Design and Feasibility Study of Solar Photovoltaic (PV) Technology Applications in Ouagadougou-Burkina Faso

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Abstract-This paper tried to design a PV system and to assess solar power cost per kWh of energy produced using different sizes of PV, batteries and inverters to be used in Ouagadougou-Burkina Faso. The system has a daily load of 12.2 kWh/day, 1.5 kW PV modules, 5 batteries, (6 V and 360 Ah), and 1 kW inverter. The results have shown that the optimum cost of PV system energy 0.31 $/kWh for the used technique, is attractive option in comparison with the cost of diesel engine energy 0.5581 $/kWh. The most expensive system is when we use 3 kW PV array, 3 batteries and 1.5 kW inverter, with an initial cost, NPC, and electricity cost of 7,680 $, 9,556 $, and 0.426 $, respectively. Investigations have shown that PV system could represent a good option to be used to supply houses in rural area of Burkina Faso. The analysis showed that using PV system instead of diesel generator will prevent greenhouse gases emission highly.

Keyword- *HOMER software**,** Energy cost, PV modules, Ouagadougou-Burkina Faso*

I. INTRODUCTION

Energy and the provision of fuel needed in this decade is the main concern of States and decision-makers for their direct impact on citizens in terms of providing amenities through electricity and transport through the fuel of cars and vehicles [1]. Full reliance on fossil fuels to secure energy supplies has become risky because of the fluctuation of oil prices and its association with political problems [2]. Excessive combustion of fossil fuels causes high environmental pollution, global warming and climate change [3, 4]. Climate change resulted in drought that has caused millions of people to flee their homes [5]. The shift to clean, renewable energies, such as solar energy, has become a modern necessity [6].

Every days sun is shine our earth and gets most of its energy from there. This is called the solar energy. Solar energy travels from the sun to the earth in rays. Some are light rays that we can see. Some are rays we can't see, like x-rays. Energy in rays is called radiant energy [7]. Today, solar energy is used in many applications such as solar distillation [8, 9], solar chimney [10, 11], concentrated power plants [12, 13], water heaters [14, 15], air heaters [16, 17], Trombe wall [18, 19], solar ponds [20, 21], and photovoltaic cells [22, 23]. Photovoltaic (PV), also called solar cell, is a solar energy device that produce electricity directly from sunlight by converting the light into electricity. PV systems produce clean, reliable energy without consuming fossil fuels and can be used in a wide different of applications [24, 25]. The solar PV technology is by far the most ideal energy conversion system [26]. It is a device that harnesses the most abundant source of energy, solar radiation [27]. PV technology is suitable for electricity generation in off-grid power plants in rural desert areas where the solar energy can reduce diesel fuel use [28, 29]. Moreover, the efficiency of PV technology is influenced by high air temperature [30, 31], humidity [32, 33], solar radiation [34, 35], and dust contamination [36-40].

The researchers have made many proposals to enhance the performance of PV modules and reduce its losses [41, 42]. In this attempt the PVT systems are taking a great part of interest as it convert the heat absorbed from solar radiation and take advantage of it as useful heat for other purposes [43-46]. In the same time, PVT technology reduces the temperature of PV panels and increases its electrical efficiency [47-51].

Many references have studied the optimum design of PV system using HOMER software [52, 53]. Ref. [54]; addresses the need for PV solar system to power a health clinic in the rural areas in southern Iraq. The authors used HOMER software computer model to determine the most economic system. They proposed system with a daily load of 31.6 kWh which is composed of 6-kW PV modules, 80 batteries (225 Ah and 6 V), and a 3-kW inverter. The total initial cost, net present cost, and cost of electricity produced from the system are 50,700 US$, 60,375 US$, and 0.238 US$/kW h, respectively. Ref. [55] proposed an optimization solution of a hybrid system of renewable energy by using the Homer software for remote areas in Tunisia. The Hybrid systems involve combination of different energy sources like wind/battery, PV/battery, wind/PV/battery, wind/PV /diesel/battery. The climatic data are specific for the area of Hawaria in Tunisia. For the wind/PV/battery the optimal configuration is composed by 8 kW panel PV, 2 wind turbine, 118 batteries and 12 kW power converters. The initial cost and the operation cost 165.450 US$, 2.102 US$/yr respectively. The authors proves that the combination of a diesel generator, as buck-up source, with the hybrid wind/PV/battery system is the best solution to guarantee the reliable supply without interruption of the load under the climatic data change.

Ref. [56] discussed the efficient system of sustainable renewable energy for domestic used and its total cost in Khartoum in Sudan. The author's method was the collection of the basic data of solar radiation, wind speed and other required input data, and then the authors used HOMER software to develop the hybrid optimization simulation. The proposed load is 54 kWh/d, and 5.3 kW as a peak. The cost of the PV module including installation has been considerate as 220 SP/W for Sudan. The authors found that it is better to use wind/PV combination system for 50 homes instead of single home system. Ref. [57] used HOMER software for optimization to find the best cost benefit of hybrid -solar power generation relative to use cost in Nigeria. The cost benefit analysis of a wind/solar hybrid system was done using HOMER software and comparison was also made with utility supply. Central grid power is the least expensive option but may not be available to most rural households far from the grid. Hence it is necessary to supply these areas from isolated power sources. The proposed system used (0.05 – 0.4 kW) PV panel with (0.4 kW DC) FD series wind turbine, (0.1 – 1.5 kW) converter, and (200 Ah / 12 V, bank size: 1-8 batteries, vision 6 FM200D) battery. The authors result obtained from the optimization gave the initial capital cost as 3,455 US$ while operating cost is 69 US$/year. Total net present cost (NPC) is 4251 US$ and the cost of energy (CoE) is 1.74 US$/kWh. The authors found that, the hybrid system have a pay-back period of about thirty-three years and at current costs. Ref. [58]; designed a hybrid power generation system suitable for remote area application by using HOMER software, having a primary load of 3 kWh/d and a 307 peak, it is being supplied by a Micro-hydro model, wind turbine models, PV array models, a diesel generator and batteries.

In this paper, the energy generated by PV technology to be estimated using weather data for Ouagadougou-Burkina Faso. HOMER software will be used for design and analysis of the 140 W PV systems. A sensitivity analysis to be carrying out on some factors: capital cost, conversion efficiency and discount rate.

II. RESEARCH METHODOLOGY

PV system size and performance strongly depend on metrological variables such as solar energy, and ambient temperature and therefore, to optimize a PV system, extensive studies related to the metrological variables have to be done [59]. The importance of the meteorological data in sizing PV systems lies in the fact that the PV modules output energy strongly depends on the available solar energy, and ambient temperature. The performance of a PV module strongly depends on the sun light conditions.

A. Study Site Specifications

Burkina Faso is an African country on the western side of the continent surrounded by land. Ouagadougou is Burkina Faso's political, economic, commercial and industrial capital, the central city of Burkina Faso. It is the largest city in Burkina Faso in terms of population and density. The climate in the city of Ouagadougou is tropical, rainy in the summer and dry in winter. Rain falls in the southwest and grows in the northeast. It is warm in the summer, so it is characterized by two seasons, a dry winter and a rainy summer from June to September, covering savannah and bushes a large area of its land.

Standalone PV systems, studied in this article, are widely used in the remote areas where there is no access to the electricity grid. These systems prove its feasibility as compared to conversional standalone power systems such as diesel generators especially for remote applications because of the difficulty in accessing the remote areas and the cost of the transportation. However, a PV system must be designed to meet the desired load demand at a defined level of security.

B. Load Estimation

Firstly in designing the PV power system. An estimation of the energy demand of the load should be done by multiplying the power of each appliance by the average number of hours of use. Then a 20% might be added to allow for losses caused by wiring [60], DC to AC conversion, dirty modules, etc. Loads whatever AC or DC loads should be described in a work sheet by load current, load voltage, daily duty cycle, weekly duty cycle, power conversion efficiency, nominal systems voltage and Amp-hour load. Table 1 shows an example of a work sheet to estimate the load demand. The designer should consider energy conserving substitutes for items that are used often. Identify large and/or variable loads and determine if they can be eliminated or changed to operate from another power source. LED lamps should be used in place of incandescent lamps. They provide better light levels with much lower power demand.

Table 1: Load Estimation

Load description	QTY		AC Load Power (W)		Total power		Daily duty cycle HRS/Day		weekly duty cycle Day/week		Power conversion efficiency (DECIMAL)		Nominal system (V)		Amp-hour load (AH/Day)	Total amp hour load AH/Day
Lamp AC [A]	19	×	1.5	=	28.5	×	0.58	×	5 days / 7	÷	0.90	÷	24	=	0.546	**5.596 (≈ 6.0)**
Lamp AC [B]	26	×	14	=	364	×	0.42	×	5 days / 7	÷	0.90	÷	24	=	5.05	

The operating voltage selected for a standalone PV system depends on the voltage requirements of the loads and the total current. If the system voltage is set equal to the voltage of the largest load then these loads may be connected directly to the system output. However, it is recommended that the current in any source circuit be kept below 20 with a 100 amperes limit for any section of the system. Keeping the current below these recommended levels will allow use of standard and commonly available electrical hardware and wires. When loads require AC power, the DC system voltage should be selected after studying available inverter characteristics. Another consideration is the possible increase in the size of your system in the future. Table 3.2 shows the suitable voltage selection for PV system.

Table 2: Selecting System Voltage

AC power demand (Watt)	Inverter input voltage (DC voltage)
<1500	12
1500-5000	24 or 48
>5000	48 or 120

A battery chargeequalizer is an electronic device that keeps all batteries ina series string at the same voltage. Almost all AC loads forstandalone PV systems will operate at 120 volts AC. Theoptimum selection of the inverter represented bychoosing an inverter meets the load and keeps the DCcurrent below 100 amperes.Selection of an inverter is important and affects boththe cost and performance of the system. Generally, theefficiency and power handling capability are better forunits operating at higher DC voltages a 48 volt unit areusually more efficient than a 12 volt unit. The designershould obtain information on specific inverters, theiravailability, cost and capabilities, from severalmanufacturers before making the decision on systemvoltage. Another fact to consider is the basic buildingblock in the array and storage subsystems gets larger asthe voltage increases. For example, a 48 volt system hasfour PV modules connected in series to form the basicbuilding block. However, the advantage of the higher operatingvoltage is the lower current required to produce the samepower. High current means large wire size and expensiveand hard to get fuses, switches and connectors. Again, aprior knowledge of the cost and availability ofcomponents and switchgear is critical to good systemdesign.

III. RESULTS AND DISCUSSIONS

When planning a PV system it is important not to lose sight of what our energy needs actually are. Only once our energy consumption needs are well defined can we then begin to design a PV system to meet them. How much energy each load consumes to meet that need must be determined. Long before people start comparing prices on PV modules but they must first create a list of needs called a "load profile."The proposed loads in this paper are energy conservative load in comparison with the load type used now days in Ouagadougou. It is representing the average daily electricity that is use by household also; we tried to define the amount of energy that the PV system must generate daily. The hourly load demand is for house needs is shown in Table 4.1. The equipment, lighting and other devices used in this house are the following: LED lights (15 W), refrigerator (50 W), television (100 W), satellite TV system (40 W), computer (45 W), radio telephone receive and transmit (12 W), phone answering machine (6 W), washing machine (800 W), monitoring equipment (100 W), battery charger (4 W) and air conditioning (1000 W).

Table 3: Load Profile for Typical House

Electrical load	Qty	Volts	Run watts	Hours / day	Days/ weeks	Surge watts	Ave. WH / Day	Per cent of total
LED Lights	6	230	15	5.00	7	15	450.0	3.69%
Refrigerator	1	230	50	8.00	7	1300	400.0	3.28%
Television	1	230	100	5.00	7	570	500.0	4.10%
Satellite TV System	1	230	40	5.00	7	1600	200.0	1.64%
Computer	1	230	45	6.00	3	135	115.7	0.95%
Radio Telephone (receive)	1	230	6	24.00	7	0	144.0	1.18%
Radio Telephone (transmit)	1	230	6	1.00	7	0	6.0	0.05%
Phone Answering Machine	1	230	6	24.00	7	0	144.0	1.18%
Washing Machine	1	230	800	0.50	4	100	228.6	1.87%
Monitoring equipment	1	230	100	0.00	7	200	0.0	0.00%
Ni-Cd Battery Charger	1	230	4	15.00	2	25	17.1	0.14%
Air- conditioning	1	230	1000	10.00	7	1000	450.0	81.93%
Total Daily Average Watt- hrs.								12,205.4
Largest AC Appliance Wattage								1000
Largest AC Appliance Surge Wattage								1600

The methodology discussed has been used to design the system in Homer software. The assessment of solar energy cost per kWh using different sizes of PV and battery at Ouagadougou have been investigated. The real data of the ambient conditions: hourly solar radiation (Direct normal (DNI), diffuse horizontal (DHI), global horizontal (GHI) irradiance) global irradiance, and ambient temperature have been used. The recorded data for 2017 have been used to assess solar energy potential shown in Figure 1. The measurement results found that the average global horizontal solar resource (July 2012) is 6.19 kWh/m^2/day and the average daily number of sunshine hours in Ouagadougou is about 10 hours.

Global radiation on a horizontal surface usually used to determine the energy input to PV system. It is expected that PV systems will work very well in Ouagadougou, where the average global horizontal annual solar resource is 5.936-6.879 kWh/m^2/day. These numbers are not the energy amount that can be produced by a PV system. There are many factors affecting the produce energy from PV include the type of PV technology, the solar declination, hour angle or azimuth and the solar elevation or zenith angle, temperature, dust, humidity, air mass, the level of sunlight and in general weather conditions. On the electrical side of the charger controller used to protect the batteries and reduce the fluctuation, inverter needs to convert DC current into AC, switches, conductors (wires), fuses and disconnects as shown in Figure 2.

The designed PV system in this section has the following components: PV arrays, inverters, battery charge controller, batteries, various wiring, mounting hardware, and combiner boxes, and sensors and monitoring equipment.

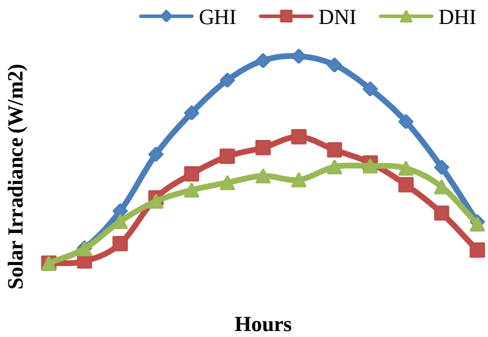

Figure 1: Irradiance in Ouagadougou on July 2017

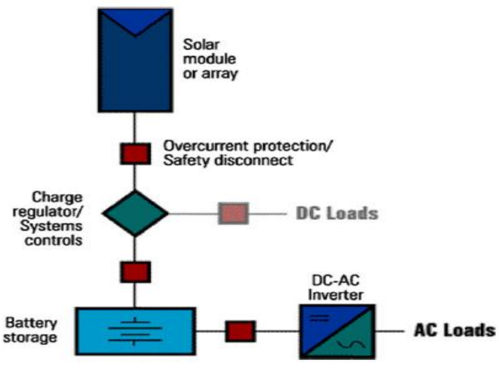

Figure 2: Standalone Photovoltaic System

Therefore, in this research PV system to be install in Ouagadougou to supply house. Table 4 shows the specification of the modeled PV system.

The feasibility of the PV system analyzed using HOMER software. HOMER contains a number of energy component models and evaluates suitable technology options based on cost and availability of resources. HOMER models a power system's physical behavior and its life-cycle cost. HOMER allows the modeler to compare many different design options based on their economic and technical merits [61].

Table 4: Modeled PV System Specification

PV module	
PV module rated power	140 Wp
Maximum voltage	17.7
Maximum current	7.91
Open circuit voltage	22.1
Short circuit current	8.68
Efficiency	13.9%
Temperature coefficient of *Voc*	-0.36 %/k
Temperature coefficient of *Isc*	0.06 %/k
Inverter	
Rated power	1 kW
AC voltage	220-240
Efficiency	94.1%

The schematic diagram in HOMER model for the built PV system is presented in Figure 3. It is found that the load demand for typical house in Ouagadougou is two times typical house in USA and this fact due to the power consumption of air conditioning, type of electrical devices and equipment used. Table 4 shows a proposed estimate of the average daily watt-hours (Wh) used by the proposed system.

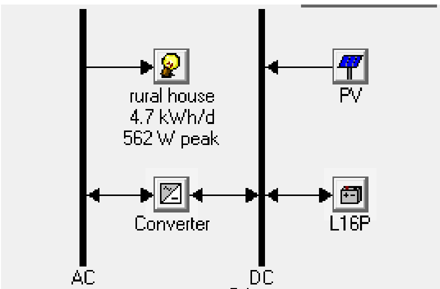

Figure 3: Homer Schematic Diagrams for the PV System

The economic assumptions of the system are given in Table 5 and Figure 4 illustrates the load profile. The load analysis calculation is listed in Table 6.

Table 5: Economic Assumptions of PV System

component	Capital ($)	Lifetime (Years)	Replacement ($)	O&M ($)	Fuel ($)
PV	6,200/kW	25	0	0	0
Inverter	1,000/kW	15	700/kW	0	0
Battery	1000/kAh	5	800/kAh	60	0

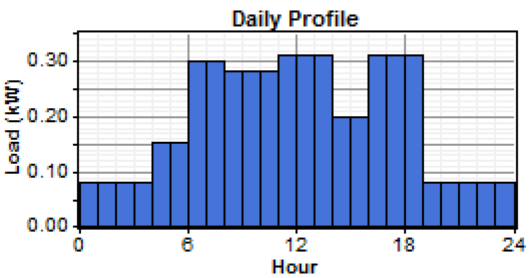

Figure 4: Hourly Load Profiles

Figure 5 shows the solar resource profile over a 1-year period. Homer introduces clearness index from the latitude information of the site (Ouagadougou). Using PV cells that are generate electricity which could be used as DC or AC electricity or both later. This electricity can be used at night by employing a storage mechanism such as a battery. Batteries used for this purpose have a large storage capacity. As we know that PV system will produce DC current in order to provide AC current we use inverter. The next step is to select the require sub-systems such as inverter, batteries, circuit breakers and special cables in order to get efficient power for home application.

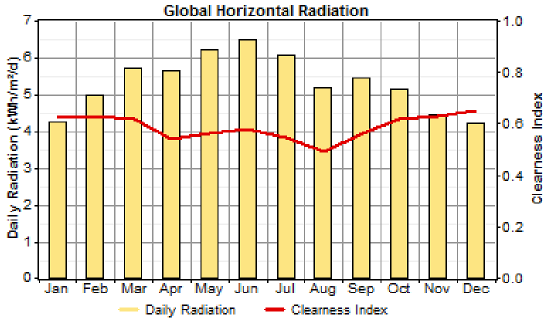

Figure 5: Solar Radiation Profiles

A. PV Array

The suggested PV modules to be used in the system simulation are 12 V, 140 W (at 1000 W/m^2, and 25 ^{o}C). These modules are connected to produce array with 24 V. Estimated capital cost of PV is 2.0$/W. The lifetime is assumed to be 25 years. 90% derating factor was applied to the electric production from each PV panel. The panels were modeled as fixed and tilted south at an angle equal to the latitude of the site. Capacities of different PV panels (0, 1, 1.5, 2, 2.5, 3, 3.5 and 4) were considered in the analysis.

B. Batteries

As the system considered working 24 hours, battery and controller were also formed as a main part of the system. Throughout battery life time HOMER assumes that the properties remain constant and not effected by external factors such as temperature. The chosen battery has a 6 V, 360 Ah capacities. The battery price estimated to be 1000 $/kAh. Its life time is considered to be 1,075 kWh of throughput per battery. Different number of batteries considered in this analysis (0, 1, 2, 3, 4, 5 and 6).

C. Inverter

An inverter is a circuit converts DC power to AC. Its efficiency is assumed to be 94.1 % for all sizes considered. The estimated price of an inverter is 1 $/W, and its lifetime is up to 15 years. Inverters of various sizes (0.5, 1, 1.5, 2, 2.5, and 3 kW) were considered in the analysis.

D. System Analysis

Homer simulates the system to determine whether it is feasible or not. Also, it estimates the life cost of installing and operating the system over its lifetime. After running the model, 108 feasible solutions are found and out of these 34 best solutions ranked according to the system minimum net present cost (NPC) are shown in Table 6. The table shows that that the greatest optimal result is achieved when the system is composed of 1.5 kW PV module, 5 batteries, and 1 kW inverter. In the optimum solution, the total NPC is 7,364 $ with operating cost of 169 $/year and the cost of energy equals to 0.329 $/kWh. The most expensive system is when we use 3 kW PV array, 3 batteries and 1.5 kW inverter, with an initial cost, NPC, and electricity cost of 7,680 $, 9,556 $, and 0.426 $, respectively.

The cost of energy in the modeled system as shown in table 4.8 is acceptable in comparison with the cost of institutive technique 0.31 $/kWh.

Table 6: Optimum Solution for Proposed PV System

PV (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
1.5	5	1.0	$ 5,200	169	$ 7,364	0.329	1.00	0.01
1.5	5	1.5	$ 5,400	169	$ 7,564	0.338	1.00	0.01
1.5	5	2.0	$ 5,600	169	$ 7,764	0.347	1.00	0.01
1.5	6	1.0	$ 5,560	174	$ 7,779	0.346	1.00	0.00
2.0	4	1.0	$ 5,840	159	$ 7,875	0.351	1.00	0.01
1.5	5	2.5	$ 5,800	169	$ 7,964	0.356	1.00	0.01
1.5	6	1.5	$ 5,760	174	$ 7,979	0.355	1.00	0.00
2.0	4	1.5	$ 6,040	159	$ 8,075	0.360	1.00	0.01
1.5	6	2.0	$ 5,960	174	$ 8,179	0.364	1.00	0.00
2.0	5	1.0	$ 6,200	162	$ 8,268	0.368	1.00	0.00
2.0	4	2.0	$ 6,240	159	$ 8,275	0.369	1.00	0.01
1.5	5	3.5	$ 6,200	169	$ 8,364	0.374	1.00	0.01
1.5	6	2.5	$ 6,160	174	$ 8,379	0.373	1.00	0.00
2.0	5	1.5	$ 6,400	162	$ 8,468	0.376	1.00	0.00
2.0	4	2.5	$ 6,440	159	$ 8,475	0.378	1.00	0.01
1.5	5	4.0	$ 6,400	169	$ 8,564	0.383	1.00	0.01
2.0	6	1.0	$ 6,560	164	$ 8,650	0.384	1.00	0.00
2.0	5	2.0	$ 6,600	162	$ 8,668	0.385	1.00	0.00
1.5	6	3.5	$ 6,560	174	$ 8,779	0.391	1.00	0.00
2.0	6	1.5	$ 6,760	164	$ 8,850	0.393	1.00	0.00
2.0	5	2.5	$ 6,800	162	$ 8,868	0.394	1.00	0.00
2.0	4	3.5	$ 6,840	159	$ 8,875	0.396	1.00	0.01
1.5	5	5.0	$ 6,800	169	$ 8,964	0.401	1.00	0.01
1.5	6	4.0	$ 6,760	174	$ 8,979	0.399	1.00	0.00
2.0	6	2.0	$ 6,960	164	$ 9,050	0.402	1.00	0.00
2.0	4	4.0	$ 7,040	159	$ 9,075	0.405	1.00	0.01
2.0	6	2.5	$ 7,160	164	$ 9,250	0.411	1.00	0.00
2.0	5	3.5	$ 7,200	162	$ 9,268	0.412	1.00	0.00
3.0	3	1.0	$ 7,480	147	$ 9,356	0.417	1.00	0.01
1.5	5	6.0	$ 7,200	169	$ 9,364	0.419	1.00	0.01
1.5	6	5.0	$ 7,160	174	$ 9,379	0.417	1.00	0.00
2.0	5	4.0	$ 7,400	162	$ 9,468	0.421	1.00	0.00
2.0	4	5.0	$ 7,440	159	$ 9,475	0.423	1.00	0.01
3.0	3	1.5	$ 7,680	147	$ 9,556	0.426	1.00	0.01

Greenhouse gases emission from the fuel of equivalent conventional system is significant. By adapting PV technology, the emission of all these harmful gases can be substantially reduced. Table 7 shows the emissions banned according to the analysis of using a PV system instead of a diesel generator for this small project.

Table 7: Amount of Emission Prevented by using a PV System Instead of Diesel Generator

Type of emission	Emission (kg/year)
Carbon dioxide (CO_2)	2,177
Carbon monoxide (CO)	5.37
Nitrogen oxide (NOx)	0.595
Unburned hydrocarbon (HC)	0.405
Sulfur dioxide	4.37
Suspended particles	47.9

CONCLUSION

In this paper, PV system designed to assess solar power cost per kWh of energy produced using different sizes of PV, batteries and inverters. The system has a daily load of 12.2 kWh/day, 1.5 kW PV modules, 5 batteries, (6 V and 360 Ah), and 1 kW inverter. The results have shown that the optimum cost of PV system energy 0.31 $/kWh and 0.329 $/kWh for intuitive and numerical techniques respectively, is attractive option in comparison with the cost of diesel engine energy 0.5581 $/kWh. The most expensive system is when we use 3 kW PV array, 3 batteries and 1.5 kW inverter, with an initial cost, NPC, and electricity cost of 7,680 $, 9,556 $, and 0.426 $, respectively. Also, this option still feasible more than the diesel generator option. Investigations have shown that PV system could represent a good option to be used to supply houses in rural area of Burkina Faso. Moreover, the analysis shows that using PV system instead of diesel generator will prevent greenhouse gases emission 2,177 kg/year of CO_2, 5.37 kg/year of CO, 0.595 kg/year of NOx, 0.405 kg/year of HC, 4.37 kg/year of SO_2, and 47.9 kg/year of suspended particles.

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