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Research Article

Competitiveness Level of Photovoltaic Solar Systems in Ouagadougou (Burkina Faso): Study Based on the Domestic Electric Meters Calibration

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The mean cost price of electricity in Burkina Faso at the end of the last quarter of 2012 was 158 FCFA/kWh for a country where more than 46% of the population lives below the national poverty threshold. To look for solution to that problem, the resort to photovoltaic solar energy is justified for that country. The purpose of this study is to promote the integration of both technical and economical surveys in solar energy preliminary projects in Ouagadougou. To reach that, investigations were carried out in some households and attention was paid from the calibration of the domestic electric meters. Energy demands collected within each household allow us to design a corresponding solar kit through optimization rules. An estimate was edited and financial viability study for each household was also carried out thereafter. In this study, only households using the national electricity network calibration meter on their disadvantage favorably answered to all financial indicators and appear as the only one that could profit from such project. This work is helpful to note that photovoltaic solar energy still stays at a primitive level of competitiveness compared to conventional energy resources for small systems in Ouagadougou.

1. Introduction

The crisis of the energy which has led all Africa for several years does not save Burkina Faso. The country's dependence on oil of which most of the electric production depends does not help the things. The country is in an energetic context where 67.2% of the consumed electricity is from the local thermal source, 15.7% is from the hydroelectric source, and 17.1% is from the imports. According to the World Bank Group (http://data.worldbank.org/ on October 23, 2013.), only 14.6% of the population has access to that resource. The report of SONABEL (Société Nationale d'Electricité du Burkina Faso), the national electricity company, estimates, at the last quarter of 2012, at 158 FCFA/kWh (African Financial Community Franc with 1 Euro = 655.96 FCFA (XOF) by the converter from Euro to Western African FCFA with rates of exchange of October 23, 2013, http://fr.coinmill.com/EUR_XOF.html#EUR=1)the average national cost of consumed electricity. This cost remains relatively high for the majority of the population in a country where 46.4% of the population lived below the national poverty line (Population below national poverty line is the percentage of the population living below the national poverty line, which is the poverty line deemed appropriate for a country by its authorities. National estimates are based on population-weighted subgroup estimates from household surveys.) [1] over the period 2000–2009.

Among the ECOWAS (Economic Community of the of West Africa States) countries, except electricity consumptions higher than 300 kilowatt-hours per month where it is preceded by Benin, Burkina Faso is the country where populations pay for the electricity from the national network expensively (from Climate Change Knowledge Portal for Development Practioners and Policy Makers database on December 15, 2012: http://donnees.banquemondiale.org/pays/burkina-faso). This high cost finds its first explanation in the lack of a real knowledge on behalf of the national electricity subscribers during the calibration of their domestic electric meters. Those are not enough informed on this cause; some of them use electric meters overgauged for their electricity consumption, which inevitably increase the final cost of their electricity invoice. Taking into account this high cost, 110 million households at low income in Africa spend more than 4 billion dollars per year for lighting based on kerosene, an expensive, ineffective, and dangerous product for safety and health [2]. According to UNDP [1], 82.4% of the population of Burkina Faso lives without modern sources of energy. That entrains significant carbon dioxide (CO_2) emissions (Refer to the quantity of greenhouse gas converted into equivalent CO_2.), essential gas in the global warming estimated in 2010 at 1.441 million Mt (https://www.cia.gov/library/publications/the-world-factbook/geos/uv.html).

CCI-BF [3] estimates that the majority of Burkinabe lives far from the electrical supply network with only 3% as national electrification rate at December 31, 2009. In Burkina Faso, 73.5% of the total population lives in rural areas [1]. For these rural communities, it is technically too complex to extend the network towards them or because the cost of an electric connection is not justified compared to other existing solutions. However, it is often essential to have access to electricity in order to ensure some basic services such as lighting, production of cold, and operation of radio or television stations sets (http://www.planete-burkina.com/economie_burkina.php.).

Paradoxically, Burkina Faso belongs to the sunniest areas of the earth, with a potential of average solar irradiation of approximately 5-6 kWh/m^2/day. That could justify the alternative to feed these isolated sites in electricity by photovoltaic (PV) solar energy. The importance of this solar resource and the real reduction of the PV technology costs [4, 5] result in very significant contributions in PV systems mainly for rural populations in Burkina Faso.

The objective of this study is to show the households in which electric consumption can be ensured by a PV system focusing on the calibration of the domestic electric meters of the national electricity supply. To succeed, we review a broad and recent literature in order to highlight the key drivers and uncertainties of PV systems costs, prices, and potential regarding economic indicators.

2. Material and Methods

2.1. Field Site Location. Burkina Faso is a landlocked country, located at the heart of west Africa, between the 9° and 15° of Northern latitude, the 2°30′ of eastern longitude, and the 5°30′ of western longitude. It covers a surface of 274 000 km^2 and is limited by six countries: Niger in the east; Mali in the north and the west; and Ivory Coast, Ghana, Togo, and Benin in the south. The total population is 17 million inhabitants in 2011 with an average annual growth simulated to be 3% over the period 2010–2015 [1]. Ouagadougou, the experimental site, is the capital of Burkina Faso located at the center of the country (Figure 1).

FIGURE 1: Location of the experimental site. Source: modified from CIA (from Central Intelligence Agency: https://www.cia.gov/library/publications/the-world-factbook/geos/uv.html).

2.2. Households Energy Needs Survey. Before the electrification of a site, it is compulsory to well know the energy demand of that site's inhabitants in order to adapt to the expected system's productivity. For this study, the data are acquired by campaigns carried out within a sample of five (5) households in Ouagadougou. There is one household in the district of Wemtenga, one in the district of Zogona, and three households in the district of Dassasgho. At Wemtenga and Dassasgho 01 where inhabitants pay for their electricity consumption by cash-power, daily electricity consumption measurements are carried out from 2012/11/09 to 2013/01/15. At Dassasgho 02, Dassasgho 03, and Zogona where inhabitants pay monthly for their electricity by bills, seven bills have been considered. As all the households' appliances work in alternative current (AC), the power of each household appliance is collected in order to well design the solar inverter power. Each average energetic need found is set constant during the year and is calculated by the following:

$$E_{ch,j} = \sum_{i=1}^{n} \left(P_i \times \Delta t_i\right). \tag{1}$$

$E_{ch,j}$ is the daily energy consumption [Wh/day], i is the electric appliance, n is the total number of electric appliances, P_i is the nominal power of the electric appliance [W], and Δt_i is the average daily duration of the operating appliance [h/day].

These households are thereafter divided into two classes according to their domestic meters calibration (3A (Amp) and 5A) and the effective cost of energy paid from SONABEL following the tariff grid of that company was calculated.

2.3. Technical Considerations. For a given household, technical aspects include the solar database and the design of the size of the main components of the PV system such as modules, batteries, inverter, and regulator. The system positioning and other technical considerations are also taken into account.

2.3.1. Solar Data Acquisition. Before any design of system PV, it is important to know the solar resource at the site of study because the weather data influence the productivity of system PV a lot. All databases used for solar data acquisition are tools for decision-makers and investors especially during the analysis of the financial resources during the projects of rural electrification [6, 7]. For this study, we used the database RETScreen previously used by Leng et al. [8], RNCan [9], RNCan [10], Suri et al. [6], Gifford et al. [11], Mermoud [12], and Mermoud and Lejeune [13].

2.3.2. Design of Modules Nominal Power. The PV module performance is highly affected by the solar irradiance and the PV module temperature. In this paper, a simplified equation is used to estimate the PV module nominal power [14]:

$$P_{\mathrm{PV}} = \frac{E_{ch,j}}{\mathrm{PR} \times E_{i,\mathrm{def}}}, \qquad (2)$$

where P_{PV} is the expected photovoltaic nominal power [$\mathrm{W_p}$]; $E_{ch,j}$ is the daily energy needs [Wh/day]; PR is the performance ratio of the photovoltaic field; and $E_{i,\mathrm{def}}$ is the daily solar irradiation received in the plan of the modules in the most unfavorable month of the year [$\mathrm{kWh/m^2/day}$].

2.3.3. Determination of Inverter Power. The inverter is the device of power electronics which allows converting the direct current (DC) to the alternative current (AC) for AC loads. The nominal power transiting the inverter to serve the demand is given by the following [15]:

$$P_{n,\mathrm{ond}} = \frac{P_{\mathrm{AC}}}{\eta_{\mathrm{ond}} \times \cos\varphi \times k_{\mathrm{loss}}}, \qquad (3)$$

where $P_{n,\mathrm{ond}}$ is the nominal output power of the inverter [W]; P_{AC} is the total power load in alternative current [W]; η_{ond} is the inverter efficiency [%]; $\cos\varphi$ is the power's factor; and k_{loss} is the reduction coefficient related to the losses in the cables.

Note that the ratio between P_{PV} and $P_{n,\mathrm{ond}}$ will hold between 0.7 and 1.2 according to PERACOD [16].

2.3.4. Design of Regulator Output Intensity. A regulator is the device which monitors the quantity of electricity, injected or tapped, corresponding to the capacity of the batteries installed. It is dimensioned by its input intensity, given by the following [17]:

$$I_{\mathrm{reg}} = \frac{N_{\mathrm{PV}} \times P_{\mathrm{PV},i}}{N_{\mathrm{PV},s} \times \eta_{\mathrm{reg}} \times U_{\mathrm{mod}}}, \qquad (4)$$

where I_{reg} is the regulator input intensity [A], N_{PV} is the total number of PV modules, $P_{\mathrm{PV},i}$ is the unit nominal power of module [$\mathrm{W_p}$], $N_{\mathrm{PV},s}$ is the PV modules number in series, η_{reg} is the regulator efficiency [%], and U_{mod} is the nominal system operating voltage [V].

2.3.5. Calculation of Battery Park Size. Because the periods of consumption always do not correspond to the hours of production, a park of batteries is installed to store produced energy. The batteries are in charge during the periods of day in order to be able to feed the site in the night or the days of very bad weather. The capacity of the park of batteries is calculated by the following equation [15, 18]:

$$C_{\mathrm{bat}} = \frac{E_{ch,j} \times \mathrm{Aut}}{\eta_{\mathrm{bat}} \times \mathrm{DOD} \times U_{\mathrm{bat}}}, \qquad (5)$$

where C_{bat} is the capacity of the batteries park [Ah]; Aut is the charged batteries autonomy [day]; η_{bat} is the battery efficiency at discharge phase [%]; DOD is the battery authorized discharge depth [-]; and U_{bat} is the battery voltage [V].

2.4. Financial Analysis. Financial analysis is ensured by the software RETScreen. The formulas used are based on the current financial terminology which can be found in the majority of the handbooks of financial analysis. The model makes the following assumptions:

(i) the year of initial investment is the year 0;
(ii) the costs and the appropriations are given for year 0 and consequently the inflation rate and the energy indexation rate are applied from year 1;
(iii) the calculation of monetary flows is carried out at the end of each year.

Frequently, it is difficult for the project recipient to cover all the expenses related to the project. In that case, this person can resort to a loan from a bank. Thus, the total cost of the project is composed of the equity at year 0 and annual payments of the debt and the expenses for operations and maintenance and the replacements in the following years.

2.4.1. Investment Cost. The calculation of the cost of the components of the solar kit is the most delicate part of the work because that represents the initial capital cost of the solar project. An estimate will be elaborate focusing on the most economic possible aspects beginning with the initial gross investment (C_i) calculated by (6) based on Table 2:

$$C_i = P_{\mathrm{PV}} \times A + C_{\mathrm{bat}} \times B + P_{n,\mathrm{ond}} \times C + I_{\mathrm{reg}} \times D, \qquad (6)$$

where C_i is the initial gross investment in FCFA and A, B, C, and D are, respectively, the chosen specific price of module, battery, inverter, and regulator in FCFA as shown in Table 1.

The costs of the other elements of the balance-of-system (BOS) such as cables, structure, and all installation costs are applied with a weighting factor (δ) to C_i. Thus, the initial total investment (C_t) is calculated by the following equation:

$$C_t = (1 + \delta) \times C_{i,\mathrm{syst}}, \qquad (7)$$

where C_t is the total initial investment in FCFA and δ is the weighting factor for the other costs.

The operations and maintenance (O&M) are adjusted on the basis of annual cost during the period of analysis of the

Table 1: Solar energy system's components costs.

Components	Specific price	Sources	Chosen specific price	
			FCFA/U	Euro[1]/U
Module (FCFA/Wp)	374	Sunny Uplands[2] [31], PHOTON[3]	374	0.57
	577	Rigter and Vidican[4] [29]		
	1640	Szabó et al. [7]		
	3936	Bilal et al. [17]		
Battery (FCFA/kWh[5])	69536	Semassou [15]	69536	107.07
	75440	Sunny Uplands [31]		
	82000	Szabó et al. [7]		
	113707	Bilal et al. [17]		
Inverter (FCFA/W)	190	PHOTON	190	0.29
	328	Semassou [15]		
	348	Rigter and Vidican[6] [29]		
	524	Bilal et al. [17]		
Regulator (FCFA/A)	3280	Intigaia[7]	3280	5.00
	5051	Bilal et al. [17]		

[1] With 1 Euro = 656.576 FCFA as currencies conversion chosen
[2] Value simulated for the year 2012.
[3] PHOTON-Newsletter for 2013/01/11 concerning inverters and module price index: http://www.photon.info.
[4] Simulation carried out according to the fall of the module cost for the year 2012.
[5] Cost of AGM lead-acid batteries of nominal voltage of 12 V.
[6] This cost refers to a simulation carried out according to the fall of the price of the inverters for the year 2012.
[7] http://intigaia.free.fr/.

Table 2: Estimate of the average cost of the electricity consumed from SONABEL.

Components	Wemtenga	Dassasgho 01	Dassasgho 02	Dassasgho 03	Zogona
Characteristic					
Type of bill	Cash-power	Cash-power	Bill per month	Bill per month	Bill per month
Amperage	5A	5A	5A	3A	3A
AC loads (W)	431	2556	210	1235	496
Electricity					
Mean electricity consumption (kWh/month)	54	161	15	48	79
Cost of the first electricity consumption level (FCFA/kWh)	96	96	96	75	75
Rough cost (FCFA/month)	5198	16149[1]	1440	3575	6137[2]
Total taxes cost[3] (FCFA/month)	2446	3091	2326	1326	1527
Proportion of the taxes [%]	32	16	62	27	20
Monthly total cost (FCFA/month)	7644	19240	3766	4901	7664
Monthly specific cost					
FCFA/kWh	141	119	256	105	97
Euro[4]/kWh	0.22	0.18	0.39	0.16	0.15

[1] This cost includes the invoicing of the first section (1 to 50 kWh) and that of the second section (51 to 200 kWh) which costs 102 FCFA/kWh.
[2] This cost includes the invoicing of the first section (1 to 50 kWh) and that of the second section (51 to 200 kWh) which costs 102 FCFA/kWh.
[3] Including all taxes.
[4] With 1 Euro = 656.576 FCFA as currencies conversion chosen.

project. In this work, the O&M relate to the replacement of the batteries, the inverter, and the regulator and we considered that the system is free from other maintenances during the project lifetime.

2.4.2. Risk Analysis. An investor or a banker will use the capacities of analysis of sensitivity and risk available in each model in order to evaluate the risk associated with the investment in a given project. For this study, we made only risk assessment on the NPV with RETScreen. That allowed evaluating how uncertainty in the estimate of this parameter (NPV) can affect the financial viability of the project.

2.4.3. Levelized Cost of Energy. The Levelized Cost of Energy (LCOE) is calculated by considering the cost of the energy consumed (8) because in the remote village, most of the energy generated is lost [17, 19] as follows:

$$\text{LCOE} = \frac{(1 - f_d)\, I + \sum_{n=1}^{N} \left[C_{\text{an}} (1 + \lambda)^n + D\right]}{\sum_{n=1}^{N} E_{\text{an}} (1 + r)^n}, \qquad (8)$$

where LCOE is the effective cost of the energy consumed from the system (FCFA/kWh), I is the total capital cost of the project [FCFA], f_d is the debt ratio, N is the project lifetime in years, n is the considered year, C_{an} is the annual expenditure [FCFA], λ is the inflation rate, D is the annual debt payment [FCFA], E_{an} is the annual electricity consumption [kWh/year], and r is the energy indexation rate.

2.4.4. Retained Assumptions and Financial Viability Parameters Simulation. The retained PR is 0.75 [6]. The assumed η_{ond} is 92% [20], and $\cos\varphi$ and k_{loss} are, respectively, set at 0.9 and 0.85 [15]. The assumed $N_{\text{PV},s}$ is 1 and η_{reg} is 95% [21]. The assumed DOD is 80% [22], η_{bat} is 85% [23], and Aut is three (3) days [21, 23]. The weighting factor (δ) is set at 12%. O&M are set at 2.7% per year from the total initial investment.

In order to carry out the financial analyses of the feasibility of the project, we considered a project lifetime of the 25 years. All monetary flows are handled in constant currency with an interest rate of 7.5% for the loan considered. The rate of the loan considered is 75% and the equity is set at 25%. The inflation rate retained is 2.8%, the indexation of the SONABEL energy rate is 4%, and the real discount rate is 5%. All the financial viability parameters such as internal rate of return (IRR), simple payback, equity payback, and net present value (NPV) are simulated by the software RETScreen.

3. Results and Discussion

3.1. Solar Irradiation and Energy Delivered to Load. Simulation carried out shows that the general trend of yearly global irradiations evolution is similar (Figure 2). Nevertheless, significant differences are observable at monthly scale.

Note that daily solar irradiation on tilted plan is higher than that on horizontal plan from September to March and lower the following months of the year. But on average, solar irradiation on the tilted plan is higher than that on the horizontal plan with 6.03 kWh/m^2/day against 5.91 kWh/m^2/day, respectively. As result, a transposition factor of 1.022 which represents an increase of 2.2% of productivity is found. August is the month in which the daily solar irradiation is the smallest on the tilted plan with the value of 5.15 kWh/m^2/day. This value has been used for the design of the PV modules size.

3.2. Households Energy Demands and Costs. Campaigns carried out indicate that the energy consumed in the households is mainly dominated by lighting (lamps), cold (ventilators and refrigerators), and electronic appliances (radios, televisions, iPad, and computers). These uses are the same as that shown by Liebard et al. [24] for 12 studied villages in the province of Kourittenga (Burkina Faso). However, it is remarkable to indicate that refrigerator used at Dassasgho 01 consumes more energy because it belongs to an old energetic class. Domestic iron used as heating is found at Dassasgho 01 and Dassasgho 03.

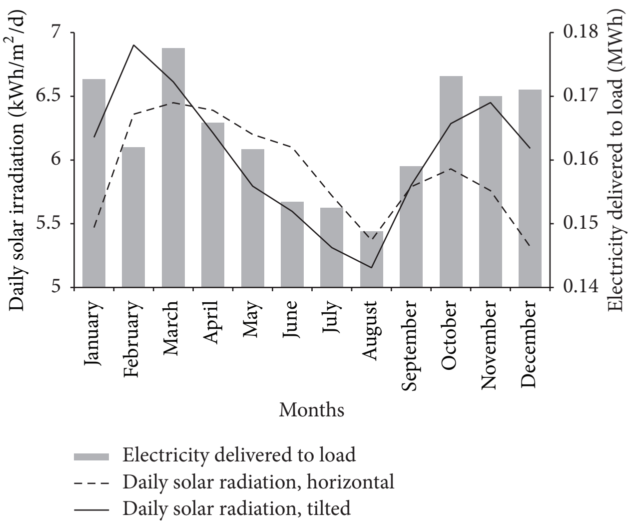

FIGURE 2: Global irradiation on full south fixed plans (principal axis) and energy delivered to load (secondary axis). The inclination angle is 15°. Data simulated by RETScreen.

Once again, Dassasgho 01 uses an electrical appliance (iron) which consumes energy a lot. Note that energy consumptions vary from a household to another. The high energy consumption is observed at Dassasgho 01 and the low one at Dassasgho 02. In fact, the dependent taxes to the bill decrease when the electrical consumptions increase for a given domestic electric calibration meters. When the electrical consumption is less than 161 kWh/month in Burkina Faso, it is desirable to gauge the domestic electric meters at 3A. With these energy consumptions, high specific electricity bills are found at Dassasgho 02 and Wemtenga. The domestic electric meters of inhabitants of these households are gauged at 5A and these inhabitants pay more than 30% of their bill as taxes. However, inhabitants at Dassasgho 01 who use the same electric calibration meters pay only 16% as taxes for their bill. That cost is low at Zogona and Dassasgho 03 where inhabitants' domestic meter calibration is 3A (Table 2).

According to the calibration of the electric meter within each household and the tariff grid used for electricity cost calculation, we classified the households into favorable, unfavorable, and buffer zone (Figure 3). Thus, Wemtenga and Dassasgho 02 are located in the "5A unfavorable area," Dassasgho 03 and Zogona are located in the "3A favorable area," and Dassasgho 01 is located at the boundary of the two evoked areas called "buffer area."

3.3. Solar Components Characteristics. According to energy needs collected, the voltage retained for all components (modules, regulator, battery, and inverter) at Wemtenga, Dassasgho 02, Dassasgho 03, and Zogona is 12 V, while it was considered to be 24 V at Dassasgho 01, where the electric consumption is significant. For all households, we

Table 3: Characteristics of the PV system components.

Components	Modules P_{PV} [$\mathrm{W_p}$]	Inverter $P_{n,\mathrm{ond}}$ [W]	Battery C_{bat} [Ah]	Regulator I_{reg} [A]
Wemtenga	575	500	575	48
Dassasgho 01	1680	2000	840*	70
Dassasgho 02	155	200	155	15
Dassasgho 03	500	700	500	45
Zogona	840	800	840	70

*U_{bat} is 24 V; C_{bat} would be equal to P_{PV} value if U_{bat} was also 12 V.

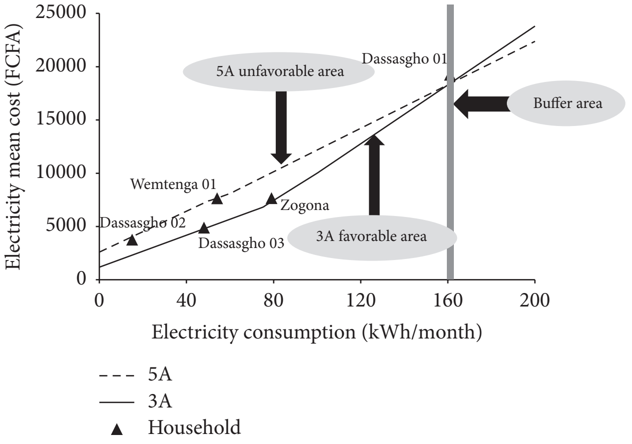

Figure 3: Households consumption according to the calibration of the meters. The cost of the electricity is calculated according to SONABEL tariff grid.

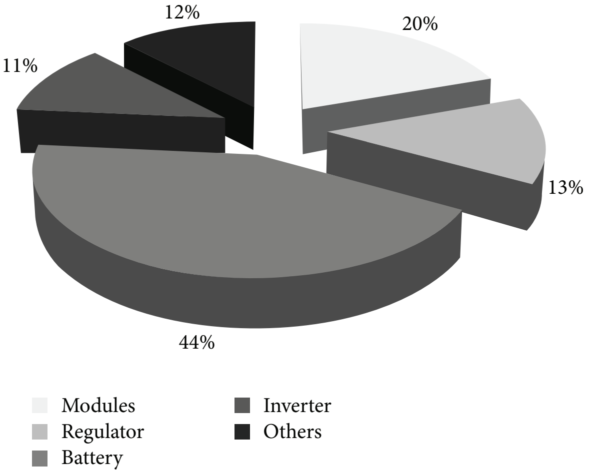

Figure 4: Solar system components costs at the beginning of the project. "Others" represents cables, installation, and transport.

chose the solar polycrystalline silicon modules of PHOTOWATT (PHOTOWATT is only chosen for simulation, not for economic aspects) for the simulation. All characteristics of the PV systems components are illustrated in Table 3. Components parameters values increase with the increase of household inhabitants energy demand. Note that, in value, the module nominal power equals the capacity of the park of batteries, which is interesting to make comparisons between systems' total cost thereafter. However, inverter's power seems strongly overestimated at Dassasgho 03, meaning that system total cost would be increased.

In the same way, it seems to be underestimated at Wemtenga, meaning that the system total cost would be decreased there. All the inverter power misestimation would distort the PV energy cost when analyzing economic aspects.

Figure 4 shows that modules participate at only 20% of the initial cost. Batteries are the most expensive PV component with 44% (Figure 4) and that percentage will reach about 65% of course of their replacements during the project lifetime.

3.4. Monetary Flows and Financial Viability Parameters Analysis. By considering the cumulative cash-flows, Wemtenga and Dassasgho 01 and Dassasgho 02 answer favorably to the project reliability because monetary flows are above the "null flow threshold" (Figure 5). That indicates that projects are viable in both households located in 5A unfavorable area and buffer area, justified or not when analyzing economic viability parameters.

Financial viability parameters show different approaches. IRR for equity is positive for Wemtenga and Dassasgho 01 and Dassasgho 02. However, it is lower than 5% at Dassasgho 01, indicating that the project is not viable there. On the one hand, simple payback and equity payback for these three households are less than the expected project lifetime of 25 years, meaning that the projects are viable there. But, by considering the recommendation of PERACOD [16], the project would be more viable at an equity payback of more 15 years.

On the other hand, NPV, main parameter in project analysis, indicate that only Wemtenga and Dassasgho 02 economically satisfy the project. For Zogona and Dassasgho 03, all financial viability parameters are potentially unfavorable for project feasibility (Table 4).

The loan ration taken at 75% seems justified for a kind of project. In fact, according to PERACOD [16], a project with a high loan rate would cost higher than that which is totally financed by the project owner. However, seeing the high investment cost, that project owner would rather become reticent. The interest rate of 7.5% on the loan admitted for the project seems reasonable according to BAfD et al. [25] because this is the rate which is applied by SGB (Société Générale des Banques) for the PV projects in Burkina Faso. However, the management of monetary flows over the

Table 4: Financial viability parameters simulated by RETScreen. Project lifetime was set at 25 years.

Financial viability	Wemtenga	Dassasgho 01	Dassasgho 02	Dassasgho 03	Zogona
IRR-equity (%)	8.6	3.5	31.5	−4.7	−6.1
Simple payback (years)	16.9	21.2	8.2	30.2	31.8
Equity payback (years)	14.4	20.5	3.7	>project	>project
NPV					
FCFA	208340	−225268	491367	−385479	−668860
Euro[1]	317.8	−343.6	749.5	−588.0	−1020.3

[1] With 1 Euro = 656.576 FCFA as currencies conversion chosen.

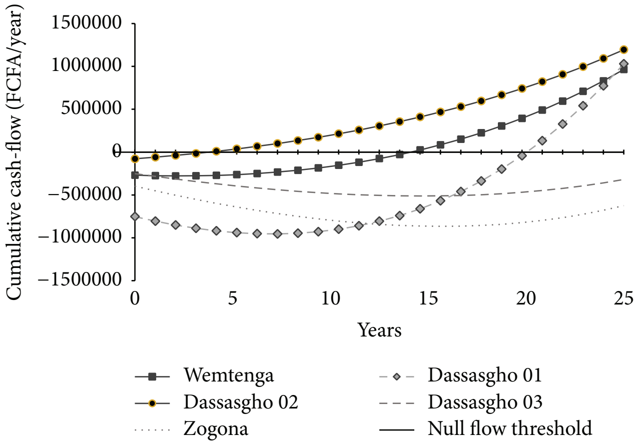

Figure 5: Cumulative cash-flows simulated by RETScreen. Note that cash-flows from Zogona and Dassasgho 03 (in broken line) which use a domestic meter calibration of 3A are below null flow line.

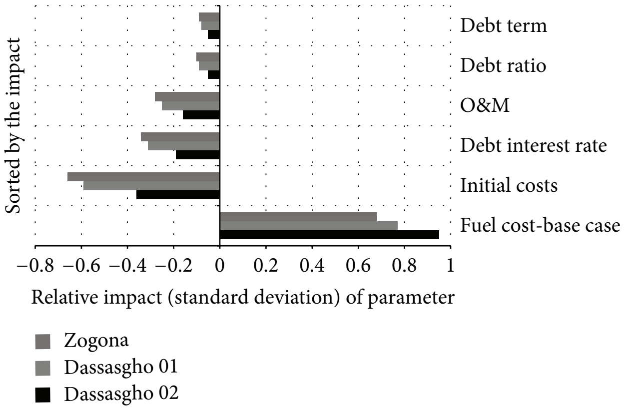

Figure 6: NPV risk analysis at a range of 10% evaluated by RETScreen. All costs in FCFA XOF and the debt term in a year for a real discount rate of 5%. Negative values indicate outcome, while positive values indicate income (savings).

duration of 25 years seems not to correspond to that applied by this company because SGB only allows the refunding of the loan over a loan term of 7 years, which could make the project compared to these 25 years less viable. The inflation rate taken at 2.8% is the same as that simulated by CIA World Factbook (https://www.cia.gov/library/publications/the-world-factbook/geos/uv.html) [26] and BAfD et al. [25] for Burkina Faso for 2013.

Indeed, that rate of 2.7% applied at O&M cost during the project lifetime seems correct. In fact, this value is slightly lower than that fixed by Short et al. [27] who admit it to be at 1-2. The energy indexation rate of 4% is different from AGIR [28] consideration. For that author, this rate was the same as the inflation rate in a study realized in France. We chose this rate because of the fluctuations of electricity cost like oil in Burkina Faso. We also chose a real discount rate of 5% like Liebard et al. [24] and Semassou [15] in their projects analysis in Burkina Faso and Benin, respectively. This rate respects Szabó et al. [7] recommendations for PV projects in Africa.

3.5. Risk Analysis on NPV. The analysis of the risk went primarily on the clear brought up to date values related to the project starting from the studied indicators. This is because this economic parameter interests more investors before the realization of their project. This analysis is also carried out in three strategic households such as Dassasgho 02, located in the 5A unfavorable zone, Zogona, located in the 3A favorable area, and Dassasgho 01, located in the buffer zone. For all these indicators, the rate of the risk which is chosen to be at 10% made it possible to show that the risk related to the project is strong for the indicator "fuel cost-base case" followed by the "initial costs" as indicated in Figure 6. The analysis shows that the impact on the NPV is stronger for the "fuel cost-base case" for households located in the 5A unfavorable zone. That means that, in these households, NPV are based on this indicator and are exposed to the risk that their projects could not be viable if the "fuel cost-base case" decreases, conversely to the 3A favorable area. For these households, the "initial costs" rather seem to be the major indicator in the risk on the NPV. A project will be profitable if the cost of the PV system components strongly decreases.

3.6. PV and SONABEL Energy Costs. Figure 7 shows that, for households located in the 3A favorable area (Dassasgho 03 and Zogona), LCOE is higher than that of the national network electricity cost, meaning that PV projects are not viable there. When the power consumption is slow and is located in the 5A unfavorable zone, the PV projects become profitable. However, by recommending the energy effectiveness in each household when realizing preliminary projects, Wemtenga and Dassasgho 02 would have their

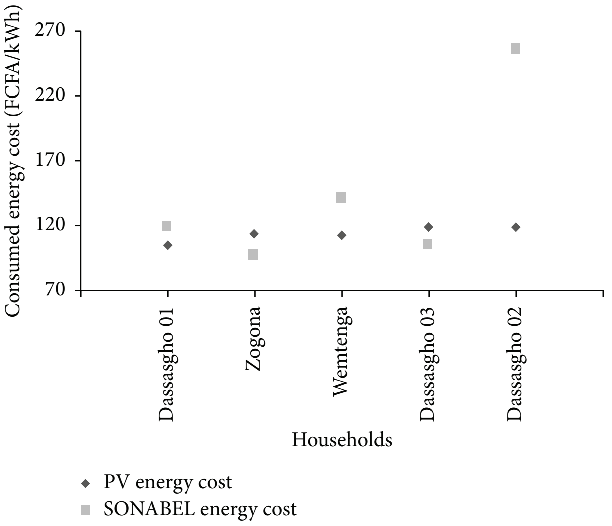

Figure 7: PV and SONABEL consumed energy costs. Households ranged from the highest energy consumption to the lowest one, like PV energy's expected costs.

domestic electric meters being changed into 3A and would not have viable PV projects.

LCOE calculated range is from 105 FCFA/kWh (Dassasgho 01) to 119 FCFA/kWh (Dassasgho 02) that is from the highest energy consumption to the lowest one. In our case, LCOE at Wemtenga is lower than that at Zogona and LCOE at Dassasgho 03 is equal to that at Dassasgho 03. The explanation given to these illogical results could reside on several assumptions carried out and the calculations uncertainties when editing the estimates of the projects especially on the misestimation of inverters nominal powers as revealed before.

The mean LCOE of 112 FCFA/kWh calculated seems realistic. The project carried out by Rigter and Vidican [29] gives an average LCOE of 132 FCFA/kWh with a discount rate of 7% for investments in PV solar project. This cost is slightly higher than those calculated there. According to BNEF, the LCOE in the first quarter of the year 2012 ranged between 81 FCFA/kWh and 126 FCFA/kWh for residential solar projects (NREL 2009 in [4]). This interval of LCOE perfectly includes those calculated in this study. Regarding the LCOE compared to SONABEL energy cost in the favorable cases focusing on the domestic meters calibration, it is clear that LCOE of PV systems remain high. That is proved in almost all countries of Africa as shown by Szabó et al. [7] studies carried out in African rural area. This is why certain authors [4, 5, 7, 18] propose to turn towards hybrid systems in order to make the system more competitive. Indeed, Lemaire [30] simply analyzes that technologies of renewable energy, and mainly the PV systems, are typically expensive, thus out of the rural populations portfolio in a development country. Note that to be economically viable, the PV projects carried out in Burkina Faso at a local scale need aids from the government. Moreover, the recipients of those projects deserve to be encouraged through flexibility on behalf of the banks.

4. Conclusion

The objective of this study is to show the hearths in which electric consumption can be ensured by an autonomous system PV instead of national network. In order to reach this objective, investigations near five households with weak average consumption power in Ouagadougou were realized. All these hearths which use the electricity of the national network were initially classified into zones of favorable, unfavorable use, and plug in comparison with the calibration of their electric meters. According to the energy needs for each household, a solar kit was dimensioned. The configuration retained for the success of the project resides in the optimization of the energy received in the field of the fixed sensors by a slope of 15 directed full south from the plan of the module by the use of the RETScreen model. Estimates were published on the most economic possible bases according to the data obtained. Using this model of analysis of clean projects of energies, the evaluation of the financial viability of each autonomous solar project in Ouagadougou was made. The results indicate that only the class of the households which use electric meters of the national network in their discredit has a level of competitiveness raised for solar projects.

The situation becomes even darker if incompressible needs were made and one gave a detailed attention to the calibration of the electric meter before performing the analysis of feasibility of the solar projects in Ouagadougou. However, the recourse for these projects can prove the justification for households with great power consumption or if subsidies could be brought on behalf of the government in order to encourage the recipients. Today, the economic situation of the majority of the countries of West Africa does not favor an ambitious energy policy directed towards the rural world. The funds of research development remain insufficient in spite of the efforts authorized by the countries. Even if it is true that the exploitation of the majority of the solar systems does not require significant expenses apart from some trickle charges, the initial investment makes them less competitive compared to the traditional energy sources.

Nomenclature

Abbreviations

CCI-BF:	Chambre de Commerce et d'Industrie du Burkina Faso (Trading and Industry Room of Burkina Faso)
ECOWAS:	Economic Community of the of West Africa States
FCFA:	Franc de la Communauté Financière Africaine (designating the currency used by many West African and Pacific countries)
NPV:	Net present value
PNUE:	Programme des Nations Unies pour l'Environnement for United Nation of Environment Program
PV:	Photovoltaic

RETScreen:	Renewable Energy Project Analysis Software
SONABEL:	Société Nationale d'Electricité du Burkina Faso (National Electricity Society of Burkina)
UNDP:	United Nations Development Program.

Symbols

Δt_i:	The average daily duration of the operating appliance
A, B, C, and D:	The chosen specific price of module, battery, inverter, and regulator, respectively
Aut:	The charged batteries autonomy
C_{bat}:	The capacity of the batteries park
C_i:	The initial gross investment
$\cos\varphi$:	The power's factor
C_t:	The total initial investment
D:	The annual debt payment
DOD:	The battery authorized discharge depth
E_{an}:	The annual electricity consumption
$E_{ch,j}$:	The daily energy consumption
$E_{i,\mathrm{def}}$:	The daily solar irradiation in the plan of the modules in the most unfavorable month of the year
f_d:	The debt ratio
i:	The electric appliance
I:	The total capital cost of the project
I_{reg}:	The regulator input intensity
k_{loss}:	The reduction coefficient related to the losses in the cables
LCOE:	The effective cost of the energy consumed from the system
n:	The total number of electric appliances
N:	The project lifetime in years
$N_{\mathrm{PV},s}$:	The PV modules number in series
N_{PV}:	The total number of PV modules
P_{AC}:	The total power load in alternative current
P_i:	The nominal power of the electric appliance
$P_{n,\mathrm{ond}}$:	The nominal output power of the inverter
$P_{\mathrm{PV},i}$:	The unit nominal power of module
P_{PV}:	The expected photovoltaic nominal power
PR:	The performance ratio of the photovoltaic field
U_{bat}:	The battery voltage
U_{mod}:	The nominal system operating voltage
δ:	The weighting factor for the other costs of the photovoltaic system
η_{bat}:	The battery efficiency at discharge phase
η_{ond}:	The inverter efficiency
η_{reg}:	The regulator efficiency
λ:	The inflation rate.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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