Energy and Power Engineering, 2026, 18(3), 141-155
https://www.scirp.org/journal/epe
ISSN Online: 1947-3818
ISSN Print: 1949-243X

# Energy Supply of a Telecommunications Center Dedicated to the Operation of Radio Equipment in Urban Areas: Case Study of the Hybrid Diesel Generator-Solar Photovoltaic-Electrical Grid System

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**How to cite this paper:** Kabore, H., Konane, D., Kabore, A., Sinon, S., Palm, K. and Sanogo, O. (2026) Energy Supply of a Telecommunications Center Dedicated to the Operation of Radio Equipment in Urban Areas: Case Study of the Hybrid Diesel Generator-Solar Photovoltaic-Electrical Grid System. *Energy and Power Engineering*, **18**, 141-155.
https://doi.org/10.4236/epe.2026.183008

**Received:** February 11, 2026
**Accepted:** March 17, 2026
**Published:** March 20, 2026



## Abstract

The objective of this work is to provide a technical and economic analysis of the energy optimization of an existing hybrid system supplying electricity to a telecommunications site. The site, characterized by a 50-meter-high, four-legged self-supporting tower made of angular sections with a permissible load of 18.6 $m^2$ and 40 m/s, is located in an urban area. However, the radio equipment at base stations (BTS) requires almost constant energy availability to ensure the operation of mobile and fixed telephone services, data, and critical infrastructure. The energy sources powering this equipment in the present study are hybrid systems, including diesel generator (DG), solar photovoltaics (PV), the national grid, and battery storage. However, combining these different energy sources to power radio equipment poses a major challenge in terms of choosing the best configuration. In this context, knowing the priority configuration type appears to be a viable solution for improving the energy reliability of the telecom site, reducing costs (investment, operation, maintenance, etc.), and limiting the carbon footprint. To address this concern, a numerical simulation based on HOMER Pro software was adopted to model the energy loads of the telecommunications center. The results show that the PV/grid configuration is the optimal solution for achieving an optimal compromise, with a significant reduction in net present cost and energy cost, respectively 76.75% and 76.77% compared to the second-best configuration (PV/battery/grid). From a technical standpoint, the optimal hybrid system allows for a total electricity production of 16,586 kWh/year shared between photovoltaics and the national grid, ensuring complete coverage of the continuous load without any capacity deficit and an electricity surplus of 20.2%.

## Keywords

Hybrid System, Energy, Electricity, Telecommunications, Optimization, HOMER Pro

## 1. Introduction

The rapid development of telecommunications networks is now a fundamental pillar of economic growth, social inclusion, and the digital transformation of modern societies. In urban areas, given the high population density, telecommunications centers ensure the continuous operation of radio equipment, in particular base transceiver stations (BTS), transmission and switching equipment, etc., whose energy availability directly determines the quality of service offered to users. According to the International Telecommunication Union [1], telecommunications infrastructure is characterized by high energy reliability requirements, near-constant power consumption, and high sensitivity to power outages. The electrical power supplying telecommunications sites is mostly direct current (−48 VDC), according to the international standard "ETSI EN 300 132-2" [2]. This energy is delivered by energy sources, notably RNE and GE, by converting alternating current into direct current, and by photovoltaic modules, by converting direct current into direct current using a step-down chopper.

In many developing countries, such as Burkina Faso, despite the gradual expansion of national electricity grids [3], the power supply to telecommunications sites continues to face major constraints such as frequent outages, voltage drops, and the continuous increase in electricity demand in urban areas. In this context, the use of hybrid energy systems [4] [5], combining the national electricity grid, generators, and renewable energy sources [6] [7], appears to be a technical and economic solution to ensure the continuity of service for telecommunications centers. In this regard, authors such as Zegueur *et al.* [8] have studied a hybrid system that supplies energy to telecommunications sites based on the technical and economic approach of different configurations such as: diesel generator only, photovoltaic-diesel-battery, wind-diesel-battery, photovoltaic-wind-diesel-battery, and photovoltaic-wind-battery. Optimization using HOMER Pro software showed that a hybrid system with 5 kW DG, 3.81 kW of photovoltaic capacity, three wind turbines, and a bank of 14 batteries was the best design for the proposed electrical system, with a net present cost of $85,673 and an energy cost of $0.214. As for

Olatomiwa *et al.* [9] presented their study on the technical and economic analysis of a hybrid system consisting of two configurations, namely PV-diesel-battery and PV-wind-diesel-battery systems, to be compared with the conventional stand-alone diesel generator system. Their results showed that the PV (10 kWp) - DG (5.5 kW) - battery (64 Trojan L16P units) system was the most economically viable option, with a total net present cost of $69,811 and a unit cost of electricity of $0.409. The authors' results also show that this system reduces $CO_2$ emissions by approximately 16.4 tons per year compared to the stand-alone diesel system.

In an effort to protect the environment from $CO_2$ emissions and, above all, in response to constantly rising energy prices, telecommunications operators are now turning to the ESCO (Energy Service Company) model [10] [11]. This model combines solar power, batteries, diesel generators, and the electrical grid to offer a comprehensive approach that includes audits, studies, renovation solution design, project implementation and management, operation and maintenance, energy monitoring, and financing.

It is in this context that the present study aims to design, analyze, and evaluate the energy supply of an existing hybrid PV-generator-national grid system. HOMER Pro software is used to simulate different configurations of the hybrid system in order to find the best optimal configuration.

## 2. Materials and Methods

### 2.1. Materials

The telecommunications site studied in this study is located in an urban area, more specifically in Gounghin/Ouagadougou in Burkina Faso. **Photo 1** shows a general view of the urban site known as Gounghin ZI. This site consists of the following components:

- A 4-legged self-supporting tower supporting the radio equipment of the base stations (BTS), made of angular sections, with a height of 50 m and a permissible load of 18.6 $m^2$ and 40 m/s;
- A 10.8 kW three-phase diesel generator supplying alternating current to the power bay via the automatic transfer switch (ATS) [12];
- An external 1000-liter fuel storage tank supplying the DG;
- A 30 A type C tariff distribution via the national power grid supplying alternating current to the power bay via the ATS;
- An automatic AC (alternating current) load switch called ATS supplying alternating current to the power bay;
- A solar field consisting of 12 modules of 325 Wp and a bank of 24 OPzS Solar 550 Ah/2 V batteries supplying the power rack with direct current;
- A power rack converting the various energy sources into direct current to supply the BTS equipment with 48 VDC.

The above components, which are installed and already in place at the Gounghin ZI telecommunications site, operate in a manner that prioritizes the solar photovoltaic system.

a) After installation b) Before installation

**Photo 1.** General view of the Gounghin ZI telecommunications site.

**Figure 1** shows the electrical wiring diagram for the various energy sources (PV, DG, and Grid) up to the 48 V DC power supply. This figure shows all the electrical components at the telecommunications site.

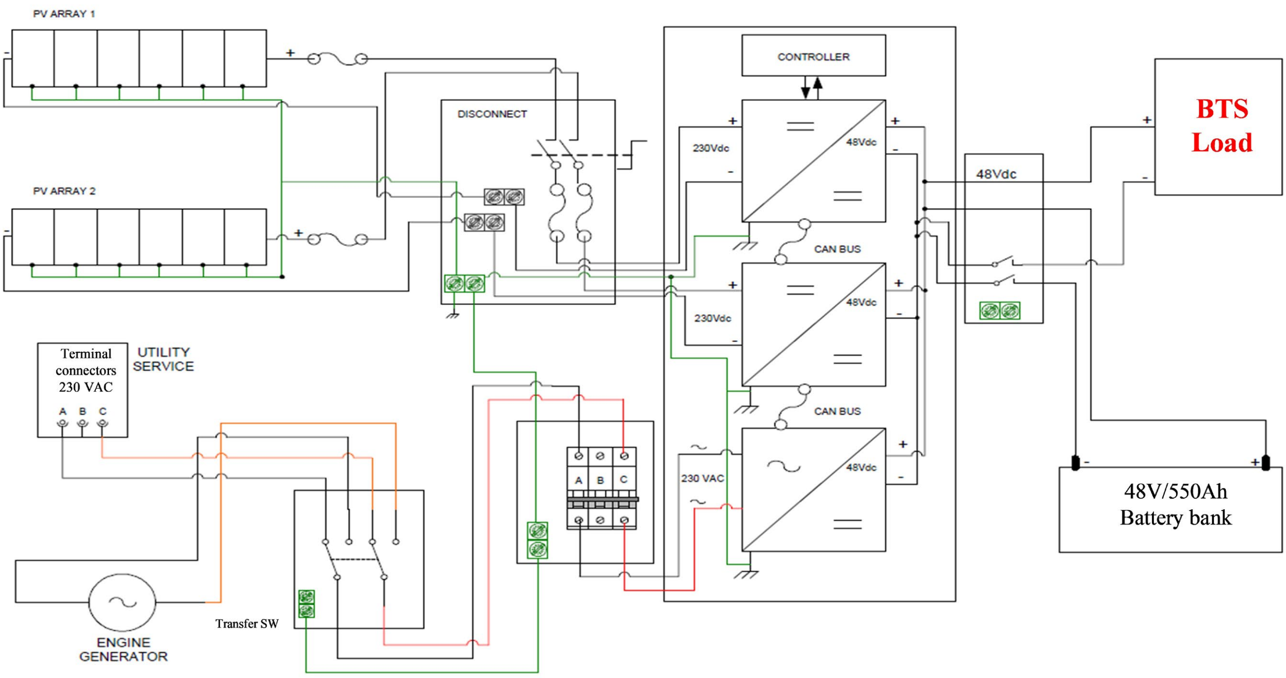


**Figure 1.** Multi-wire electrical wiring diagram for the Gounghin ZI site.

## 2.2. Methods

### 2.2.1. Working Hypothesis

To ensure the consistency of our analysis, the following hypotheses are adopted:

- The production of the solar photovoltaic field is based on sunshine data for the city of Ouagadougou;
- Fuel and component costs are based on current market values in Burkina Faso;
- The electrical grid is available but subject to frequent outages;
- The energy storage system is included to smooth out fluctuations in solar production.

### 2.2.2. Solar Energy and Telecom Load

The Gounghin ZI telecommunications site is located in a very sunny area at geographical coordinates 12˚21.978'N and 1˚32.485'W and therefore has enormous solar energy potential. The average monthly and daily data for daily solar radiation were obtained from NASA's surface meteorology database [13] and from the field at the site, respectively. These data were implemented in HOMER Pro, which introduces a clarity index based on the latitude and longitude of the site in question. Figure 2 and Figure 3 show the monthly variation in solar radiation as a function of the clarity index and the evolution of daily sunshine, respectively. Solar radiation appears to be well distributed at the Gounghin ZI site, with a huge average solar potential of 5.55 kWh/(m$^2$.day) and an average daily sunshine duration of 6.5 hours. This analysis shows that the site studied has high solar irradiance for photovoltaic applications.

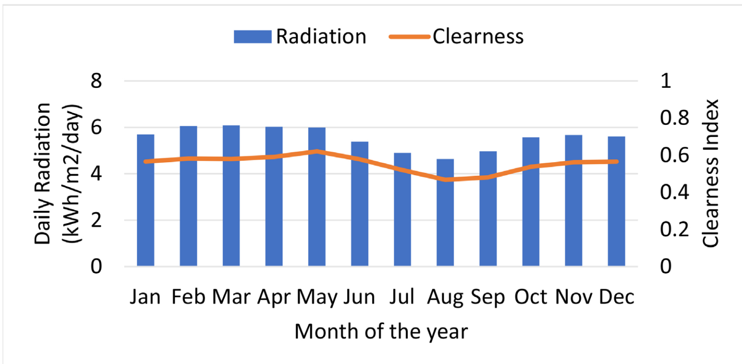


Figure 2. Change in average monthly solar radiation.

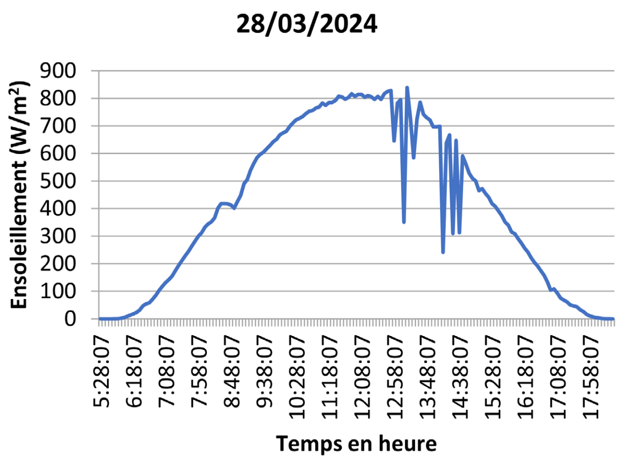


Figure 3. Change in daily sunshine.

The electricity consumption of the Gounghin ZI site obtained on the monitoring platform (gFMS) in terms of power and implemented under HOMER Pro is shown in Figure 4. This is a primary load (BTS equipment) in direct current with an average consumption of 35.12 kWh per day.

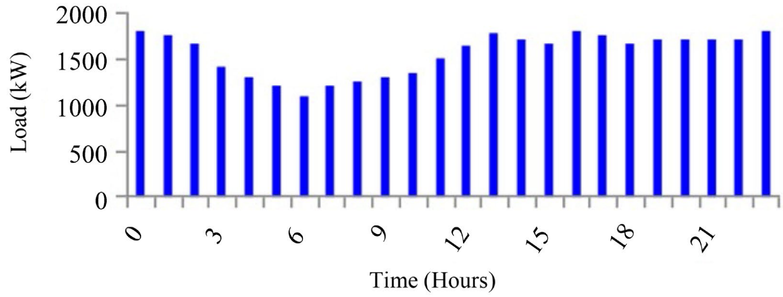


**Figure 4.** Daily load profile for the Gounghin ZI site.

#### 2.2.3. Governing Equations

The model used in this study is the ESCO model, which combines solar power, batteries, a diesel generator, and the electrical grid. The mathematical model for each component is defined in the section below.

**1) PV model**

The Equation (1) for calculating the output power of the solar photovoltaic field can be evaluated using the following expression [8] [14]:

$$P_{PV} = Y_{PV} f_{PV} \left( \frac{\bar{G}_T}{\bar{G}_{T,STC}} \right) \left[ 1 + \alpha_P \left( T_C - T_{C,STC} \right) \right] \tag{1}$$

where,

$Y_{PV}$ is the nominal power of the solar photovoltaic field (kWp);

$f_{PV}$ is the derating factor (%);

$\bar{G}_T$ & $\bar{G}_{T,STC}$ are the solar radiation incident on the photovoltaic field and the standard incident radiation (W/m$^2$), respectively;

$\alpha_P$ is the power temperature coefficient (%/C);

$T_C$ &$T_{C,STC}$ are respectively the temperature of the photovoltaic cell and the standard temperature (˚C).

**2) Generator model**

The diesel generator is used as a backup in this study to power the Gounghin ZI site when the first two energy sources (PV + storage and grid) are unavailable.

The fuel consumption of the diesel generator, defined in Equation (2), is evaluated assuming the following linear relationship [14]:

$$FC_{diesel} = F_O . P_{DG} + F_1 . P_{DR,S} \tag{2}$$

where,

$F_O$ is the intercept coefficient of the generator's fuel curve (L/kW);

$P_{DG}$ is the rated power of the generator set (kW);

$F_1$ is the slope of the fuel curve of the diesel generator (L/kW);

$P_{DR,S}$ is the output power of the generator set (kW).

**3) Electricity grid**

The Gounghin ZI telecommunications site is a hybrid on-grid site, *i.e.*, connected to the grid with other energy sources, with the grid being the secondary energy source supplying the power rack continuously or intermittently depending on the load shedding of the grid. The type of tariff subscribed to for this site is type C 30 A.

**4) Energy storage system model**

Due to the intermittent nature of solar energy, storage in accumulators is necessary to ensure the reliability and stability of energy production. Lead-acid batteries with a capacity of 1.1 kWh, a nominal voltage of 2 V, and a service life of 25 years were used in this study. The expression for determining the storage capacity of the batteries is given by Equation (3) [9] [15]:

$$C_{wh} = \frac{E_L \times AD}{\eta_{inv} \times \eta_{bat} \times \eta_{cabl} \times DoD} \tag{3}$$

where,

$E_L$ is the average daily energy consumption (kWh);

$AD$ is the daily battery autonomy (days);

$\eta_{inv}$ & $\eta_{bat}$ & $\eta_{cabl}$ are the efficiency of the inverter, battery, and cables, respectively (%);

$DoD$ is the depth of discharge of the battery (%).

**5) Converter**

The 10.8 kW generator and the grid produce alternating current, while the load is 48 V direct current. This requires a rectifier for energy transfer. The system uses a rectifier with 95% efficiency and a 15-year lifespan. In addition, the photovoltaic modules produce direct current, but at very high voltages. Solar chargers (step-down choppers) are used for direct-to-direct conversion. The proposed system model is shown in **Figure 5**.

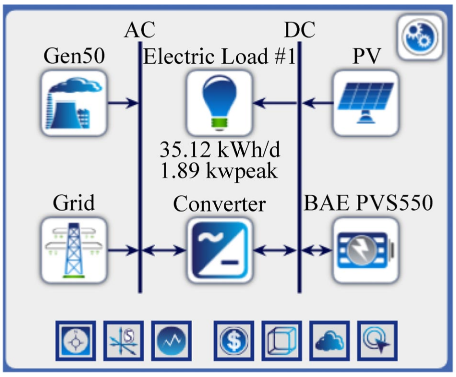


**Figure 5.** On-grid hybrid system model on the HOMER Pro interface [14].

**6) Economic data**

The total NPC (lifecycle cost) is the main objective function of HOMER Pro. This is the value used by the software to rank all types of system configurations among the optimization results and to calculate the total annual cost and the levelized cost of energy (LCOE).

The expression used to evaluate the NPC is illustrated in Equation (4) [8], [14]:

$$C_{NPC,tot} = \frac{C_{ann,tot}}{CRF} \tag{4}$$

where,

$C_{ann,tot}$ is the total annualized cost ($/year);

$CRF$ is the capital recovery factor, expressed as follows in equation (Equation 5):

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (5)$$

with,

$N$, the number of years;

$i$, the real annual discount rate (%).

Another practical economic measure for comparing systems in HOMER Pro is the discounted energy cost (COE). It can be evaluated using Equation (6) [8] [14]:

$$COE = \frac{C_{ann,tot}}{E_d} \quad (6)$$

with,

$C_{ann,tot}$, the total annual cost ($/year);

$E_d$, the total electrical load served (kWh/year).

The economic parameters for each component in **Figure 5** are shown in **Table 1**.

**Table 1.** Economical component input

| Components | Capital cost | Replacement cost | Operating and maintenance cost | Lifespan |
|---|---|---|---|---|
| PV | 150 USD/Unit | 0.00 | 40 USD | 25 years |
| Diesel generator | 5000 USD | 0.00 | 500 USD | 15,000 hours |
| Battery | 300 USD/Unit | 100 USD | 50 USD | 20 years |
| Converter | 750 USD | 750 USD | 0.00 | 15 years |
| Fuel | 15,000 USD | -- | -- | Over the lifetime of the diesel |
| Electricity grid | 2545 USD/year | -- | 25 USD | Over a period of 30 years |

The HOMER PRO optimizer was used to determine the exact optimal size of the other components. As for the grid, the system is simulated with or without it, with an annual capacity purchased ranging from 0 to 5 kW for a 30 A distribution as indicated in the field. The various characteristics of the existing components on site are used and implemented in the above software.

**7) Electricity surplus model**

Electricity surplus refers to electricity production exceeding demand, resulting in excess energy that cannot be used, *i.e.*, that is neither consumed by the DC load, nor stored in batteries, nor fed into the grid. Equation (7) shows how to calculate it.

$$Ex_{el} = \frac{P_{el} - C_{el}}{P_{el}} \times 100 \quad (7)$$

where,

$Ex_{el}$ is the electricity surplus (%);

$P_{el}$ is the total electricity production (kWh/year);

$C_{el}$ is the total energy consumption (kWh/year).

## 3. Results and Discussion

### 3.1. Synoptic Diagram

The synoptic diagram representing the hybrid power supply architecture combining the photovoltaic field, the electrical grid, the generator, battery storage, converters (AC/DC and DC/DC), and measurement and supervision systems is shown in Figure 6.

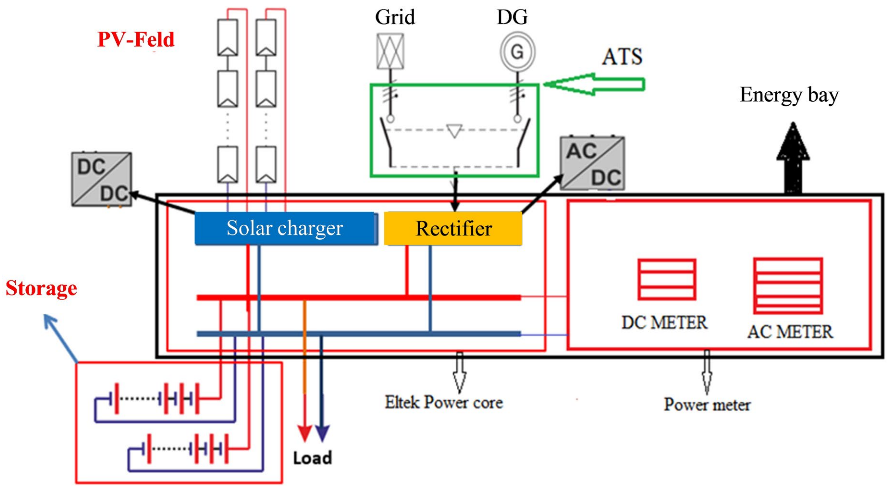


Figure 6. Single-line diagram of the hybrid power supply architecture.

The main objective is to ensure a continuous and reliable power supply to critical loads, typically telecommunications equipment operating at −48 VDC. An hourly simulation based on time series was performed using HOMER Pro software for all possible configurations of the architectural diagram of the Gounghin ZI telecom site, over an annual period. This simulation aims to evaluate the operational performance of the system, including annual electricity production, annual energy supplied to the load, surplus electricity, and the fraction of renewable energy. The simulation results present and analyze those relating to the optimal system configuration.

### 3.2. Optimal Configurations

In this section, we present the three best hybrid system configurations compared to the conventional diesel/battery backup system. The performance parameters of the PV, diesel, grid, battery, solar charger, and rectifier, respectively, for the

PV/grid, PV/battery/grid, PV/diesel/grid, and diesel/grid system configurations are presented in Table 2. The table simultaneously evaluates the technical, energy, and economic performance of each configuration.

Table 2. Performance parameters of different types of configurations.

| Parameters | Configuration type | | | |
|---|---|---|---|---|
| | **PV/grid** (Best optimal) | **PV/battery/grid** ($2^{nd}$ best optimal) | **PV/diesel/grid** ($3^{rd}$ best optimal) | **Diesel/battery** ($4^{th}$ best optimal) |
| Photovoltaic capacity (kWp) | 5 | 5 | 5 | - |
| Generator capacity (kW) | - | - | 2.5 | 2.5 |
| Grid capacity (kW) | 5 | 5 | 5 | - |
| Battery capacity (parallel string) | - | 6 | - | 48 |
| Rectifier capacity (kW) | 2 | 2 | 2 | 3 |
| Solar charger capacity (kW) | - | - | - | - |
| Distribution strategy | CC | CC | CC | CC |
| Total investment cost ($) | 2250 | 45,450 | 14,750 | 360,350 |
| Total NPC cost ($) | 38,253 | 164,503 | 7.95 M | 92.3 M |
| Total replacement cost ($) | 636.41 | 5227 | 636.41 | 37,681 |
| Total operating and maintenance cost ($) | 35,486 | 116,533 | 7.93 M | 91.88 M |
| Total fuel cost ($/year) | - | - | 61.4 | 1079 |
| Total cost ($) | 38,252 | 164,503 | 7.95 M | 92.27 M |
| Operating cost ($/year) | 2785 | 9209 | 613,881 | 7.11 M |
| Cost of energy (COE) ($) | 0.231 | 0.993 | 47.98 | 556.83 |
| Photovoltaic production (kWh/year) | 8,103 | 8103 | 8103 | - |
| Grid generation (kWh) | 8,483 | 5381 | 7765 | - |
| Diesel generation (kWh) | - | - | 751 | 14,100 |
| Total electricity generation (kWh/year) | 16,586 | 13,484 | 16,619 | 14,100 |
| Primary DC load (kWh/year) | 12,819 | 12,819 | 12,819 | 12,819 |
| Renewable energy share (%) | 33.8 | 58 | 33.6 | - |
| Capacity deficit (kW) | 0 | 0 | 0 | 0 |
| Unmet load (kWh/year) | 0 | 0 | 0 | 0 |
| Electricity surplus (%) | 20.2 | 0 | 20.3 | 0 |
| Fuel consumption (liters/year) | - | - | 245 | 4315 |

### 3.2.1. PV/Grid Configuration

The optimal configuration at 5.55 kWh/m$^2$ per day of average solar radiation is based exclusively on the combination of the photovoltaic field (5 kWp) and the electrical grid (5 kW), without energy storage or a generator. In terms of energy, it has an annual photovoltaic production of 8103 kWh, supplemented by 8483 kWh supplied by the grid, for a total production of 16,586 kWh/year. This energy fully satisfies the annual DC load of 12,819 kWh, with no capacity deficit or unsatisfied load. However, a 20.2 % electricity surplus is observed, indicating a limitation on solar self-consumption in the absence of storage. This surplus DC energy is dissipated into the environment and cannot be fed into the grid. For this reason, the addition of several battery strings can compensate for the loss of electricity production, thereby optimizing the use of surplus electricity and increasing the overall autonomy of the system.

The average monthly electricity production of the photovoltaic field and centralized electricity grid is shown in Figure 7. We can see that the share of production from each energy source, namely PV and the grid, represents 48.9% and 51.1% respectively in an urban area well served by the electricity grid. Here, we consider that energy production by the grid is virtually continuous and uninterrupted.

The share of renewable energy reaches 33.8%, which remains moderate but acceptable in an urban context with a grid.

Economically, this configuration is characterized by a very low initial investment ($2250), a total discounted cost ($38,253), and a minimal cost of energy ($0.231/kWh). Annual operating costs are also limited ($2785/year). Furthermore, the total NPC for the diesel/standalone battery system is $92.3 million, which is more than 2400 times higher than that of the photovoltaic/grid configuration. Therefore, the hybrid system based on the latter is considered a cost-effective solution compared to the diesel/standalone battery system.

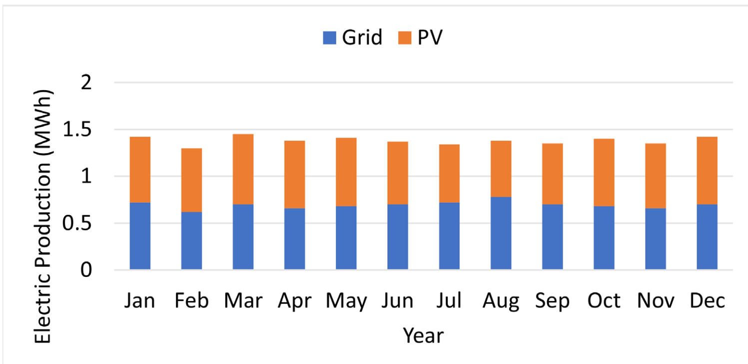


Figure 7. Variation in average monthly electricity production from photovoltaic and grid sources.

### 3.2.2. PV/Battery/Grid Configuration

The second-best optimal combination includes a 5 kWp photovoltaic generator, 5 kW of grid electricity production, and a nominal storage capacity of 143 kWh. Photovoltaic production remains the same (8103 kWh/year), but the grid contribution decreases significantly to 5381 kWh/year thanks to the use of storage. Total annual production amounts to 13,484 kWh, which is sufficient to cover the annual load without any shortfall. The total absence of surplus electricity shows better utilization of solar energy, resulting in a renewable share of 58%.

The average monthly electricity production of the hybrid system is shown in Figure 8.

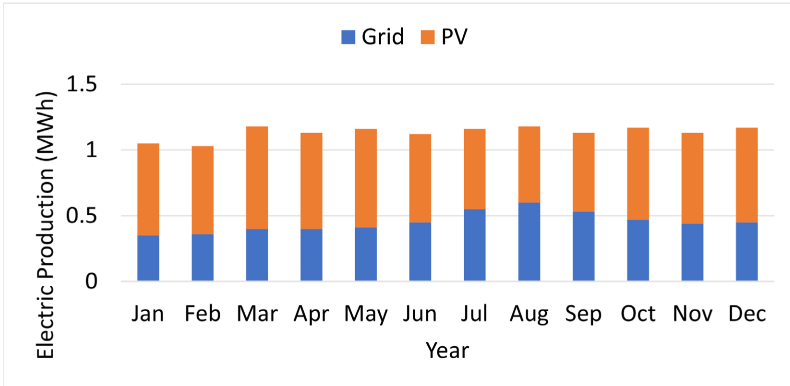


**Figure 8.** Variation in average monthly electricity production from photovoltaics with storage and from the electricity grid.

Solar energy, including the storage system, provides nearly 60.1% of total annual production, followed by the grid at 39.9%.

From an economic standpoint, the introduction of batteries leads to a sharp increase in initial investment ($45,450), NPC ($164,503), and COE ($0.993/kWh). Operating and maintenance costs, estimated at $116,533, are also higher due to battery aging. On the other hand, the total NPC of the autonomous diesel/battery system is approximately 561 times higher than that of this system. Therefore, this configuration is a good technical compromise for maximizing the use of renewable energy, but its high cost limits its economic profitability.

#### 3.2.3. PV/Diesel/Grid Configuration

The third best optimal configuration combines the PV field (5 kWp), the interconnected power grid (5 kW), and a 2.5 kW diesel generator. Annual PV production is 8103 kWh, supplemented by 7765 kWh from the grid and 751 kWh produced by the generator. Total annual production reaches 16,619 kWh, fully covering the load without any deficit. However, a 20.3% electricity surplus is observed, similar to the PV/grid configuration.

The average monthly electricity production of the hybrid system is illustrated in Figure 9. Solar energy provides nearly 48.8% of total annual production, followed by the grid and diesel, which account for 46.7% and 4.52%, respectively. The diesel engine runs 489 hours/year (capacity factor of 3.43%) to produce 751 kWh/year of energy using 245 liters of fuel. The high number of operating hours of the diesel engine increases operating costs and contributes to $CO_2$ emissions of 5.55 kg/year into the environment.

Economically, despite a moderate initial investment ($14,750), this configuration has an extremely high NPC ($7.95 million) and a COE of $47.98/kWh. These values are explained by very high operating costs ($613,881/year) related to annual fuel consumption (254 liters/year), maintenance, and the limited lifespan of the generator. However, this system is still better than the diesel/battery stand-alone system, as the latter's NPC is more than 1060% higher than that of the PV/grid/diesel system.

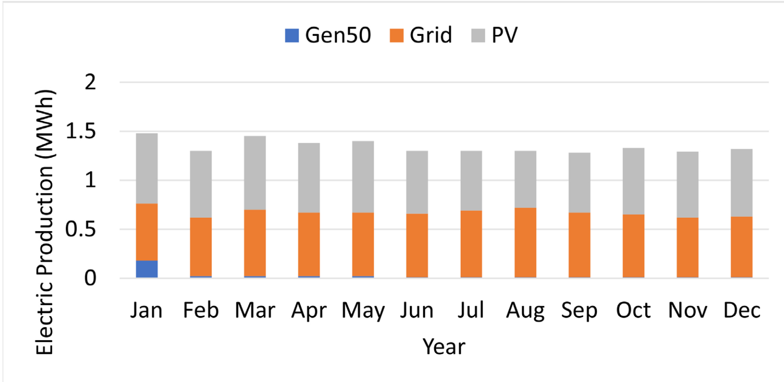


**Figure 9.** Evolution of average monthly electricity production from photovoltaics, the generator, and the national grid

## 4. Conclusions

To meet the high demand for high-frequency data such as internet connection, communications, etc. in urban areas, mobile phone operators are now resorting to the large-scale deployment of telecommunications stations, most of which face several technical, economic, and environmental challenges. These challenges include ensuring the continuous, uninterrupted operation of energy sources at these telecom sites, taking into account electricity production, investment costs, energy costs, and carbon dioxide ($CO_2$) emissions. To address this constraint, this study analyzes the technical and economic feasibility of a centralized hybrid system combining photovoltaics with storage, the electrical grid, and a diesel generator to power a telecommunications station located in Gounghin ZI Ouagadougou, Burkina Faso. HOMER Pro software was used for the numerical simulation of the different types of system configurations considered. The results showed that the PV/grid configuration is the optimal solution from a technical and economic standpoint. From an economic perspective, this configuration has the lowest net present cost (NPC), estimated at $38,253, and a levelized cost of energy (COE) of $0.231/kWh. In comparison, the second-best hybrid system (PV/battery/grid) has a higher NPC of $164,503 and a COE of $0.993/kWh.

From a technical standpoint, the optimal hybrid system enables a total electricity production of 16,586 kWh/year shared between photovoltaics and the grid, ensuring complete coverage of the DC load (BTS radio equipment) without any capacity shortfall. However, given the 20.2% electricity surplus, adding several battery strings is strongly recommended in order to compensate for the loss of electricity production and optimize the overall autonomy of the system.

## Data Availability Statement

The data presented in this study are available upon request from the corresponding author, who declares that no AI tools were used to obtain these data.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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