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Feasibility Analysis For A Stand-Alone Photovoltaic System In Ouagadougou (Burkina Faso): Technico-Economical Approaches

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ABSTRACT

In Ouagadougou, to obtain the meter installation and final connection by the national electricity company, inhabitant pays 842 865.05 FCFA[1]. Thus, the mean price of electricity at the end of June 2015 is 140 FCFA/kWh. This cost seems very high for a country where 46.4% of the population lives below the international poverty line. In order to look for a palliative solution to that situation, the resort to photovoltaic solar energy is justified such the country benefits from significant resources in solar irradiation. The purpose of the present study that we carry out in that option is to try an alternative energy solution focusing on the economic and environmental returns in solar energy preliminary projects in Ouagadougou. To succeed such project, we chose the photovoltaic solar energy in remote area knowing that the country is sufficiently sunny. Three households with the same current intensity of national domestic meters calibration were retained according to their energy demand surveys made within each household allow to design a corresponding solar system following the rule of art. The Levelized Cost of consumed

[1] FCFA means 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

Energy (LCOE) from the project was also carried out thereafter regarding each energy demand. In this paper, it is found that solar photovoltaic systems generate environmental economies depending a considered country. Indeed, when the cost of the system is considered at the most economic possible, all the households are suitable for the project and the LCOE decreases when the consumption of the energy increases. We concluded that stand-alone PV projects still stay at a less level of feasibility compared to conventional energy resources for small systems in Ouagadougou.

Keywords: energy demand, stand-alone system, design, financial viability, Ouagadougou.

1. INTRODUCTION

At worldwide scale, 1.6 billion people are currently private from electricity. IEA[2], UNDP[3] and UNIDO[4] estimate that it will be necessary to invest 756 billion dollars (equivalent to 36 billion per year) between 2010 and 2030 to ensure the access to electricity for all (UNEP[5] 2011). Thus, in Africa, the 110 million households at low income spend more than 4 billion dollars per year for lighting based on kerosene, an expensive, ineffective and dangerous product for safety and health (UNEP 2011).
According to UNDP (2011), it is 82.4% of Burkina Faso population who lives without modern fuels. In the most cases, supplying demand energy using for example diesel fuel is so expensive and increases the amount of CO_2 emitted (Ould Bilal et al. 2012). Doing Business project presented in June 2015 indicated that the reliability and the transparency of electricity tariff index is null in Burkina Faso. Thus, the country is ranked 183 out of 189 countries in getting electricity with a mean price of electricity of 140 FCFA/kWh in Ouagadougou.

Then, from the studies carried out at the end of the last quarter 2012 by SONABEL[6], Burkina Faso's electricity company, the mean effective cost of electricity is 158 FCFA/kWh. However, in that country, 46.4% of the population lives below the international poverty line and the environment constitutes also the first economical capital. Therefore, the reduction of poverty necessarily passes by a durable management and a valorization of the environment in general and natural renewable resources in particular. Consequently, energy seems to be the crucial factor for the competitiveness of the economy in Burkina Faso and its macro-economic balance. The CSLP[7] 2006-2008 indicates that the government will get busy to improve the administration of the energy sector and the national energy coverage to reduce the

[2] International Energy Agency
[3] United Nations Development Programme
[4] United Nations Industrial Development Organization
[5] United Nations Environmental Programme
[6] Société Nationale d'Electricité du Burkina
[7] Cadre Stratégique de Lutte contre la Pauvreté

cost of the energy and to create the best possible conditions of participation of the private sector with the development of energetic infrastructures (Burkina Faso & Communauté européenne 2007). The characteristics of the residential energy consumption in rural areas are very interesting from social behavior and lifestyle change. According to Yaungket & Tezuka (2013), solar energy system is a good option for rural off-grid electrification. Among this, PV is one of the best options (Nikhil & Subhakar 2 012). However, Amani et al. (2016) demonstrated that the economic situation of the majority of the countries of West of Africa does not favor an ambitious energy policy directed towards the rural world. That because the funds to research development remain insufficient in spite of the effort authorized by these countries. Indeed, the population misuse most of the time the national electric meters and that makes more competitive photovoltaic projects. In order to know additional reasons of feasibility of such projects, we purpose to work with three households where the electric meters are well calibrated.

The objective of this paper is to propose a stand-alone photovoltaic (PV) system at rural electricity consumption consideration which minimizes as better as possible the effective energy produced cost compared to the national electricity effective cost.

2. MATERIAL AND METHODS

2.1. Experimental site

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. With a surface of 274 000 km^2, the country is limited by six others countries as following: Niger in the East; Mali in the North and the West; Ivory Coast, Ghana, Togo and Benin in the South. The total population is 17 million inhabitants in 2011 (UNDP 2011). Urban and rural populations are respectively estimated at 26.5% and 73.5% from the total population (UNDP 2011). Ouagadougou, the experimental site, which is the capital of that country is a town located at the center of Burkina Faso (figure 1).

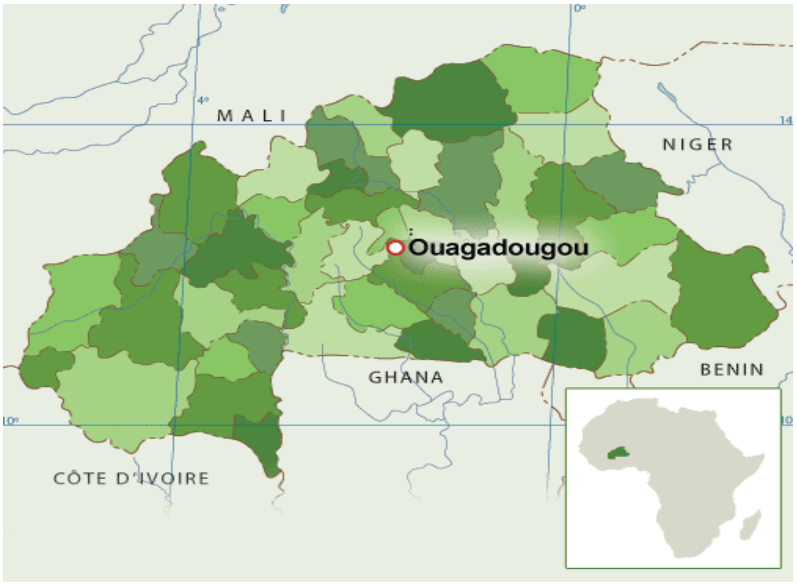

Figure 1: Location of the experimental site
Source: http://www.afdb.org/fileadmin/uploads/afdb/Maps/Countries_2013/burkinofaso_detail.gif

2.2. Energetic parameters

2.2.1. Solar irradiation data sources

The weather data affect a lot the productivity of a PV system. This is the reason why before any design of such system, it is primarily important to know the solar irradiation of the experimental site. The knowledge of these data is not easy, so we used various databases acquired as well on the ground as from calculations carried out from satellites data. There are many weather data sources, but none is perfect. Thus, it is significant to understand advantageous and limited points of each one. For this study, we used four databases which are PVGIS, PVSYST, RETScreen and SolarGIS. Their characteristics are described in table 1. SolarGIS and RETScreen have respectively good spatial and temporal resolutions but not PVSYST. Then, the uncertainty of RETScreen seems higher than the others databases mainly at ground scale. All these databases are used as tools for decision-makers especially during the financial resources analysis (Suri et al. 2006 & Szabo et al. 2011) during rural electrification projects (Suri et al. 2006 & Szabo et al. 2011). For Ouagadougou, a fixed 15° full South from the plan of the system was chosen in order to obtain a better sunning of the module surface at midday standard time and a better total daily sunning (ABB 2012).

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Table 1: Description of databases used.

Databases	Data sources	Spatial coverage	Spatial resolution	Temporal coverage	Measured parameters	Uncertainty (±)	Accessibi-lity
PVGIS[8]	CM-SAF[9]	Europe & Africa	30 km × 30 km	1998-2011 (monthly)	GHI[10], DHI[11]	5%	F ree on Web
PVSYST[12]	NASA[13]-SSE[14]	Worldwide	110 km × 110 km	1983-1993 (monthly)	GHI, AT[15] (10 m)	3-5%	F ree for one month and paying thereafter
RETScreen	Ground	Worldwide	Interpola-tion	1982-2006 (monthly)	GHI, DHI	0.7-2%	Free downloada ble software
	WRDC[16] & NASA-SSE					3-5%	
SolarGIS	NOAA NCEP[17]	Worldwide	1 km × 1 km	1994- 2011 (monthly)	AT (2 m)	3-5%	Paying on Web
	Meteosat PRIME		90 m × 90 m	1994-2010 (monthly)	GHI, DHI		

2.2.2. Energy demand survey

The data were acquired by campaigns carried out within a sample of three (3) households in Ouagadougou. These households are located in two districts of this town: one in the district of Wemtenga and two in the district of Dassasgho. We called the second ones Dassasgho 01 and Dassasgho 02. In all these households, the national electric meters used are calibrated at 5A at Wemtenga and Dassasgho 01 where inhabitants pay their electricity consumption by cash-power, daily electricity consumption measurements were carried out from 2012/11/09 to 2013/01/15. At Dassasgho 02 where inhabitants pay their electricity by bills, seven bills have been considered in this paper. These activities allowed to approximate the average daily consumption of electricity in each household, and thereafter the expected module power. As all the households' appliances function in alternative current (AC), the power of each household appliance was collected in order to well design the solar inverter power. Each average energetic need found was set constant during the year.

[8] Photovoltaic Geographic Information System
[9] Climate Monitoring Satellite Application Facility
[10] Global Horizontal Irradiance
[11] Global Direct Irradiance
[12] Photovoltaic System
[13] National Aeronautics and Space Administration
[14] Surface meteorology and Solar System
[15] Ambient Temperature
[16] World Radiation Data Center
[17] National Centers for Environmental Prediction

After, the effective cost of energy paid from the national electricity network company (SONABEL) following the tariff grid of that company was calculated.

2.3. Technical approaches

Recognizing the advantages of PV system, many systems have been installed worldwide in recent years. To achieve the commercialization and widespread use, a number of issues need to be addressed. These issues are related to the design and sizing of the system, that includes technical and financial aspects of PV system to supply electricity (Phuangpornpitak & Tia 2013).

2.3.1. Design of module size

The main components of a PV system are the PV module(s), the battery bank, and the power conditioning units (inverter and regulator) (Nikhil & Subhakar 2012; Ould Bilal et al. 2013).

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 power. The estimate of the PV module output is given by the following equation (Chikh et al. 2011):

$$P_{PV} = \frac{E_{ch,\,j}}{PR \times E_{i,\,def}} \quad (1)$$

Where P_{PV} is the expected photovoltaic nominal power [W_p]; $E_{ch,j}$ is the daily energy needs [Wh/day]; *PR* the performance ratio of the photovoltaic field [-]; $E_{i,def}$ the daily solar irradiation received in the plan of the modules in the most unfavorable month of the year [kWh/m²/day].

The *PR* retained was 0.75 (Suri et al. 2006).

2.3.2. Determination of inverter power

The inverter is the device of power electronics which allows converting the DC current from DC bus bar to the AC current for AC loads. The power transiting the inverter to serve the demand is given by equation 2 **(**Semassou 2011**)**:

$$P_{n,\,ond} = \frac{P_{AC}}{\eta_{ond} \times \cos\varphi \times k_{loss}} \quad (2)$$

Where $P_{n,ond}$ is the nominal output power of the inverter [W], P_{AC} is the total power load in alternative current [W], η_{ond} the inverter efficiency [%], *cos* φ is the power's factor and k_{loss} is the reduction coefficient relating to the losses in the cables.

The assumed η_{ond}, *cos* φ and k_{loss} were respectively 92% (Tassembedo et al. 2012), 0.9 and 0.85 (Semassou 2011).

Note that the ratio between P_{PV} and $P_{n,ond}$ must belongs between 0.7 and 1.2 for a well-designed system according to PERACOD (2006).

2.3.3. Design of regulator output intensity

The solar regulator or controller is the device charged to monitor the load and the discharge of batteries. It is dimensioned according to its input intensity, given by equation 3 (Ould Bilal et al. 2012):

$$I_{reg} = \frac{N_{PV} \times P_{PV,i}}{N_{PV,s} \times \eta_{reg} \times U_{\text{mod}}} \quad (3)$$

Where I_{reg} is the regulator input intensity [A], N_{PV} is the total number of PV modules, $P_{PV,i}$ is the unit nominal power of module [W_p], $N_{PV,s}$ is the PV modules number in series, η_{reg} is the regulator efficiency [%] and U_{mod} is the nominal system operating voltage [V].
The assumed $N_{PV,s}$ was 1 and η_{reg} was 95% (PACER 2007).

2.3.4. Calculation of Battery park size

The batteries ensure the storage of the energy provided by the photovoltaic generator the day and restore to the consumptions when there is no sun. The capacity of the park of batteries is calculated by the following equation (SMA 2010 & Semassou 2011):

$$C_{bat} = \frac{E_{ch,j} \times Aut}{\eta_{bat} \times DOD \times U_{bat}} \quad (4)$$

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].
The assumed *DOD* was 80%, η_{bat} was 85% (Acquaviva 2011) and *Aut* was three (3) days (PACER 2007 & Acquaviva 2011).

According to energy needs collected, the voltage retained for all components (modules, regulator, battery and inverter) at Wemtenga and Dassasgho 02 is 12V and 24V at Dassasgho 01 where the electric consumption is significant. For all households, we chose the solar polycrystalline silicon modules. The manufacturer chosen for the simulation is PHOTOWATT.

2.4. Financial viability

2.4.1. Financial parameters

The general financial parameters summarize the various rates applied during the financial analysis and the duration of the project. For this study, the lifetime of the solar project is taken at 25 years (RNCan 2005) similar to the lifetime of the solar modules. Economical calculations were carried out in constant currency. The inflation and indexation of energy rates are respectively taken at 2.8% and 4% when the real discount rate was taken at 5%.

2.4.2. Financial indicators

This sub-section presents several indicators of financial viability which are calculated automatically by the RETScreen software in the worksheet ‘‘financial analysis’’. On the basis of entered data, the model provides the financial indicators for the analyzed project, facilitating the process of evaluation of the project by the planners and the decision makers. There, we considered that the initial investment will have set out again in own capital stocks (share of the recipient of the project) and in a financing (loan on behalf of a bank). This section presents the equations used in the model of financial analysis. 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:

- the year of initial investment is the year 0;
- the costs and the appropriations are given for year 0 and consequently, the inflation rate and the energy indexation rate are applied as from year 1;
- the calculation of monetary flows is carried out at the end of each year.

2.4.3. Investment cost of the project

The total cost of the project includes the cost of each component of the PV system. That is composed by the equity at the year 0 and annual payments of the debt, the expenses of operations and maintenance and the replacements of the batteries, regulator and inverter, the following years. Before validating the estimate of the installation, we exposed the unit cost of each component of the system. This cost results only from approximations and parameters retained and consigned in table 2. This investment is called there by gross investment.

Table 2: Solar energy components costs.

Components	Specific price	Sources	Chosen specific price
Module (FCFA/Wp)	374	Sunny Uplands (2012)[18], PHOTON[19] (2013)	374
	577	Rigter and Vidican (2010)[20]	
	1 640	Szabo et al. (2011)	
	3 936	Ould Bilal et al (2012)	
Battery (FCFA/kWh[21])	69 536	Semassou (2011)	69536
	75 440	Sunny Uplands (2012)	
	82 000	Szabo et al. (2011)	
	113 707	Ould Bilal et al (2012)	
Inverter (FCFA/W)	190	PHOTON (2013)	190
	328	Semassou (2011)	
	348	Rigter et Vidican (2010)[22]	
	524	Ould Bilal et al (2012)	
Regulator (FCFA/A)	3 280	Intigaia[23]	3280
	5 051	Ould Bilal et al (2012)	

[18] Value simulated for the year 2012.
[19] PHOTON-Newsletter for 2013/01/11concerning inverters and module price index: http://www.photon.info.
[20] Simulation carried out according to the fall of the module cost for the year 2012.
[21] Cost of AGM lead-acid batteries of nominal voltage of 12V.
[22] This cost refers to a simulation carried out according to the fall of the price of the inverters for the year 2012.
[23] www.intigaia.free.fr.

The others expenditure of the PV system include cables, transport and installation costs. Thus, both gross investment and the others expenditure correspond to the global initial investment of the project. The operations and maintenance (O&M) were adjusted on the basis of annual cost during the period of analysis of the project. In this work, the O&M relate to the replacement of the batteries, the inverter and regulator and we considered that the system is free from others maintenances during the project lifetime.

2.4.4. Financing of the project

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 (Amani at al. 2016). Thus, the financing of the project was set at 100% divided in equity and debt. It was divided into 25% like own capital stocks and the others 75% as loan at a bank. The others parameters (encouragements and subsidies, analyzes income tax, returned for reduction of the greenhouse gas (GHG)) were neglected in this paper. The interest rate considered for the loan is 7.5%. The duration of the loan was fixed at 25 years. Refunding was applied at a constant annual installment over all the duration of the loan. It is the rate applied by the ‘‘*Société Générale des Banques (SGB)*’’ of Burkina Faso for any solar project in Burkina Faso. The duration of the loan retained is 25 years contrary to the clauses of the SGB which grants the loan for the duration of refunding for only 7 years.

2.4.5. Debt payment

The payments of the debt are a succession of regular annual payments according to the loan duration**.** The annual payment of the debt or annual installment (D) is calculated using the following equation:

$$D = I \times f_{d} \times \frac{i}{1-\frac{1}{(1+i)^{N}}} \quad (5)$$

Where I is the total capital cost of the project [FCFA], f_d the debt ratio, i the effective rate of annual interest on the debt and N the duration of the loan in years.

The annual payment of the debt was set constant for each year, and that, over all the duration of the project.

2.5. Monetary flows

The calculation of monetary flows includes all the expenditure (outgoing flows) and the incomes (entering flows) induced by the project, on an annual basis.

Outgoing flows are consisted of the own capital stocks invested at year 0 and the expenditure related to O&M of the system the subsequent years. The stockholders' equity relates to the portion of the total investment required to finance the project which is paid immediately and consequently, not-built-in in the financial analysis.

Entering flows result primarily from the savings carried out by the exploitation of PV system. Indeed, this saving corresponds to the cost of the electricity consumed with the SONABEL during the system lifetime.

Cumulative monetary flow over the duration of the project is calculated by the following formula:

$$F = F_{ent} - F_{sort} \quad (6)$$

With F, F_{ent} and F_{sort} respectively the cumulated monetary flow, the cumulated entering flow and the cumulated outgoing flow during the project lifetime (N) considered, expressed in FCFA.

In a detailed way, it is expressed by:

$$F = \sum_{n=1}^{N} R_{an}(1+r)^n - \left[(1- f_d)I + \sum_{n=1}^{N} C_{an}(1+\lambda)^n + D \right] \quad (7)$$

With R_{an} the saving carried out by the use of the PV system [FCFA], r the energy indexation rate, n the year considered, C_{an} the annual expenditure [FCFA], λ the inflation rate.

2.6. Levelized cost of energy

For the calculation of the Levelized Cost of consumed Energy (LCOE), we did not considered the cost of the energy generating because in remote villages, most of the energy generated was lost (Nikhil & Subhakar 2012, Ould Bilal et al. 2012). So we expressed the LCOE by equation 8.

$$LCOE = \frac{F_{sort}}{\sum_{n=1}^{N} E_{an}(1+r)^n} \quad (8)$$

With $LCOE$ the effective cost of the energy produced by the system (FCFA/kWh) and E_{an} the annual electricity consumption [kWh/year].

2.7. Environmental impacts

Like any project of clean energy, PV project profits from an option for the analysis of GHG emissions. This analysis was been possible by the RETScreen model's sheet called ''*analysis of the emissions''* (Leng and al. 2004, RNCan 2005 & RNCan 2006). This analysis relates to the quantities of CO_2 avoided from the electricity production by the PV system according to RNCan (2006):

$$\Delta_{GHG} = e_{ref} \times E_{an} \quad (9)$$

Where Δ_{GHG} is the equivalent of GHG avoided per year in equivalent of CO_2 [tCO_2/year], e_{ref} is the emissivity of GHG in the reference case [tCO_2/MWh], and E_{an} is the annual quantity of electricity consumed from the PV system [MWh/year].

3. RESULTS

3.1. Solar irradiation on tilted plan

The general trend of global irradiation is globally similar for all the four databases excepted slight differences (Figure 2). PVSYST and SolarGIS give low values. RETScreen gives values relatively equal to the average of all the databases while PVGIS seems to overestimate them. On average, global horizontal irradiation and tilted irradiation are respectively 5.87 kWh/m2/day and 6.02 kWh/m2/day. That result

to a transposition factor of 1.026 which represents an increase of 2.6% of productivity on the inclined plan compared to the horizontal one. For the design of the PV module size thereafter, the smallest irradiation on tilted plan found on August has been retained.

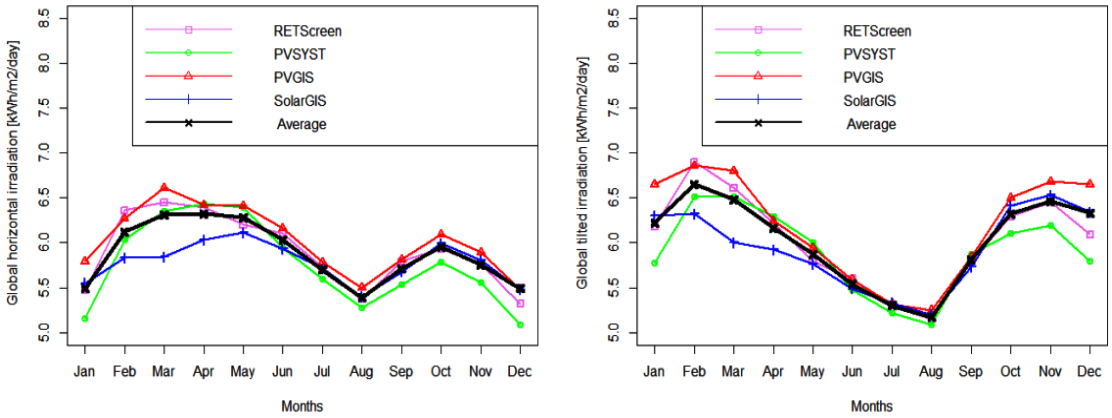

Figure 2: Global irradiation on horizontal (at left) and tilted (at right) plan. The inclination angle is 15° oriented in full South.

3.2. Energy needs and energy cost

Average daily energy consumption is 1810 Wh/day, 5380 Wh/day and 500 Wh/day respectively at Wemtenga, Dassasgho 01 and Dassasgho 02.

From these households, only inhabitants of Dassasgho 02 pay electricity more expensive than the national average electricity cost of 158 FCFA/kWh (table 3). Wemtenga is not so far from that national average value with 141 FCFA/kWh. We note that the cost of electricity decreases when the consumption increases. For these needs, AC loads are respectively 431 W, 2556 W and 210 W at Wemtenga, Dassasgho 01 and Dassasgho 02.

Table 3: Estimate of the average cost of the electricity consumed from SONABEL.

Components		Wemtenga	Dassasgho 01	Dassasgho 02
Characteristic	Type of bill	Cash-power	Cash-power	Bill per month
	Amperage	5A	5A	5A
Electricity	Mean electricity consumption (kWh/month)	54	161	15
	Cost of the first electricity consumption level (FCFA/kWh)	96	96	96
	Rough cost (FCFA/month)	5 198	16 149	1 440

	Total cost[24] (FCFA/month)	2 446	3 091	2 326
Monthly total cost (FCFA/month)		7 644	19 240	3 766
Monthly specific cost (FCFA/kWh)		141	119	256

We notice that modules powers are equal to the batteries capacities (in term of value) in all households. That allows any comparison between further costs of module and battery for others studies.

3.3. Solar kit and PV system components cost

Simulation carried out using all software indicated 15° as the optimal angle for annual operation of a fixed oriented PV system in Ouagadougou. For this inclination angle, the characteristics of PV solar kit component are indicated in table 4.

Table 4: Characteristics of the PV system components.

PV system components	Components parameters	Households		
		Wemtenga	Dassasgho 01	Dassasgho 02
Modules	P_{PV} *[Wp]*	575	1680	155
Inverter	$P_{n,ond}$ *[W]*	500	2000	200
Battery	C_{bat} *[Ah]*	575	840[25]	155
Regulator	I_{reg} *[A]*	48	70	15

From these components, modules participate at only 20% from the initial cost. Batteries are the most expensive PV component with 44% (figure 3) and that percentage will reach about 65% of course of their replacements during the project lifetime. Then, the cost of the O&M varies very little when considering by year. Note that O&M cost were adjusted at around 2.7% of the total initial investment per year.

[24] Including all taxes

[25] At Dassagho 01, if U_{bat} was also 12V, C_{bat} would be equal to P_{PV} value

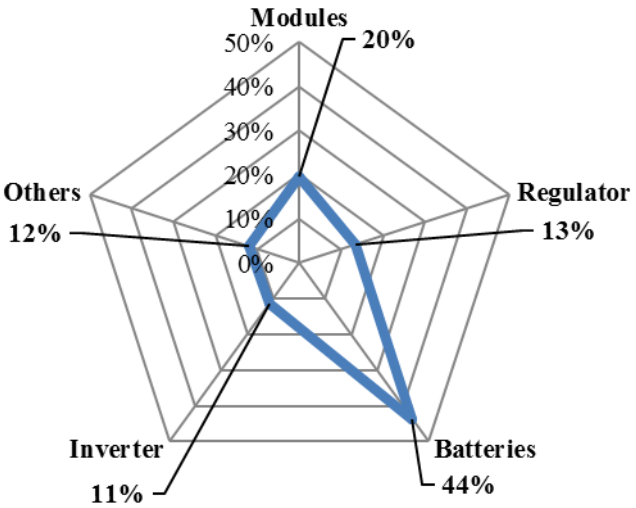

Figure 3: Solar kit components costs at the beginning of the project. "Others" represents cables, installation and transport costs.

3.4. Monetary flows of the project

The initial cost of the system calculated are 1 077 444, 3 007 342 and 313 411 FCFA respectively at Wemtenga, Dassasgho 01 Dassasgho 02. In general, the initial capital costs proportionally increase with the expected installed modules powers (figure 4).
The monetary outflow (debt and O&M) and inflow (savings) are presented in figure 4. As result, the estimated specific initial cost range from 1790 FCFA/Wp (Dassasgho 01) to 2022 FCFA/Wp (Dassasgho 02). Then, considering all households, on average, this cost is 1895 FCFA/Wp. Figure 4 shows that savings are higher than both debt payment and O&M indicating that these all projects are feasible.

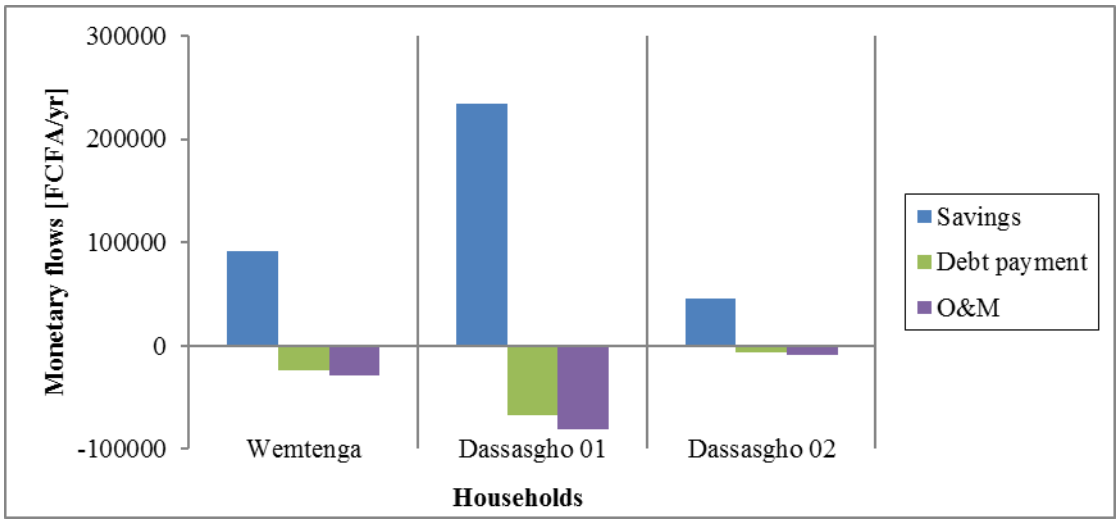

Figure 4: Annual monetary flows during the lifetime of the project.

3.5. LCOE

For all these projects, the LCOE ranges from the highest energy consumption (at Dassasgho 01) to the lowest one (at Dassasgho 02) as illustrated by table 5. The average LCOE of 112 FCFA/kWh was estimated.

Table 5: PV and SONABEL energy consumed costs.

Households	Energy consumed [kWh/year]	Specific initial cost [FCFA/Wp]	PV energy cost [FCFA/kWh]	SONABEL energy cost [FCFA/kWh]
Wemtenga	660	1874	113	141
Dassasgho 01	1970	1790	105	119
Dassasgho 02	180	2022	119	256

3.6. Expected CO2 avoided

The emissivity of GHG differs from a nation to another one and is provided by the national company of production and distribution of electricity. This value is not included in the RETScreen software tool for Burkina Faso, so we evaluated it for some countries during the project lifetime of 25 years. Figure 5 shows that for a PV project, no CO2 production is expected in Canada. However, that is not the same case in the others chosen countries. For a project at Dassasgho 01 for example, expected CO2 avoided is about 4 tons in France but four (4) times more in China during the same project lifetime. Considering these four countries, China is the country where more CO2 production would be avoided according to such project. Thus, PV projects are there more suitable (in respect to environmental impacts) than the others because of the importance of the carbon footprint reduction.

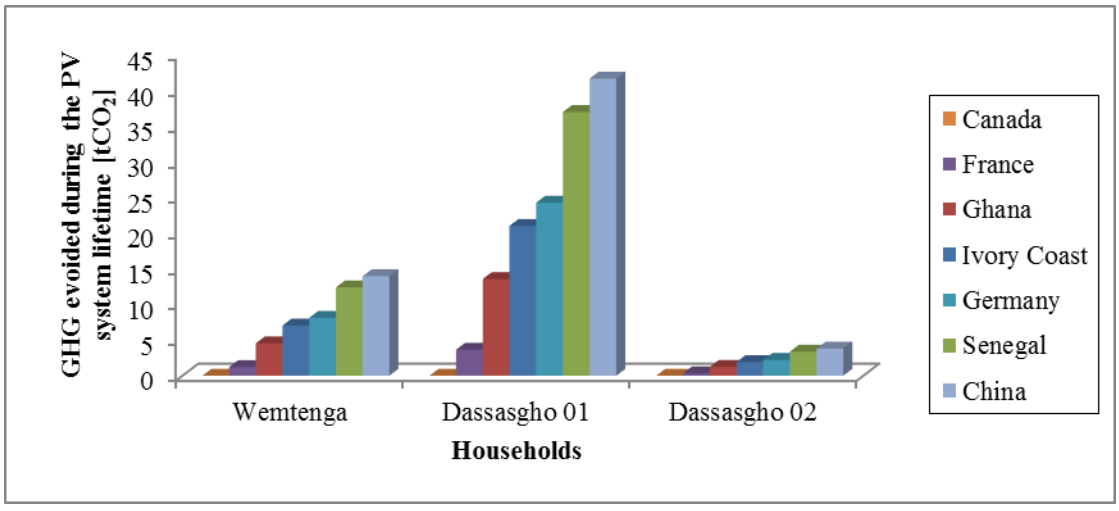

Figure 5: GHG avoided from the project lifetime in some countries. The emissivity of GHG in the reference country case is given by RETScreen.

4. DISCUSSION AND CONCLUSION

This study was been simplified by maintaining the energy needs constant during the year like Chikh et al. (2011). However, that could contain some bias because we did not work out an energy grid calculation which depends on the seasons as recommended by PACER (2007). Indeed, PACER (2007) and Chikh-Bled et al. (2009) research revealed that the energy requirements are higher in summer than in winter because of the use of air-conditioners and ventilators for the air conditioning inside the dwellings. So the consideration of energy consumption at summer would be viable because a large part of the total energy produced by a PV system is lost when the batteries are entirely charged or also lost at load processes and discharge of these batteries as mentioned by Ould Bilal et al. (2012).

For the system design, the inclination angle of 15° simulated by the software RETScreen seems to correspond to the optimal angle with a high transposition factor of 1.026 showed by PVSYST. This inclination angle was also chosen by Tassembedo et al. (2012) and simulated by Mehrtash et al. (2012) during their studies on the establishment of a residential PV system in Ouagadougou. As result, the mean global horizontal irradiation of 5.87 kWh/m2/day calculated by the databases are included in those found by Liebard et al. (2010) for Kourittenga (located at few kilometers in the South of Ouagadougou) PV project. Studies carried out by Amani et al. (2016) on the same tilted plan showed a transposition factor of 1.022 because of the using of only the RETScreen software. Low values of global irradiation shown by PVSYST and SolarGIS could guarantee all safety measurements in comparison with the expected energy of the PV generator. Unfortunately, that will increase the total price of the system. High values provided by PVGIS would be more representative of the climate for these last years, regarding the evolution of the climate (Mermoud & Lejeune 2012). The problem of considering this database resides in the underestimate of PV system energy even if economies could be realized there. In fact, RETScreen which provides values closed to the average of all the databases seems to be the best database which gives coherent values.

For each project, 25% as own capital stocks and the others 75% as loan at a bank has been chosen. The choice of these shares was inspired by the work of PERACOD (2006). According to this author, the committed own capital stocks must lie between 25 and 50%. That because below 25%, the loan seems too high and above 50%, a producer would not invest in a PV project because of the high capital costs.

This interest rate of 7.5% seems reasonable according to BAfD et al. (2012). This consideration was made in order to make more flexible the loan. The inflation rate taken at 2.8% is the same simulated by CIA World Factbook (2011) and BAfD et al. (2012) for Burkina Faso for the year 2013. Thus, that rate applied for O&M cost during the project lifetime seems correct.

The energy indexation rate of 4% is different from AGIR (2010) consideration. For that author, this rate was the same like the inflation rate in a study realized in France. Nevertheless, 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. (2010) and Semassou (2011) in their projects analysis like in respectively Burkina Faso and Benin. This rate respects Szabo et al. (2011) recommended rate for PV projects in Africa.
Considering a small project size like ours, we had not taken into account any financing such as carbon compensation for avoided quantities of CO2. The situation is far from Liebard et al. (2010), project which profited from substantial aids and subsidies. For their project, in fact, local operators contributed only at 1.7% from the initial investment.
The mean initial capital cost of 1895 FCFA/Wp found in this study seems to correspond to the values simulated by Rigter and Vidican (2010) in their research carried out in China. According to these authors, these costs were estimated at 1935 FCFA/Wp for 2012 and simulated to 1765 FCFA/Wp for 2015. However, these estimates do not correspond to Mehrtash et al. (2012) values which are closed to 2526 FCFA/Wp for residential PV systems for small size like ours. Also, our values seem to be an undervaluation of the cost of the installed system when considering the use of AGM lead-acid batteries lifetime of 14 years contrary to 5 years that recommended Szabo et al. (2011) for PV projects in Africa. The analysis showed that this replacement duration of the batteries appears flattering. Indeed, a system requires batteries for several cycles whose unit cost is also high.
The mean LCOE of 112 FCFA/kWh calculated seems realistic. Moreover, the project carried out by Rigter and Vidican (2010) gives an average LCOE of 132 FCFA/kWh with a discount rate of 7% for investments in PV solar project. That LCOE found in their study is slightly higher than those calculated in this study. The LCOE in the first quarter of the year 2012 ranged between 81 FCFA/kWh and 126 FCFA/kWh for residential solar projects (Bazilian 2012). This interval of energy costs includes perfectly the LCOE calculated in this study. LCOE estimated by Bazilian et al. (2012) for PV solar projects in Africa range from 101 FCFA/kWh to 258 FCFA/kWh. It is also in this interval that LCOE evaluated in our study are located.

Parameters calculated in this study can allow the feasibility analysis of stand-alone PV system in Ouagadougou for several households regarding their electricity consumption and a well-calibrated meters. So, this paper could be used as a guideline for both public and private agencies and could also be used as a basic information for future project planning in remote areas in Burkina Faso. Thus, to promote PV system applications, it would be necessary to set up an organization, which will solely be responsible for the users and system managers training after the installation of the PV system in order to enjoy the full benefits of both economic and social aspects.

REFERENCES

[1] ABB 2012, ‘Document d'application technique n°10 : Installations photovoltaïques’, *Technical Application Papers,* 72p.

[2] Acquaviva, V 2011, 'Analyse de l'intégration des systèmes énergétiques a sources renouvelables dans les réseaux électriques insulaires', *PhD thesis of the University of Corse, France,* 253p.

[3] AGIR 2010, 'Générez des revenus grâce au photovoltaïque', *Guide du photovoltaïque*, 23p + Annex.

[4] Amani KL, Sam, R, and Zougmoré, F, Competitiveness Level of Photovoltaic Solar Systems in Ouagadougou (Burkina Faso): Study Based on the Domestic Electric Meters Calibration,' *International Journal of Photoenergy*, vol. 2016, Article ID 9698070, 10 pages, 2016. doi:10.1155/2016/9698070.

[5] BAfD, OCDE, PNUD et CEA, 2012. 'Perspectives économiques en Afrique : Burkina Faso', 16p. http://www.africaneconomicoutlook.org visited on February 1st, 2013.

[6] Bazilian, M, Onyeji, I, Liebreich, M, MacGill, I, Chase, J, Shah, J, Gielen, D, Arent, D, Landfear, D & Zhengrong, S, 2012, 'Re-considering the Economics of Photovoltaic Power',*Bloomberg New Energy Finance (BNEF),* 19p.

[7] Burkina Faso & Communauté européenne 2007, 'Document de stratégie pays et programme indicatif national pour la période 2008-2013', 111p + Appendix. http://ec.europa.eu/development/icenter/repository/scanned_bf_csp10_fr.pdf visited on September 20th, 2013.

[8] Chikh, M, Mahrane, A & Bouachri, F 2011, 'PVSST 1.0 sizing and simulation tool for PV systems', *MEDGREEN 2011-LB, Energy Procedia*, vol. 6,pp.75–84.

[9] Chikh-Bled, B, Sari-Ali, I & Benyoucef, B, 2010,'Méthode de dimensionnement optimal d'une installation photovoltaïque', *Revue Internationale d'Héliotechnique n°41* : 25-30. http:\\www.comples.org consulted on january 22th, 2013.

[10] CIA World Factbook 2012, 'Taux d'inflation (indice des prix à la consommation) – Monde'. https://www.cia.gov/library/publications/the-world-factbook/rankorder/2042rank.htmlconsulted on March 13th 2013.

[11] Leng, GL, Monarque, A, Graham, S, Higgins, S & Cleghorn, H 2004, 'RETScreen International: Results and impacts 1996-2012', *Natural Resources Canada, ISBN 0-662-11903-7, Cat. M39-106/2004F-PDF, CTEC-Varennes*, 44p.

[12] Liébard, A, Civel, Y-B, Maigne, Y, Guichard, N, Rigaud, C & Salès, S 2010, 'De l'électricité verte pour cent mille ruraux au Burkina Faso', *Fondation Energies pour le Monde, Ministère des Mines, des Carrières et de l'Energie*, 40p.

[13] Mehrtash, M, Quesada, G, Dutil, Y & Rousse, D 2012, 'Énergie photovoltaïque résidentielle : implantation dans divers pays', *CIFEM2012 – ART-5-89*, 5p.

[14] Mermoud, A& Lejeune, T 2012,'User's Guide PVsyst : Contextual Help',*PVsyst SA*, 232p. Disponible sur www.pvsyst.com.

[15] Nikhil, PG & Subhakar, D 2012, 'An improved algorithm for photovoltaic system sizing',*2nd International Conference on Advances in Energy Engineering, Energy Procedia*, vol. 14,pp.1134 –1142.

[16] Ould Bilal, B, Sambou, V, Kébé CMF, Ndiaye, PA & Ndongo, M 2012, 'Methodology to Size an Optimal Stand-Alone PV/wind/diesel/battery System Minimizing the Levelized cost of Energy and the CO_2 Emissions', *ICAEE 2011: 27-28 December 2011, Bangkok, Thailand, Energy Procedia*, vol. 14, pp. 1636 – 1647.

[17] PACER 2007, 'Installations Photovoltaïques Autonomes : Guide pour le dimensionnement et la réalisation', *PACER & Direction du Développement et de la Coopération*, 171p.

[18] PERACOD 2006, 'Etude de faisabilité technico-économique de la filière photovoltaïque raccordée réseau au Sénégal', *Direction de l'énergie, Sénégal et GTZ, Allemagne*, 115p.

[19] Phuangpornpitak, N & Tia, S 2013, Opportunities and Challenges of Integrating Renewable Energy in Smart Grid System, *10th Eco-Energy and Materials Science and Engineering Symposium (EMSES2012), Energy Procedia*, vol. 34, *pp.* 282 – 290.

[20] Rigter, J & Vidican G 2010, 'Cost and optimal feed-in tariff for Small scale photovoltaic systems in China', *Masdar Institute of Science and Technology*, 45 p.

[21] RNCan 2005, 'Logiciel RETScreen : manuel de l'utilisateur en ligne', *NASA, PNUE et GEF*, 125p.

[22] RNCan 2006, 'Analyse de projets d'énergies propres : manuel d'ingénierie et d'études de cas RETScreen®, chapitre introduction à l'analyse de projets d'énergies propres', *Centre de la technologie de l'énergie de CANMET - Varennes* (*CTEC)*, 92p.

[23] Semassou, C 2011. Aide à la décision pour le choix de sites et systèmes énergétiques adaptes aux besoins du Benin. Thèse de docorat de l'Université Bordeaux 1, 210p.

[24] SMA 2010, 'Approvisionnement en énergie solaire des sites isolés et systèmes de secours : principes, applications et solutions SMA', *Recueil Technologique 2, INSELVERSOR-AFR104310*, 44p.

[25] Sunny Uplands 2012, 'Alternative energy will no longer be alternative', *The Economist*. http://www.economist.com/news/21566414-alternative-energy-will-no-longer-be-alternative-sunny-uplands. Retrieved 2012-12-28 consulted on March 11th, 2013.

[26] Suri, M, Huld, TA, Dunlop, ED, Albuisson, M & Wald, L 2006, 'Online data and tools for estimation of solar electricity in Africa: the PVGIS approach', *Proceedings from 21st European Photovoltaic Solar Energy Conference and Exhibition, 4-8 October 2006, Dresden, Germany (preprint)*, 4p.

[27] Szabó, S, Bódis, K, Huld, T & Moner-Girona, M 2011, 'Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension', *Environ. Res. Lett. 6 034002*. http://iopscience.iop.org/1748-9326/6/3/034002/fulltext/ consulted on January 20th, 2013.

[28] Tassembedo, SS, Kam, SZ, Koalaga, Z & Zougmore, F 2012, 'Modélisation, dimensionnement et simulation d'un système photovoltaïque autonome : cas d'un centre multimédia rural burkinabè', *CIFEM2012 – ART-5-35*, 6p.

[29] PNUD 2011, 'Sustainability and Equity: A Better Future for All', *Human Development Report 2011*, New York, 202p. http://hdr.undp.org/en/statistics/hdi/ consulted on January 10th, 2013.

[30] UNEP 2011, 'Vers une économie verte : Pour un développement durable et une éradication de la pauvreté', *Synthèse à l'intention des décideurs*, 52p.www.unep.org/greeneconomy consulted on August 11th, 2013.

[31] Yaungket, J & Tezuka, T 2013, 'A survey of remote household energy use in rural Thailand', *10th Eco-Energy and Materials Science and Engineering (EMSES2012), Energy Procedia*, vol. 34, pp.64-72.