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Comparison of Two Methods for Optimizing the Electricity Production Cost for Rural Electrification: Case of PV/Biogas Generator Hybrid Power Plant in Burkina Faso

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Abstract: In fossil fuels depletion and climate change context, converting renewable energies into electricity is an asset for the electrification in West Africa rural areas. However, the massive production of electricity from renewable energies still comes up against a high cost per kWh of electricity produced. The optimization method choice is essential in the feasibility study of electrification projects with a view to achieve a cost per kWh of electricity that is bearable for both, the users and the project implementation structure. In this study, the optimization methods of genetic algorithm and that of the Homer software are compared in order to determine which is the best for the production cost optimization of an hybrid power plant at the Dori site, located in the Sahelian zone of Burkina Faso, in West Africa. The electricity production cost optimization on this site, by the two methods showed that the genetic algorithm method is the best indicated with kWh cost of $0.589 against a kWh cost of $0.620 for the Homer software. With both methods, the amount of CO_2 equivalent avoided from being emitted into the atmosphere is the same, i.e. 161127 tons per year. The genetic algorithm optimization method is best suited for the study of rural electrification projects in the Sahelian zone of Burkina Faso.

Keywords: Hybrid Power Plant, Renewable Energies, Electricity, Optimization

1. Introduction

Most of the African populations in the West African zone live in rural areas. It represents 64% of the population of Sub-Saharan Africa (World Bank 2010). The average rate of access to electricity in sub-Saharan Africa is very low, 16% of households and less than 5% in rural areas (French Development Agency, 2010). However, one of the first conditions necessary for the South countries development, in particular the rural world is the access to electricity. The need to develop electrification in rural areas is essential in order to meet the needs for electrical energy at a bearable cost for the population.

Renewable energies, inexhaustible on a human scale, are a relevant response to the current and future energy problem in this part of the world [1]. However, the massive conversion of renewable energies still faces a rather high cost of electricity production [2]. This is why it is necessary to combine several sources of renewable energies, in order to use hybrid systems for the production of electricity. The use of hybrid systems is an interesting solution for the electrification of areas where the electricity network does not exist, or its extension requires a relatively high investment cost. The development of hybrid electrical systems requires that they become more economically attractive. Optimizing the sizing of hybrid power plants offers huge economic benefits [3]. It is then essential to carry out a technical and economic analysis based on real observations or on predictions of the evolution of the costs of the various components of the hybrid electrical system.

The optimization of a hybrid power plant allows to find the power of the elements of the plant that is needed to produce electricity at the cheapest possible cost per kWh and bearable by the population concerned by the electrification project. Different criteria are used to optimize the hybrid system depending on the installation site. The most frequently used criteria are: the probability of load loss or the probability of power supply loss and the cost of energy produced. Studies on the optimal configuration of a mini distribution network, considering the diesel generator as the main source have been carried out by LI et al [4]. They made a comparison between the results obtained under the Homer environment and those obtained using the genetic algorithm. Genetic algorithm method is also used by Ko and al to minimize hybrid power plant life cycle cost [5]. In problem with strong interactions parameters, the Non-dominated Sorting Genetic Algorithm-Two (NSGA-II) gives better results, hence NSGA-II choice [6]. In this study, it is about optimization by genetic algorithm of hybrid power plant composed by solar photovoltaic and generator operating with biogas and without electrochemical electricity storage.

The objective of this study is to find an optimization method best suited for optimizing the electricity production cost of hybrid power plants intended for decentralized rural electrification of Dori site, located in Sahelian zone of Burkina Faso, in West Africa.

2. Study Site Presentation

Dori is the leader in province of Seno, located in Sahel region in Burkina Faso [7] (Figure 1).

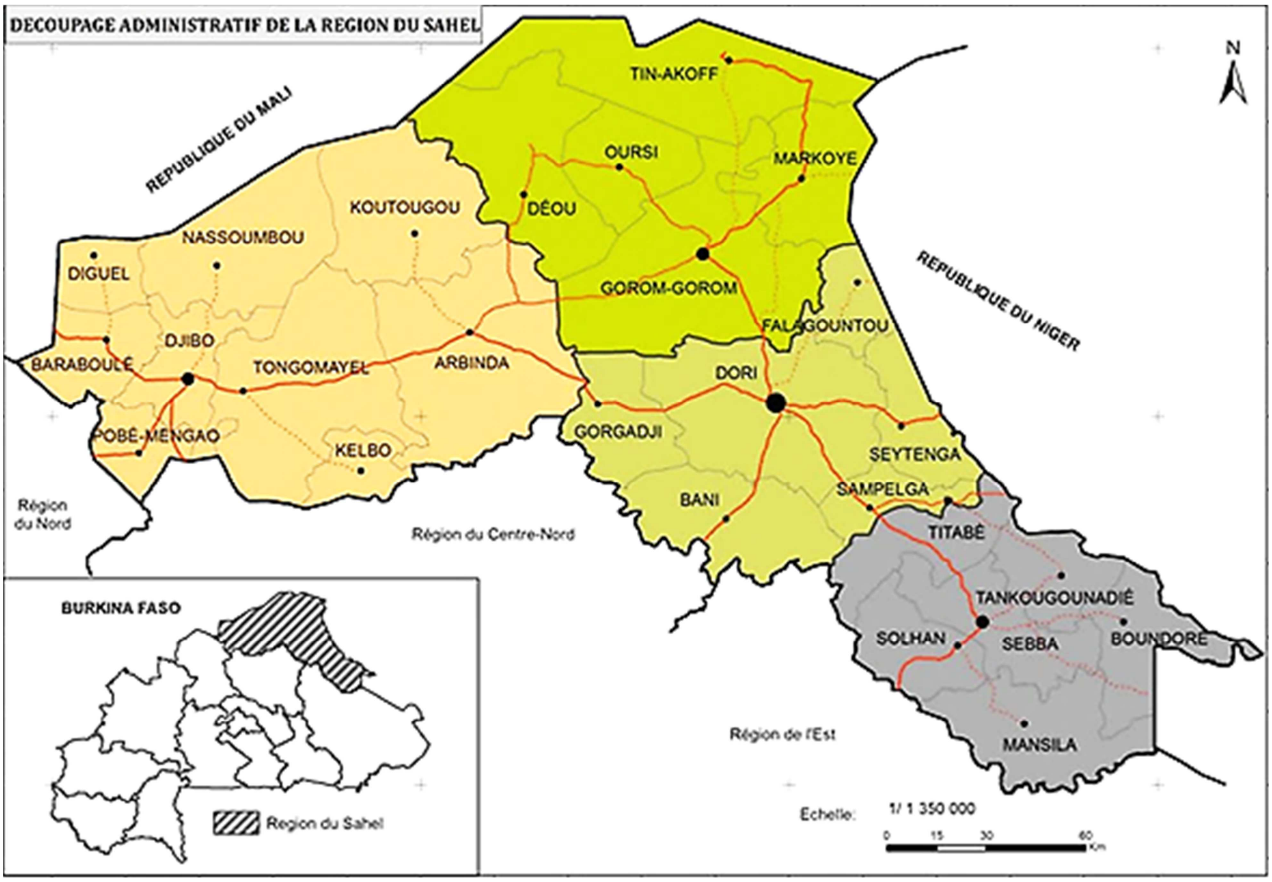

Figure 1. *Geographic location of study site.*

Table 1 gives geographical coordinates and Dori site inhabitants number [8].

Table 1. *Geographical coordinates and inhabitants number at studied site.*

sites	Coordinates		Area (km^2)	inhabitant number (-)	inhabitant density (inhab/km^2)
	Latitude	Longitude			
Dori	14°02'N	0°02'W	6 863	400 557	58

The study site climate is Sahelian type characterized by dry and rainy season alternation of 3 to 4 months. The annual rainfall is less than 600 mm and is characterized by variability in precipitation distribution, strong evapotranspiration of 3 m/year and significant variations in daily and annual temperatures. Livestock is the main socio-economic activity. It is a source of income for more than 80% of population of Burkina Faso and contributes 10% to gross domestic product [9]. At Dori site, breeding mainly concerns cattle, goats, sheep, donkeys, pigs, equines and poultry. Table 2 gives livestock estimation in 2020.

Table 2. *Livestock's number at Dori site.*

Species	Donkey	Cattle	Camelin	Goat	Equine	Sheep	Pig	Poultry
Number	20293	1149894	1408	1259787	8503	610896	4355	581466

3. Material and Method

The generating elements optimal definition of hybrid electrical system that use renewable energies comprise the modeling steps of energy resources available at the site, of optimization, methodology definition of system each element and constraints definition [10]. The electricity production cost optimization is carried out by genetic algorithm method. The results will be compared to those obtained by simulation in Homer sales software.

3.1. Renewable Energies Modeling

3.1.1. Solar Radiation Modeling

The global solar radiation is sum of direct radiation and diffuse radiation. The solar direct radiation on a horizontal plane is given:

$$S_{DR} = 1370\exp\left[-\frac{T_L}{0.9+9.4\sin(h)}\right]\sin(h) \tag{1}$$

S_{DR} being solar direct radiation, T_L is Link disorder factor, h is sun height, 1370 is conversion factor.

The solar diffuse radiation is calculated by:

$$S_{DifR} = 54.8\sqrt{\sin(h)}\left(T_L - 0.5 - \sqrt{\sin(h)}\right) \tag{2}$$

S_{DifR} is solar diffuse radiation, T_L is Link disorder factor, h is sun height in sky.

3.1.2. Biogas Production Modeling

Biogas production allows the recovery of organic waste by producing renewable energy [11, 12]. Five (05) types of animal droppings are considered in this study [13]. This is waste from pigs, cattle, goats, sheep and poultry. The digester sizing is done basing on livestock numbers present at the site. Depending on animal species, animal's number required to produce organic material quantity to produce one (1) m^3 of biogas per day is known.

Table 3. *Animals number for one m^3 of biogas production per day.*

Species	Cattle	Pig	Sheep	Goat	Poultry
Number	1	3	11	11	93

With livestock number at site, slurry quantity per day is calculated with relationship below [14]:

$$Q_{\text{slur}} = 30\left(n_{ca} + \frac{1}{3}n_{pi} + \frac{1}{11}n_{sh} + \frac{1}{11}n_{ga} + \frac{1}{93}n_{po}\right) \tag{3}$$

Q_{slur} is slurry available per day quantity, n_{Ca} is cattle number, n_{pi} is pig number, n_{sh} is sheep number, n_{go} is goat number, n_{po} is poultry number.

If the livestock numbers at a given site are known, the biogas volume produced per day is evaluated according to the following relationship [15]:

$$V_{Biogas} = n_{ca} + 3n_{pi} + 11n_{sh} + 11n_{go} + 93n_{po} \tag{4}$$

V_{Biogas} is biogas available volume per day, n_{Ca} is cattle number, n_{pi} is pig number, n_{sh} is sheep number, n_{go} is goat number, n_{po} is poultry number.

The digester power is calculated based on methane content in biogas and calorific value of this biogas [16]. 100% methane content in biogas has 12.67 kWh/m^3 calorific value. The digester electrical power is given by following relationship [17]:

$$P_{Dig} = \frac{tP_{CI100}V_{Biogas}}{24} \tag{5}$$

P_{Dig} is digester power, t is methane content in biogas, P_{CI100} is 100% methane content calorific value in biogas, V_{Biogas} is biogas volume per day, *24* is one-day hour number.

3.2. Hybrid Electric Power Plant Elements Modeling

3.2.1. Biogas Generators Modeling

Several parameters permit to describe the performance of biogas engines, among which are specific consumption and efficiency. The Specific Consumption (CS) is equal to the amount of gas consumed during one hour to produce 1 kW of electrical power [18]. For biogas generators, it is expressed in g/kWh or Nm^3/kWh [19]:

$$CS = aP^2(t) + bP(t) + c \tag{6}$$

where: a, b and c are generator constants characteristic, $P(t)$ is generated power by generator at t time.

Biogas generator overall efficiency η_{GBio} sets the efficiency of chemical energy converting biogas into electrical energy. It is directly related to specific consumption [19]:

$$\eta_{GBio} = \frac{3600}{PCI \cdot CS} \tag{7}$$

PCI is biogas lower calorific value; CS is generator specific consumption.

3.2.2. Photovoltaic Field Modeling

A photovoltaic system directly converts sunlight into electricity. The main device of a photovoltaic system is a solar cell. Cells may be grouped to form panels or arrays. In order to maximize the extracted output power from a photovoltaic power plant, the understanding and modeling of photovoltaic cell is necessary. The single-diode equivalent circuit model is arguably the most popular used photovoltaic cell model thanks to its relatively appropriate trade-off between accuracy and simplicity [20]. This model has been confirmed to be more accurate than other model [21].

Although single-diode equivalent circuit model imitates the behavior of physical photovoltaic cells better than ideal photovoltaic cell model. It can also lack accuracy, especially in the situations where the photovoltaic cell presents many defects and/or important temperature variation [22]. The configuration of the simulated ideal solar cell with single-diode, shunt resistance and series resistance is shown in Figure 2.

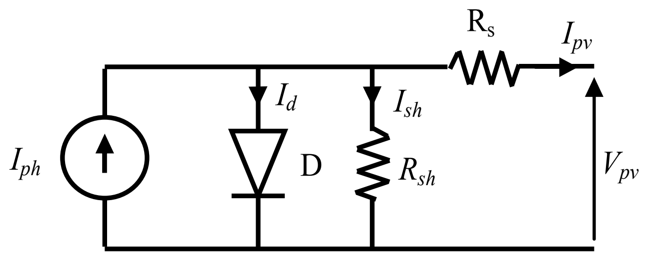

Figure 2. *Single Diode model of photovoltaic cell.*

In Figure 2, I_{ph} is the photo generated current, I_d is the diode current, I_{sh} is the shunt resistance current, I_{pv} is the output current, and V_{pv} is the terminal voltage. According to the existing literature, the presence of this shunt resistance represents the construction defects that cause leakage currents within the PV cell, i.e., any parallel high-conductivity paths (shunts) free carriers produced by the solar irradiation across the photovoltaic cell P-N junction or on the photovoltaic cell edges [23, 24].

A high shunt resistance means that the clear majority of these carriers generate power, whereas a low resistance indicates large losses [25]. The magnitude of the shunt resistance varies with different fabrication methods since it is intimately related to the construction defects. The Current-voltage (I-V) characteristics of the solar cell with single-diode, shunt resistance and series resistance are given by:

$$I_{pv} = I_{ph} - I_s \left[\exp\left(\frac{q\left(V_{pv} + R_s I_{pv}\right)}{akT} \right) - 1 \right] - \frac{V_{pv} + R_s I_{pv}}{R_{sh}} \quad (8)$$

I_S represents the saturation current, a is the ideality factor of the diode, k is the Boltzmann's constant ($1.380653*10^{-23}$ J/°K), q is the absolute value of electron's charge ($1.60217646*10^{-19}$ C), T is the temperature of the junction.

The output power is given by:

$$P = I_{pv} V_{pv} \quad (9)$$

Photovoltaic generator performance depends on illumination, temperature and on the load to be supplied.

3.2.3. Inverter Modeling

An inverter input power is the power produced by photovoltaic field. Output power can be expressed from input power and efficiency [26]:

$$P_{out} = \eta_{inv} P_{in} \quad (10)$$

P_{out} is inverter output power, P_{in} is inverter input power, η_{inv} is inverter efficiency.
with:

$$\eta_{inv} = \frac{p}{p + p_0 + kp^2} \quad (11)$$

$$p = \frac{P_{out}}{P_n} \quad (12)$$

η_{inv} is inverter efficiency, p_0 and k are coefficients calculated from data provided by manufacturer, p is reduced power.

3.3. Hybrid Power Plant Architecture and Modeling

The architecture of the studied installation is alternative bus. It consists of photovoltaic and biogas generators combination, as shown in Figure 3.

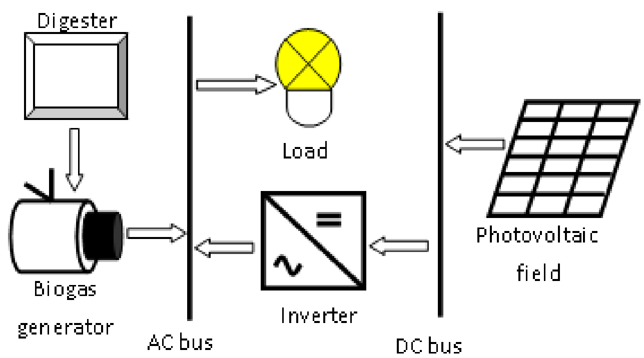

Figure 3. *Studied system synoptic architecture.*

3.4. Hybrid Power Plant Technic and Economic Analysis

The "objective function" takes into account costs of acquisition, operation, maintenance and renewal of photovoltaic field, inverter, digester and biogas generators. It can be written according to the following relation:

$$\begin{cases} OF = C_{I-Dig} + C_{I-GBio} + C_{I-PV} + C_{I-Inv} \\ +C_{M-Dig} + C_{M-GBio} + C_{M-PV} + C_{M-Inv} \\ +C_{Op-Dig} + C_{Op-GBio} + C_{Op-PV} + +C_{Op-Inv} \\ +C_{R-Dig} + C_{R-GBio} + C_{R-PV} + C_{R-Inv} \\ +V_{R-Dig} + V_{R-GBio} + V_{R-PV} + V_{R-Inv} \end{cases} \quad (13)$$

where: C_{I-PV} is photovoltaic field investment cost, C_{I-Inv} is inverter investment cost, C_{I-Dig} *is* digester investment cost, C_{I-GBio} is biogas generator investment cost, C_{M-PV} is photovoltaic field maintenance cost, C_{M-Inv} is inverter maintenance cost, C_{M-Dig} is digester maintenance cost, C_{M-GBio} is biogas generator maintenance cost, C_{Op-PV} is photovoltaic field operation cost, C_{Op-Inv} is inverter operation cost, C_{Op-Dig} is digester operation cost, $C_{Op-GBio}$ is biogas generator operation cost, C_{R-PV} is photovoltaic field renewal cost, C_{R-Inv} is inverter renewal cost, C_{R-Dig} is digester renewal cost, C_{R-Gbio} is biogas generator renewal cost, V_{R-PV} is photovoltaic field residual value, $V_{R\ -Inv}$ is inverter residual value, V_{R-Dig} is digester residual value, V_{R-GBio} is biogas generator residual value.

Thus, for hybrid electric system, objective function can be expressed:

$$\begin{aligned} F(x) &= a_1\left[1+m_{PV}PW(i,a,d)A(a,n_{PV})-S(a,d)\frac{nr_{PV}}{n_{PV}}\right]x_1^{1-b_1} \\ &+a_2\left[1+PW(i,\bar{a},d)-S(a,d)\frac{nr_{Inv}}{n_{Inv}}\right]x_1x_2^{-b_2} \\ &+a_3\left[1+2m_{Dig}PW(i,a,d)A(a,n_{Dig})-S(a,d)\frac{nr_{Dig}}{n_{Dig}}\right]x_3^{1-b_3} \\ &+a_4\beta D_{\max}\left[1+PW(i,\bar{a},d)-S(a,d)\frac{nr_{GBio}}{n_{GBio}}\right]x_4^{-b_4} \\ &+NPW(i,a,d)\left[C_0(a_5\beta+b_5)+b_0\right]x_4\sum_{T=1}^{24}X_{t+4}+NPW(i,a,d)a_0\sum_{t=1}^{24}X_{t+4} \end{aligned} \tag{14}$$

Where: a_1 is photovoltaic field acquisition coefficient 1, a_2 is inverter acquisition coefficient 1, a_3 is digester acquisition coefficient 1, a_4 is biogas generators acquisition coefficient 1, b_1 is photovoltaic field acquisition coefficient 2, b_2 is inverter acquisition coefficient 2, b_3 is digester acquisition coefficient 2, b_4 is generator acquisition coefficient 2, a_5 and b_5 are consumption parameters of each biogas generator, C_0 is 1 Nm^3 biogas cost, a_0 and b_0 are consumption parameters of each biogas generator, x_1 photovoltaic field power, x_2 is inverter power, x_3 is digester power, x_4 is biogas generator power, $A(a,n_{Dig})$ is digester factor of investment cost annualization, $A(a,n_{PV})$ is PV field factor of investment cost annualization, $S(a,d)$ discount factor, D_{max} is maximum load value, β is load rate, m_{Dig} is digester unit percentage corresponding to maintenance cost, m_{PV} is PV field percentage corresponding to maintenance cost, nr_{PV} is PV field remaining lifetime, n_{PV} is PV field total lifetime, nr_{Inv} is inverter remaining lifetime, n_{Inv} is inverter total lifetime, nr_{Dig} is biogas plant remaining lifetime, n_{Dig} is biogas plant total lifetime, nr_{GBio} is biogas generators lifetime, n_{GBio} is biogas generators total lifetime, X_{t+4} is biogas generator number in operation at each hour of day, N is biogas generators number, $PW(i,a,d)$ is current expenditure discount factor, $PW(i,\bar{a},d)$ non-current expenditure discount factor.

The hybrid electric system must be able to satisfy load power at all times. This constitutes constraint:

$$\frac{\eta_{Inv}F_{PV}}{1000}G(t)x_1+\eta_{Inv}x_2+x_{GBio}X_{t+2}=D(t) \tag{15}$$

Where: $G(t)$ is solar radiation, η_{Inv} is inverter efficiency, x_2 is inverter power, x_{GBio} is biogas generator power, X_{t+2} is biogas generator number in operation at each hour of day F_{PV} is various losses factor recorded on photovoltaic field, $D(t)$ is load power at every hour.

The problem formulation therefore boils down to constrained optimization problem, which can be expressed in form:

$$\begin{cases} Min\left[F(x)\right] \\ \dfrac{\eta_{Inv}F_{PV}}{1000}G(t)x_1+\eta_{Inv}x_2+x_4X_{t+4}=D(t),\ t=1:24 \end{cases} \tag{16}$$

Min[F(x)] is minimum value of function *F(x), F(x)* is objective function, x_1 is nominal photovoltaic field power, $G(t)$ is solar radiation, η_{Inv} is inverter efficiency, x_2 is an inverter power, x_4 is a biogas generator nominal power, X_{t+4}(t = 1: 24) is biogas generator number in operation at each hour of day, $D(t)$ is for load power at each hour.

For technical-economic analysis, genetic algorithm will be defined in Matlab environment.

3.5. Optimization Methods

3.5.1. Genetic Algorithms Method

There are multitude methods for optimization problems. Simulated annealing and genetic algorithms are the most popular stochastic methods used to design energy conversion systems [27]. Genetic algorithms evolve by iterations and consist in: creating set of individuals called populations, evaluating individuals (solutions), combining (crossing of parents) to give new population, making mutations in order to improve new selected population quality. The structure of the genetic algorithm used in this work is presented on Figure 4.

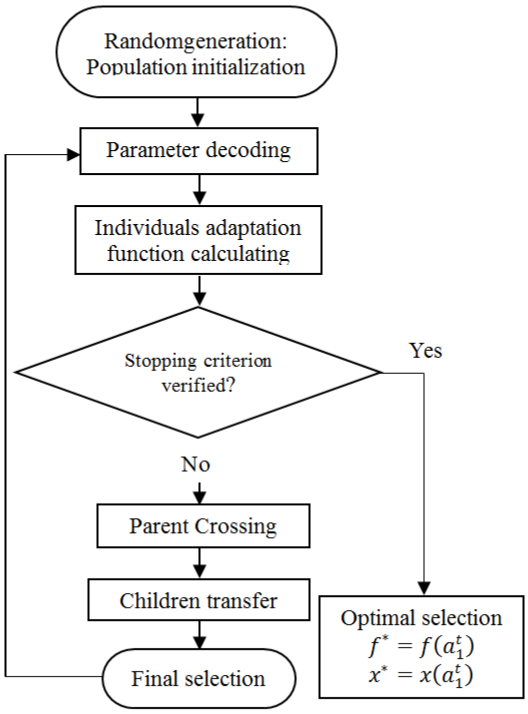

Figure 4. *Genetic algorithm structure.*

3.5.2. Homer Software

Homer means: Hybrid Optimization of Multiple Energy Resources. It is software for hybrid energy systems optimization [28]. It performs optimization task by performing hourly simulation of the energy flow between electric load and other system components over period of one year.

For each hybrid system configuration, Homer software performs installation time analysis. At each time step, the software observes consumption and compares it to photovoltaic production which has priority. In the case of this energy lack, Homer software must choose between use generator and Batteries. Homer software main features are: taking into account hourly load profile as well as controllable loads, time simulation of multi-source production system, production system economic optimization and sensitivity analysis. Homer operation is analyzed for hybrid systems comprising: photovoltaic installation, one or two generators, with or without electrochemical storage unit. For parameters such as number of devices and powers, Homer software simulates system operation for each of defined values.

Homer software presents financial analysis on project life cycle, based on comparison results of produced kilowatt-hour costs by different sources. Thus, for each architecture and configuration, it is possible to observe the following outputs: global cost of updated kilowatt-hour (LCOE: Levelized Cost Of Electricity), distribution of expenditure items, detail corresponding to each source, daily charts over system life, sensitivity analysis graphs, economic analysis compared to reference installation, sensitivity analysis presented in graphical form [29].

4. Results and Discussions

The chosen site for this study is that of Dori located in the Sahel region of Burkina Faso, in West Africa. This study is carried out for 20 years project duration. It is question of finding optimal production costs per kilowatt-hour (kWh) of electricity by hybrid power plant at Dori site. The technical-economic optimization is carried out by genetic algorithm. The optimization results will compare to those obtained with Homer software.

4.1. Electrical Load Analysis

According to population growth forecast of Dori site, request profile that hybrid power plant must meet is estimated [30].

Figure 5 shows load profile that hybrid power plant should satisfy.

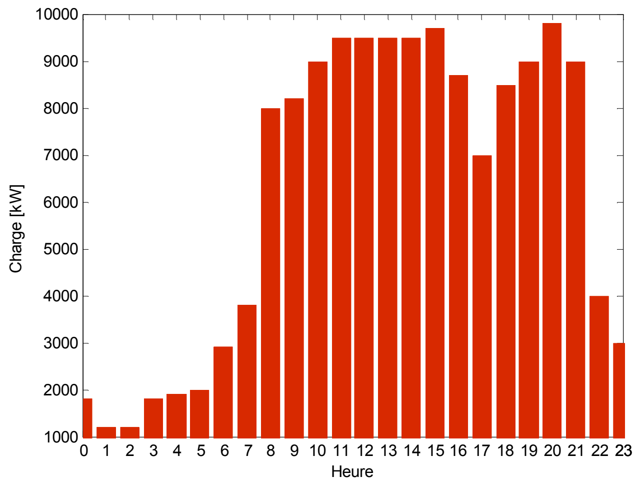

Figure 5. *The site load profile.*

4.2. Simulation Results

4.2.1. Results with the Genetic Algorithm

The table below summarizes the optimal results of the generator elements powers, obtained after simulation with the genetic algorithm.

Table 4. *Optimal sizes of elements of the hybrid power plant calculated by the genetic algorithm.*

Digester Power (kW)	Biogas generators power (kW)	Photovoltaic field power (kW)	Inverter power (kW)
25128	12250	1960	2100

The simulation results with the genetic algorithm method give 25128 kW of digester power, 12250 kW of biogas generators power, 1960 kW of photovoltaic field pawer and 2100 kW of inverter power.

The table below gives the optimal costs of hybrid power plant at Dori's site.

Table 5. *Optimal costs of the hybrid power plant at the Dori site.*

Initial capital ($)	Operating cost ($)	Maintenance cost ($/year)	Renewal cost ($)	Residual value ($)	kWh cost ($)
134911765	4562630	15514014	130986	49476	0.589

The simulation with the genetic algorithm results give a cost per kWh of electricity produced by the hybrid power plant of $ 0.589 at Dori site.

Technical-economic optimization with the genetic algorithm is a method which in addition to giving the global configuration of the system, also allows to simulate the dynamics of the system.

4.2.2. Results with Homer Software

Table 6 presents different power values of the hybrid plant elements calculated by Homer.

Table 6. *Hybrid power plant optimal size calculated by Homer software.*

Digester power (kW)	Biogas generators power (kW)	Photovoltaic field power (kW)	Inverter power (kW)
30769	12000	2000	2200

The simulation results with the Homer software give 30769 kW of digester power, 12000 kW of biogas generators power, 2000 kW of photovoltaic field power and 2200 kW of inverter power.

Table 7 shows the hybrid plant costs calculated by the Homer software.

Table 7. *Hybrid power plant costs calculated by Homer.*

Initial capital ($)	System total cost ($)	Operation and maintenance cost ($/year)	kWh cost ($)
156494560	326548512	13302754	0.620

The simulation with the Homer software results gives an Initial capital of $156494560, System total cost of $326548512, Operation and maintenance cost of $13302754 and cost per kWh of electricity produced by the hybrid power plant of $0.620 at Dori site. These results are related to the specificity of the Homer software.

Homer software is a time series model that performs an hourly energy balance along a year for each system configuration entered by the user. In Homer, linear cost functions are adopted and components size to be considered must be planned in advance, in order to achieve the optimization. To compare the costs of the kWh produced by solar and biogas sources, the Homer software uses rules and models that can be influenced by the parameters chosen by the user. Thus, Homer considers auxiliary sources to have a fixed cost and a marginal cost. In the Homer software, the simulation is essentially oriented towards economic optimization, the results are therefore necessarily optimistic.

4.3. Optimization Results Comparison

Table 8 gives the optimum power of the various generating elements of the hybrid power plant, obtained by simulation with the genetic algorithm and with the Homer software.

Table 8. *Optimum size of generating elements of the power plant.*

	Digester power (kW)	Biogas generators power (kW)	Photovoltaic field power (kW)	Inverter power (kW)
Genetic algorithm	25128	12250	1960	2100
Homer software	30769	12000	2000	2200

The observation on the generating elements size of the hybrid power plant is that, apart the digester size, the other generating elements (generator, PV field and inverter) size is practically the same. The digester power obtained by Homer software (30769 kW) is higher than that obtained by the genetic algorithm (25128 kW). The difference between digester powers obtained by genetic algorithm and by Homer software is 5641 kW, i.e. a difference of 18.33%. This is due to the fact that the Homer software does not make the optimal sizing, while the genetic algorithm permits to optimize the hybrid power plant elements sizing.

Table 9 shows the optimal costs of the hybrid plant obtained by simulation with the genetic algorithm and with the Homer software.

Table 9. *Power plants optimal costs.*

	Initial capital ($)	Operation and maintenance cost ($/year)	kWh cost ($)
Genetic algorithm	134 911 765	20076644	0.589
Homer software	156 494 560	13302754	0.620

The initial capital of the hybrid power plant obtained with the Homer software ($156494560) is higher than that obtained with the genetic algorithm ($134911765). However, the operating and maintenance cost obtained with the genetic algorithm is the highest, i.e., $20076644 against $13302754 for the Homer software. The model developed with the genetic algorithm gives a cost per kWh equal to $0.589 and the simulation with the Homer software gives a cost per kWh equal to $0.620. The difference observed is about 3% between the cost of the kWh obtained with the genetic algorithm and that obtained with the Homer software.

The difference of 3% between the kWh costs obtained by using the two optimization methods seems acceptable to us. He indicates that the model developed with the genetic algorithm can be used very well as a decision-making tool in projects for the implementation of hybrid photovoltaic power plants-biogas generators. In addition, the genetic algorithm allows for the sizing and optimization of the hybrid power plant, while the Homer software is only used for optimization.

4.4. Analysis of Gases Consumed and Emitted by the Hybrid Electric Power Plant

The combustion of biogas in generator engines produces carbon dioxide, carbon monoxide, nitrogen oxide, unburned biogas which are greenhouse gases and polluting particles. These quantities are obtained by simulation with the genetic algorithm and in the Homer software. The observation is that the quantities of biogas consumed and gases released after combustion are the same for both with the genetic algorithm and with the Homer software.

Table 10 gives the nature and quantities of greenhouse gases produced during the combustion of biogas in generators, obtained by simulation with the two methods.

Table 10. *Quantities of gas emitted by the plant.*

Pollutant	Emissions (kg/year)
Carbon dioxide	14487.41
Carbon monoxide	357.18
Unburned hydrocarbons	37.11
Particulate matter	40.22
Sulfur dioxide	0
Nitrogen oxides	2902.48

The amount of CO_2 equivalent is calculated by considering the effect of each gas on global warming. The quantities of biogas consumed and the gases emitted by the generators and the quantity of CO_2 equivalent avoided on each site are calculated.

Table 11. *Quantities of biogas consumed and gases emitted by the generators.*

Quantity of biogas consumed (tons)	CO_2 equivalent of biogas consumed (tons)	CO_2 equivalent of the gases released (tons)	CO_2 equivalent avoided (tons)
82118	1028106	866979	161127

The photovoltaic field, in its operation, does not produce greenhouse gases. The carbon dioxide (CO_2) equivalent quantity is calculated by considering only the methane consumed and the gases emitted after the combustion of the biogas in the generators. The carbon dioxide equivalent quantity is calculated by considering the effect of each gas on global warming.

So, 866979 tons of CO_2 equivalent is emitted per year by the hybrid power plant. The quantity of biogas consumed by the generators is eighty-two thousand one hundred and eighteen (82118) tons. The global warming potential of methane is 25 times greater than carbon dioxide (CO_2). The CO_2 equivalent of this quantity of biogas is one million twenty-eight thousand one hundred and six (1028106) tons per year. This quantity of CO_2 could have been emitted into the atmosphere if it were not recovered as electricity.

Compared to the quantity of CO_2 equivalent emitted by the hybrid power plant of eight hundred and sixty-six thousand nine hundred and seventy-nine (866979) tons by the generators per year, the emission of approximately one hundred and sixty-one thousand one hundred and twenty-seven (161127) tons of CO_2 per year into the atmosphere is avoided.

5. Conclusion

In this study, a comparison of electricity production cost obtained by the genetic algorithm method and that using the Homer software was carried out. The simulation was made with the data of Dori site, located in Sahelian zone of Burkina Faso, in West Africa.

The objective is to find, between the genetic algorithm method and that using the Homer software, the best optimization method suited for the optimization of electricity production cost of hybrid power plants intended for the decentralized rural electrification. Using the project life cycle cost equation, the function to be optimized was defined taking into account the investment, maintenance and operating costs and the residual value of power plant, to a 20-year lifetime of project.

The simulation results with the two optimization methods showed that the model developed with the genetic algorithm gives a cost per kWh equal to $0.589 and the simulation with the Homer software gives a cost per kWh equal to $0.620. The difference observed is about 3% between the cost of the kWh obtained with the genetic algorithm and that obtained with the Homer software. The difference of 3% between the kWh costs obtained by using the two optimization methods seems satisfactory.

The genetic algorithm optimization method which gives the lowest cost per kWh, is best suited for optimizing the cost of electricity production for a hybrid renewable energy power plant intended for decentralized rural electrification. From this study, it clearly appears that the resolution method choice also seems essential for the quality of the results obtained.

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