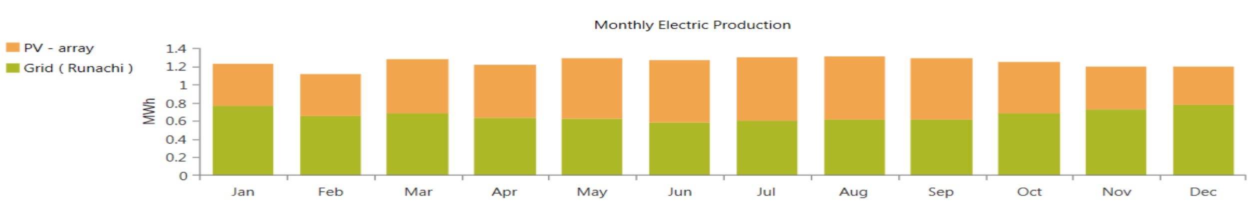

Figure 53: Scenario 7, the monthly electrical output of the two power generation systems for (1.408 kW, 33.79 kWh/day).

The final summary results for all scenarios are displayed in Tables 15 and 16 for the 24-hour electricity supply for a 25-year lifetime. The scenarios with the lowest NPC and COE are the best for producing 24 hours of electricity for residential buildings.

Table 15: The summary result of all scenarios according to NPC and COE for (0.704 kW,16.9 kWh/day).

<table>
<tr><th>Scenarios</th><th>System electrical sources</th><th colspan="2">NPC (IQD)</th><th colspan="2">COE (IQD/kWh)</th></tr>
<tr><td>1</td><td>Diesel generator</td><td>18,679,960</td><td rowspan="2">20,010,385</td><td>232.63</td><td rowspan="2">129.76</td></tr>
<tr><td>2</td><td>Grid (Public)</td><td>1,330,425</td><td>18</td></tr>
<tr><td>3</td><td>National grid (Prepaid system)</td><td colspan="2">24,057,150</td><td colspan="2">156</td></tr>
<tr><td>4</td><td>National grid (Runaki project)</td><td colspan="2">12,333,920</td><td colspan="2">79.98</td></tr>
<tr><td>5</td><td>National grid (Public) + (PV system)</td><td colspan="2">10,723,270</td><td colspan="2">69.54</td></tr>
<tr><td>6</td><td>National grid (Prepaid system) + (PV system)</td><td colspan="2">18,428,570</td><td colspan="2">100.8</td></tr>
<tr><td>7</td><td>National grid (Runaki) + (PV system)</td><td colspan="2">10,058,960</td><td colspan="2">55.02</td></tr>
</table>

Table 16: The summary result of all scenarios according to NPC and COE for (1.408 kW,33.79 kWh/day).

<table>
<tr><th>Scenarios</th><th>System electrical sources</th><th colspan="2">NPC (IQD)</th><th colspan="2">COE (IQD/kWh)</th></tr>
<tr><td>1</td><td>Diesel generator</td><td>37,360,060</td><td rowspan="2">40,093,134</td><td>232.63</td><td rowspan="2">130</td></tr>
<tr><td>2</td><td>Grid (Public)</td><td>2,733,074</td><td>18.5</td></tr>
<tr><td>3</td><td>National grid (Prepaid system)</td><td colspan="2">48,100,060</td><td colspan="2">156</td></tr>
<tr><td>4</td><td>National grid (Runaki project)</td><td colspan="2">33,555,960</td><td colspan="2">108.83</td></tr>
<tr><td>5</td><td>National grid (Public) + (PV hybrid system)</td><td colspan="2">21,393,710</td><td colspan="2">69.38</td></tr>
<tr><td>6</td><td>National grid (Prepaid system) + (PV system)</td><td colspan="2">36,721,340</td><td colspan="2">100.44</td></tr>
<tr><td>7</td><td>National grid (Runaki) + (PV system)</td><td colspan="2">22,836,590</td><td colspan="2">62.46</td></tr>
</table>

4 Conclusion

In the Kurdistan Region, residential buildings obtain energy from multiple electrical power sources to ensure a continuous electricity supply, including the conventional power grid, diesel generators during national grid outages, the Prepaid metering national grid system, and the Runaki project. Over the past decade, diesel generators have served as the primary source of energy for households. in this paper, seven cases were analyzed. The utilization of HOMER Pro software allowed a comprehensive examination of techno-economic aspects, demonstrating that the optimal configuration yields a net present cost (NPC) and a cost of energy (COE). In 2024, data obtained from households in the Raparin neighborhood of Erbil City revealed that these households purchased different kinds of energy from the local diesel generator. The study focuses on Raparin but could benefit from a brief discussion on scalability to wider Erbil or Kurdistan Region contexts. This study concentrated on the 0.704 kW and 1.408 kW, averaging 12.5 hours annually, whereas the same load was acquired from the Public national grid for 11.5 hours. The total energy purchased from the two different electrical sources is 16.9 kWh/day, 6168 kWh/year, and 33.79 kWh/day, 12333 kWh/year. The study assumes that homes utilize the same electrical load across various sources, indicating that households consume 6168 kWh//year and 12333 kWh/year, annually, from all energy sources that provide continuous electricity for 24 hours a day. The load profiles are (0.704 kW,16.9 kWh/day), and (1.408 kW, 33.79 kWh/day), directly connected to the scenarios. The HOMER Pro results for the 25-year lifetime project indicated that the diesel generator has a high COE of 232.63 IQD/kWh. Therefore, when the photovoltaic rooftop solar system is integrated into the Public national grid to replace the diesel generator, the NPC and COE for 0.704 kW, 16.9 kWh/day, reduce from 20,010,385 IQD to 10,723,270 IQD and 129.7 IQD/kWh to 69.54 IQD/kWh, respectively. the NPC and COE for 1.408 kW, 33.79 kWh/day, reduce from 40,093,134 IQD to 21,393,710 IQD and 130 IQD/kWh to 69.38 IQD/kWh, respectively. The combined solar system with Prepaid metering and the Runaki project from the national grid reduces the NPC and COE for both electrical load profiles in comparison to scenarios 3 and 4, respectively.

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