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Financial Analysis of Photovoltaic Installations in Burkina Faso

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Authors' contributions

This work was carried out in collaboration among all authors. Authors LM and BH designed the study, performed the statistical analysis, wrote the protocol, managed the analyses of the study and proposed the first draft of the manuscript. Authors AD, AO and NB managed the literature searches and proposed the first corrections. Authors SF, AL, PT and JDB proposed the final correction. All authors read and approved the final manuscript.

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ABSTRACT

This article focuses on the economic and financial calculations concerning the production of electrical energy from photovoltaic installations connected to the grid. The estimation of energy production is done in fifteen cities in Burkina Faso. Among these localities, ten cities are homes to synoptic stations. The economic return in terms of the return on investment of the electricity production from PV installations is calculated by using the method of budgeted capital. The cost of the energy produced by photovoltaic installations during their operational lives (taken here equal to

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25 years) is calculated and compared with other economic parameters. The observation shows that Gaoua records the smallest production and that the highest production is recorded in Ouahigouya. The analysis of the cash flows generated by the operation of these PV installations shows that the profits are perceptible from the 8th year in Ouahigouya and the 9th year in Gaoua. An Internal Rate of Return (IRR) of 14.42% is obtained in the locality of Ouahigouya. For locality of Gaoua the IRR is equal to13.72%. The calculation of Leveled Cost Of Energy (LCOE*)* gives an average value of 60 Fcfa / kWh for a discount rate of 4%. This value is almost equal to half the average price of electricity in Burkina Faso, which is 119 Fcfa / kWh.

Keywords: Solar photovoltaic energy; grid connection; capital budgeted; cash flow; average discounted cost of energy.

1. INTRODUCTION

Nowadays, renewable energies occupy a place of choice in the energy mix of many African countries. The use of solar renewable energy especially, is an effective way to fight against global warming, a means for a green economic growth and sustainable development of developing countries [1-3].

Photovoltaic (PV) is a sustainable and renewable energy conversion technology that can help to effectively meet the energy needs of a growing world population and reduce the negative impact of the use of fossil fuels [4,5]. The global share of solar photovoltaic energy has increased significantly (0.26 GW to 16.1 GW) with an annual growth rate ~~of~~ more than 40% between 2000 and 2010 [6-8].

Although the solar resource is available and free, still the cost of solar installations is not accessible to all. Today, technological innovations allow division of the manufacturing costs by 100, and governments are increasingly encouraging consumers to use this source of energy [1,6,9,10] which is clean and environmentally friendly.

Given that, the price of electricity sold to consumers is a function of the price of electricity leaving the plant, an understanding of the feasibility and profitability of the different energy technologies being a paramount for the determination of an energy management policy in a country [11,12,13].

As a country with significant solar potential, Burkina Faso enjoys an average of 5.5 kWh/m²/day of sunshine and average solar irradiation duration of 3000 h/year [14].

However, the country knows an important energy deficiency. It is obvious that the government alone cannot meet this demand for energy that is growing day by day. The private sector is one of the solutions to this problem. However, the lack of knowledge in solar energy field, the high investment cost and the low demand for energy, especially in rural areas, where need in energy is most pressing does not motivate private investment particularly in Burkina.

In this article, we will try to analyze the profitability of a standard investment in photovoltaic installations in Burkina Faso built for the sale of energy to the National Company of Electricity (SONABEL) by injecting into the grid or off-grid for localities which are not connected to the national grid.

2. MATERIALS AND METHODS

The study is done for fifteen localities in Burkina Faso (Fig. 1). The geographic coordinates (latitude, longitude and altitude) of the various sites are summarized in Table 1.

In order to carry out this study, we had put hypotheses on certain parameters:

- ✓ The study of an installation already done and ready to produce Energy;
- ✓ Year 0 being the year of installation conception;
- ✓ The number of hours of sunshine a year;
- ✓ The value of expenses in relation to revenues;
- ✓ The average electric price which varies according to the rate of inflation [15] and which is the price compared to the domestic use and small and average companies;
- ✓ The degradation of the installation which plays on its production.
- ✓ etc.

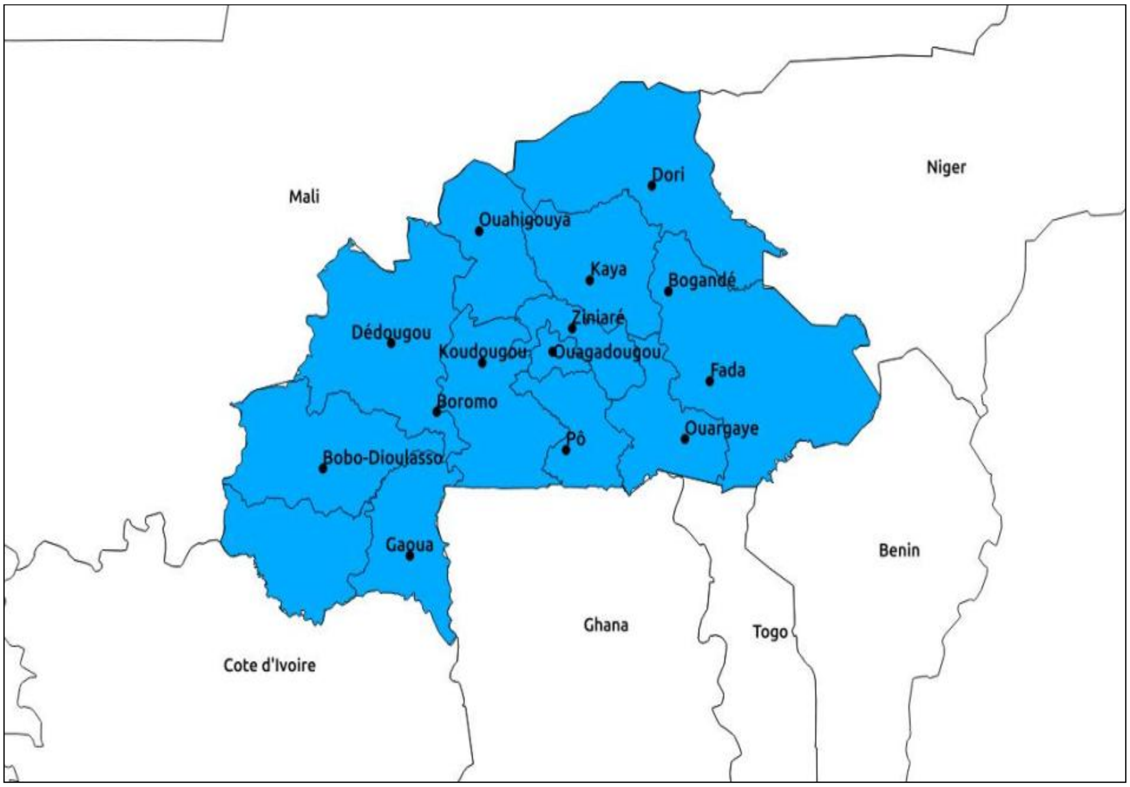

Fig. 1. Location of the sites on the map of Burkina Faso

Table. 1. Geographical coordinates of the sites

Localities	Regions	Latitude (°N)	Longitude (°O,°E)	Altitude (m)
Ouagadougou	Centre	12°21'56''	1°32'O	301
Ouahigouya	Nord	13°34'58''	2°25'17''O	328
Bobo-Dioulasso	Hauts -Bassins	11°10'37''	4°17'52 ''O	425
Boromo	Boucle du Mouhoun	11°44'43''	2°55'48''O	266
Pô	Centre-Sud	11°22'08''	1°22'38''O	299
Fada	Est	12°03'41''	0°21'30''E	302
Gaoua	Sud-Ouest	10°17'57''	3°15'02''O	331
Dori	Sahel	14°02'07''	0°02'04''O	276
Dédougou	Boucle du Mouhoun	12°26'31''	3°28'14''O	301
Bogandé	Est	12°58'13''	0°08'58''O	275
Koudougou	Centre-Ouest	12°15'04''	2°22'28''O	297
Ouargaye	Centre-Est	11°28'36''	0°02'58''E	278
Kaya	Centre-Nord	13°05'	1°05'O	326
Ziniaré	Plateau-Central	12°35'	1°18'O	308
Banfora	Cascades	10°37'36''	4°45'29''N	285

Table 2. Calculation elements

Size of PV plant	Electric tarification	Expenses	Degradation	Inflation
2 to 10 MW_p	60-95Fcfa	11% [18]	0.5% [18]	2.6 [27]

The average cost of kWh for small and medium-sized enterprises and domestic consumption in Burkina Faso is estimated at 119 Fcfa [16].

In this work, we performed the simulations for several purchase prices of kWh (as shown in Table 2) and for several sizes of installation in W_p to see their influence on the different Parameters of the study.

The radiation data in the synoptic stations are global averages on the horizontal plane. Table 3 shows measured radiation values in nine of the ten synoptic stations. In order to take into account the inclination and orientation of the panels we used simulation software.

Plant productivity is estimated using PVGis photovoltaic productivity simulation software, which provides annual average irradiation by optimizing tilt and orientation.

Burkina Faso being in the northern hemisphere, the optimal orientation of the modules is taken south. The optimal inclinations provided by the software are shown in Table 4.

For these localities, the averages of inclination, global irradiation and the equivalent number of hours are respectively estimated in deg °, kWh/m²/year and hour for a south orientation (Table 4).Table 5 shows in detail the estimated cost of a 2 MWp installation according to the

Table. 3. Mean global horizontal radiation measured in synoptic stations

Localities	Irradiation (kWh/m^2/year)(Météo)	Measuring period
Ouagadougou	2168	1976-2016
Ouahigouya	2193	1982-1993
Bobo-Dioulasso	2201	1976-1990
Boromo	2184	1985-2005
Pô	2141	1985-1994
Fada	2309	1976-1992
Gaoua	2147	1976-2002
Dori	2434	1976-1996
Dédougou	2168	1986-1993
Bogandé	-	-
Koudougou	-	-
Ouargaye	-	-
Kaya	-	-
Ziniaré	-	-
Banfora	-	-

Table 4. Values of the global solar irradiation of the different sites

Localities	Irradiation (kWh/m^2/year) (Pvgis)	Optimal inclinaison (°)	Number of hours equivalent (h)
Ouagadougou	2260	15	2260
Ouahigouya	2300	16	2300
Bobo-Dioulasso	2200	15	2200
Boromo	2240	15	2210
Pô	2220	14	2220
Fada	2230	15	2230
Gaoua	2190	14	2190
Dori	2300	17	2300
Dédougou	2260	15	2260
Bogandé	2270	16	2270
Koudougou	2270	15	2270
Ouargaye	2210	15	2210
Kaya	2280	16	2280
Ziniaré	2260	15	2260
Banfora	2200	14	2200

Table 5. Estimated cost of 2MWp installation

Designation	Price (Fcfa)
Module, supports	960 000 000
Inverters, cables, substation	800 000 000
Network connection	250 000 000
Project study, works control, labor	95 000 000
Insurance	10 000 000
Total	2 115 000 422

different elements (modules, supports, inverters, labor, insurance, maintenance, etc.).

Cash flow is the sum of all cash inflows and outflows in a company [5,6]. Studies have shown that the cost of a PV plant as well as its investment profitability can be determined from the study of cash flow. GUAITA-PRADAS et al. have determined the return on investment of a PV plant (20 kWp) coupled to the grid in the locality of Ketesso in “Côte d'Ivoire” [17].

Several parameters are important for this study. Those are:

2.1 Net Present Value (NPV)

NPV is the difference between the value of revenues and the expenses incurred in an investment. It provides an estimation of the net financial benefit to the investor if the investment is undertaken [17]. A positive NPV value means that the investor's financial situation will improve if the project moves forward. Likewise a negative NPV value indicates a financial loss.

$$NPV = -D + \sum_{j=0}^{n} \frac{CF_i}{(1+i)^j} \tag{1}$$

Where D is the down payment, *i*is the interest rate, and n is the lifespan of the installation. Despite the fact that the NPV is easy to use, because it is an intuitive tool, it presents limitations in evaluating the profitability of an installation, since it does not distinguish a project with capital expenditures and costs, and offers no indication of the extent of the effort needed to achieve the results.

2.2 Repayment or Payback (PB)

The profitability of an investment can be analyzed from its repayment (PB) which is the number of years needed to recover the initial investment. PB is evaluated by adding the cash flow values throughout the life of the installation.

2.3 The Internal Rate of Return (TRI) or IRR

The TRI is widely used in project appraisal as it is an indicator of the expected return of profitability. It is compared to the bank interest rate or the cost of funds used to finance a project. An investment project will generally be retained only if its predictable TRI is sufficiently higher than the bank interest rate [17,18].

Another highly indicative and accepted parameter in the evaluation of an investment's profitability is the IRR. IRR is a reduction in the investment value, and can be easily compared to the interest rates of a loan taken in a bank. The IRR is also defined as the interest rate that equals the NPV of a series of cash flows to zero. Mathematically, he satisfies the equation:

$$0 = -D + \sum_{j=0}^{n} \frac{CF_i}{(1+IRR)^j} \tag{2}$$

2.4 Leveled Cost of Energy (LCOE)

The LCOE methodology is a benchmarking or ranking tool for evaluating the cost effectiveness of different energy production technologies. The Leveled Cost of Energy (LCOE) is an important parameter that compares energy costs and the full cost of energy production for a given system. LCOE is a calibration tool sensitive to the assumptions used for the calculations, especially when these are extrapolated several years in the future (over the lifetime of the installation). The determination of LCOE theoretically takes into account all the costs associated with an installation, for its entire lifetime [19-21]. These are:

- Acquisition of land cost, construction cost, renovation cost of the system, initial investments cost, repayment of loans costs and financial expenses;
- Maintenance cost, labor cost and material cost;
- Cost of buying fuel (zero in the case of renewable energy, for example for a wind turbine, a PV installation);
- Additional costs such as the costs of decommissioning of the facilities at the end

of the life, the costs of the tone of CO_2 produced (if it is marketable in a market), etc. [20-22].

The costs and the generated electricity may vary according to the location, the production capacity, the complexity of the installation, the efficiency of the installation and the life of the power plant [5-23].

The LCOE can be defined as the ratio between the sum of costs and the value of energy production over the life of the project (of the facility) and can be applied to virtually all technologies of Energy especially renewable energies [24,25]. It is calculated using the following equation:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} = \frac{Capital\,Outlay + \sum_{n=1}^{N} \frac{Expenses_i}{(1+r)^n}}{\sum_{n=1}^{N} \frac{Energy\,Production \times (1-DR)^n}{(1+r)^n}} \quad (3)$$

n, C_t, E_t, r are successively the life of the installation, all costs, net annual energy production and the annual discount rate.

3. RESULTS AND DISCUSSION

The simulations were carried out for the localities mentioned in Fig. 1. Comparing the results on the productivity of a photovoltaic installation shows that the lowest production is recorded in Gaoua and the largest in Ouahigouya. Fig. 2 below shows the energy productions of the first and the twenty-fifth year. In view therefore of the results of Fig. 2, we will focus our study on the localities of Ouahigouya and Gaoua. In order to evaluate the influence of the size of the installation and the purchase price of the kWh on the various parameters studied, we have made the simulations for several sizes and prices.

Overall, production fell by around 11.5% from the first year to the 25th year.

3.1 Cash Flow in the Different Regions

At the time of investment (year 0) occurs only a money outflow. After installation, the energy production, the sale and expenses start in year 1 supposed as the beginning year of energy production. Expenditures were estimated equal to 11% of revenues generated by the sale of

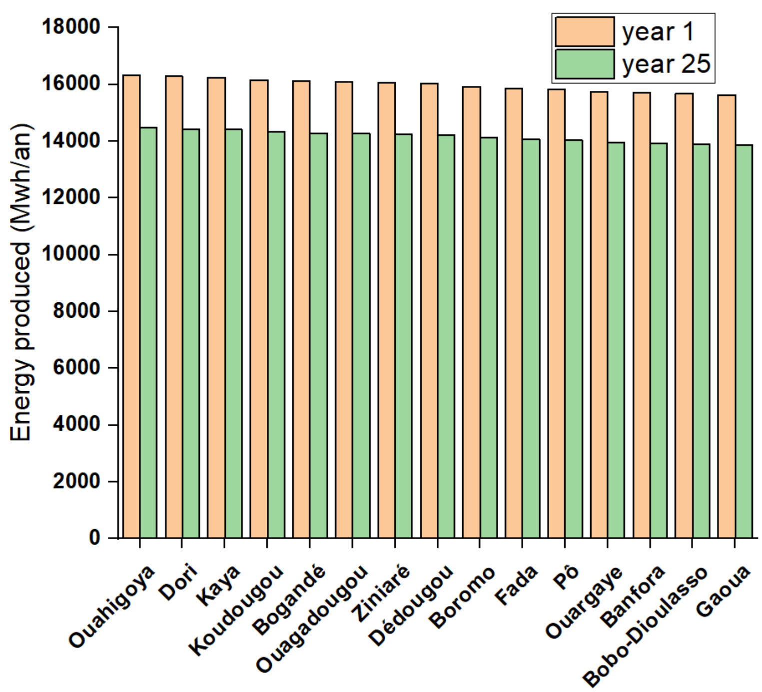

Fig. 2. Energy produced in the 1st and the 25th year for a 10 MWp installation

Table 6. Cumulative cash flow of facilities in Ouahigouya for different sizes

Year	10kWp	50kWp	100kWp	500kWp	1000kWp	2000kWp	4000kWp	6000kWp	8000kWp	10000kWp
0	-10575002	-52875010	-105750021	-528750106	-1057500211	-2115000422	-4230000829	-6345001243	-8460001657	-10575002110
1	-9266969	-46334845	-92669691	-463348456	-926696911	-1853393822	-3706787629	-5560181443	-7413575257	-9266969110
2	-7931637.35129	-39658186.75645	-79316374.5129	-396581873.5645	-793163746.129	-1586327492.258	-3172654969.516	-4758982453.774	-6345309938.032	-7931637461.29
3	-6568437.33107142	-32842186.6553571	-65684374.3107142	-328421872.553571	-656843744.107142	-1313687488.21428	-2627374961.42857	-3941062441.64285	-5254749921.85714	-6568437441.07142
4	-5176787.32643088	-25883936.6321544	-51767874.2643088	-258839372.321544	-517678743.643088	-1035357487.28618	-2070714959.57235	-3106072438.85853	-4141429918.14471	-5176787436.43088
5	-3756093.58619349	-18780467.9309675	-37560936.8619349	-187804685.309675	-375609369.619349	-751218739.238699	-1502437463.4774	-2253656194.7161	-3004874925.9548	-3756093696.1935
6	-2305749.96759735	-11528749.8379868	-23057500.6759735	-115287504.379868	-230575007.759735	-461150015.519471	-922300016.038941	-1383450023.55841	-1844600031.07788	-2305750077.59735
7	-825137.677681109	-4125688.38840555	-8251377.77681109	-41256889.8840555	-82513778.7681109	-165027557.536222	-330055100.072444	-495082649.608667	-660110199.144887	-825137787.68111
8	686374.990725687	3431874.95362843	6863748.90725686	34318743.5362843	68637488.0725686	137274976.145137	274549967.290274	411824951.43541	549099935.580549	686374880.725685
9	2229432.92852213	11147164.6426107	22294328.2852213	111471640.426107	222943281.852213	445886563.704426	891773142.408852	1337659714.11328	1783546285.8177	2229432818.52213
10	3804694.48548039	19023472.4274019	38046943.8548039	190234718.274019	380469437.548039	760938875.096078	1521877765.19216	2282816648.28823	3043755531.38431	3804694375.48039
11	5412831.75113237	27064158.7556618	54128316.5113236	270641581.556618	541283164.113236	1082566328.22647	2165132671.45295	3247699007.67942	4330265343.90589	5412831641.13236
12	7054530.8415185	35272654.2075925	70545307.415185	352726536.075925	705453073.15185	1410906146.3037	2821812307.6074	4232718461.9111	5643624616.2148	7054530731.5185
13	8730492.19192099	43652460.9596049	87304920.9192099	436524603.596049	873049208.192099	1746098416.3842	3492196847.7684	5238295272.15259	6984393696.53679	8730492081.92099
14	10441430.8557064	52207154.2785319	104414307.557064	522071536.785319	1044143074.57064	2088286149.14128	4176572313.28255	6264858470.42382	8353144627.5651	10441430745.7064
15	12188076.809405	60940384.0470249	121880767.09405	609403834.470249	1218807669.9405	2437615339.88099	4875230694.76199	7312846042.64298	9750461390.52398	12188076699.405
16	13971175.2641573	69855876.3207863	139711751.641573	698558757.207863	1397117515.41573	2794235030.83145	5588470076.6629	8382705115.49435	11176940154.3258	13971175154.1573
17	15791486.9836602	78957434.9183011	157914868.836602	789574343.183011	1579148687.36602	3158297374.73204	6316594764.46409	9474892147.19613	12633189529.9282	15791486873.6602
18	17649788.6087492	88248943.043746	176497885.087492	882489424.43746	1764978849.87492	3529957699.74984	7059915414.49968	10589873122.2495	14119830829.9994	17649788498.7492
19	19546872.9887538	97734364.943769	195468728.887538	977343643.43769	1954687287.87538	3909374575.75076	7818749166.50152	11728123750.2523	15637498334.003	19546872878.7538
20	21483549.5197691	107417747.598845	214835494.197691	1074177469.98845	2148354940.97691	4296709881.95382	8593419778.90764	12890129668.8615	17186839558.8153	21483549409.7691
21	23460644.4899867	117303222.449933	234606443.899867	1173032218.49933	2346064437.99867	4692128875.99733	9384257766.99467	14076386650.992	18768515534.9893	23460644379.9867
22	25479001.4322327	127395007.161163	254790013.322327	1273950065.61163	2547900132.22327	5095800264.44654	10191600543.8931	15287400816.3396	20383201088.7862	25479001322.2327
23	27539481.4838634	137697407.419317	275394813.838634	1376974068.19317	2753948137.38634	5507896274.77268	11015792564.5454	16523688847.318	22031585130.0907	27539481373.8634
24	29642963.7541716	148214818.770858	296429636.541716	1482148181.70858	2964296364.41716	5928592728.83432	11857185472.6686	17785778209.503	23714370946.3373	29642963644.1716
25	31790345.6994612	158951728.497306	317903455.994612	1589517278.97306	3179034558.94612	6358069117.89224	12716138250.7845	19074207376.6767	25432276502.5689	31790345589.4612

energy produced [17]. It takes into account insurance, general maintenance, cleaning of electrical wires, etc. Just like the energy produced, the revenues and expenses depend on the size of the PV plant.

Accumulated cash flows allow to evaluate the return of the investment.

3.1.1 Influence of the size of the installation on the return on investment time

Tables 6 and 7 show the cumulative cash flow of PV installation in the cities of Ouahigouya and Gaoua for different sizes, the purchase price of the kWh taken equal to 90Fcfa. The tables show that whatever the size of the installation is, the return on investment takes place around 7.5 years after in Ouahigouya and 8 years later in Gaoua. Thus, the size of the facility does not affect the recovery time of the investment.

3.1.2 Influence of the purchase price on the return on investment

In this part, the size of the installation is fixed to 10 MWp for a purchase price of the kWh ranging from 60 to 95Fcfa. After the simulations, we found that the time of return on investment of the installations in the 13 regions takes place between the 7th year (95Fcfa / kWh) and the 12th year (60Fcfa / kWh). Fig. 3 shows the return on investment for an installation of 10MWp for a purchase price ranging from 60 to 95 Fcfa in the localities of Ouahigouya and Gaoua. The return on investment therefore depends very strongly on the selling price of kWh. The higher the price of kWh is, the faster the return on investment is.

We note here that for the same installation and for any price of purchase of kWh, the return on investment in the city of Ouahigouya comes

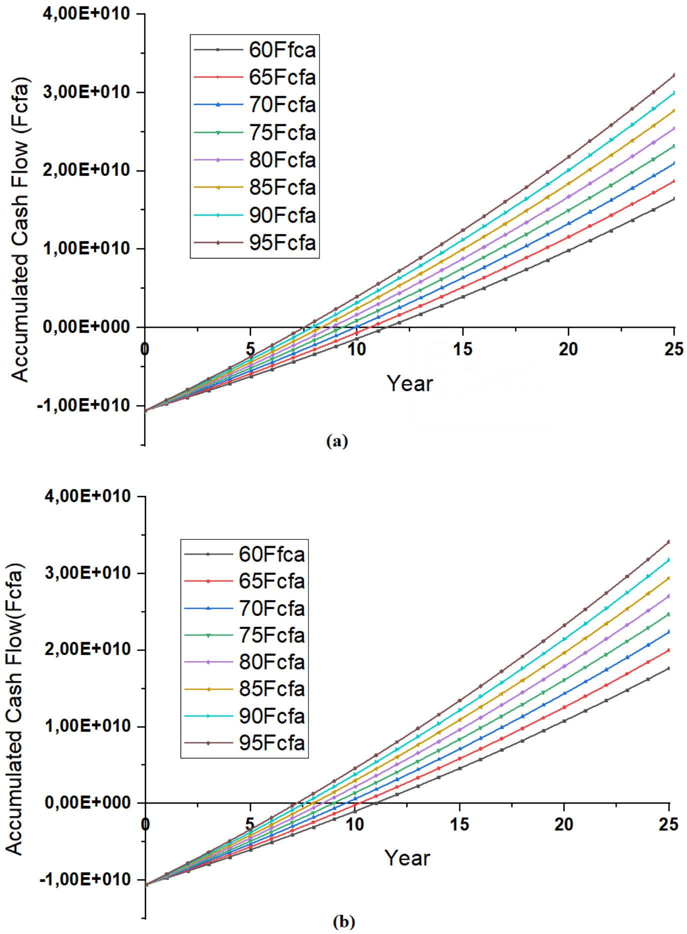

Fig. 3. Accumulated flux at Gaoua (a) and Ouahigouya (b) for different purchase prices per kWh ((a) -60 Fcfa- (h) -95 Fcfa)

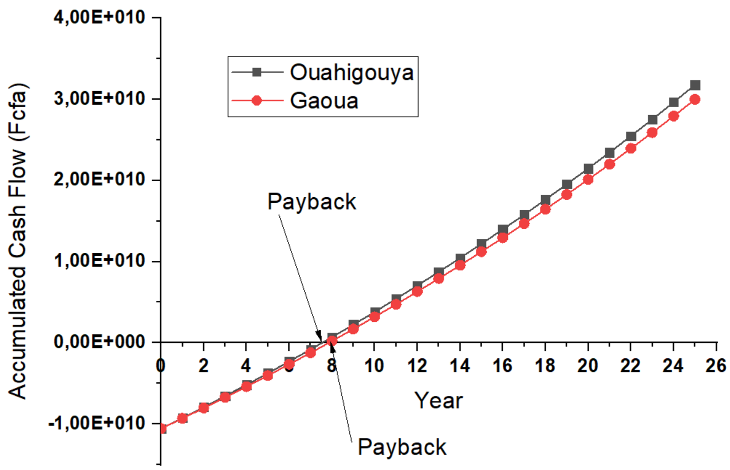

Fig. 4. Cash flow accumulated for a 10MWc installation with a purchase price of 90 Fcfa / kWh in the cities of Ouahigouya and Gaoua

Table 7. Cumulative cash flow of facilities in Gaoua for different sizes

Year	10kWp	50kWp	100kWp	500kWp	1000kWp	2000kWp	4000kWp	6000kWp	8000kWp	10000kWp
0	-10575002	-52875010	-105750021	-528750106	-1057500211	-2115000422	-4230000829	-6345001243	-8460001657	-10575002110
1	-9322478.3	-46612551.7	-93225104.4	-466125523	-932251045	-1864502090	-3729004165	-5593506247	-7458008329	-9322510450
2	-8043814.430381	-40219395.895279	-80438792.790558	-402193964.95279	-804387928.90558	-1608775857.81116	-3217551700.62232	-4826327550.43348	-6435103400.24464	-8043879289.0558
3	-6738464.84580305	-33692814.9289135	-67385630.8578269	-336928155.289135	-673856309.578269	-1347712619.15654	-2695425223.31308	-4043137834.46962	-5390850445.62616	-6738563095.78269
4	-5405872.61539496	-27030024.2177799	-54060049.4355598	-270300248.177799	-540600495.355598	-1081200990.7112	-2162401966.42239	-3243602949.13359	-4324803931.84478	-5406004953.55598
5	-4045469.18513825	-20228181.064505	-40456363.1290099	-202281816.64505	-404563632.290099	-809127264.580199	-1618254514.1604	-2427381770.7406	-3236509027.32079	-4045636322.90099
6	-2656674.13529209	-13284383.4446212	-26568767.8892424	-132843840.446212	-265687679.892424	-531375359.784847	-1062750704.56969	-1594126056.35454	-2125501408.13939	-2656876798.92424
7	-1238894.93275564	-6195668.76841042	-12391338.5368208	-61956693.6841042	-123913386.368208	-247826772.736417	-495653530.472834	-743480295.209251	-991307059.945668	-1239133863.68209
8	208473.321737755	1040987.38309286	2081973.76618571	10409867.8309285	20819736.6618571	41639473.3237141	83278961.6474283	124918442.971142	166557924.294857	208197366.61857
9	1686048.15170242	8428672.54847801	16857344.096956	84286719.48478	168573439.96956	337146879.93912	674293774.87824	1011440662.81736	1348587550.75648	1685734399.6956
10	3194459.96836845	15970538.7032647	31941076.4065295	159705381.032647	319410763.065295	638821526.13059	1277643067.26118	1916464601.39177	2555286135.52236	3194107630.65295
11	4734352.3396483	23669803.6047019	47339606.2094038	236698030.047019	473396061.094038	946792122.188075	1893584259.37615	2840376389.56422	3787168519.7523	4733960610.94037
12	6306382.26471676	31529752.164632	63059503.329264	315297515.64632	630595032.29264	1261190064.58528	2522380144.17056	3783570216.75584	5044760289.34112	6305950322.9264
13	7911220.4543214	39553737.8510079	79107474.7020158	395537372.510079	791074746.020158	1582149492.04032	3164298999.08063	4746448499.12094	6328597999.16126	7910747460.20157
14	9549551.61694309	47745184.1186584	95490367.2373168	477451835.186584	954903671.373168	1909807342.74634	3819614700.49267	5729422051.23901	7639229401.98535	9549036713.73168
15	11222074.7509287	56107585.8699148	112215170.73983	561075852.699148	1122151706.3983	2244303412.79659	4488606840.59319	6732910261.38978	8977213682.18637	11221517063.983
16	12929503.4427206	64644510.9457199	129289020.89144	646445103.457199	1292890207.9144	2585780415.8288	5171560846.6576	7757341270.48639	10343121694.3152	12928902079.144
17	14672566.1713102	73359601.6478571	146719202.295714	733596010.478571	1467192021.95714	2934384043.91428	5868768102.82857	8803152154.74285	11737536206.6571	14671920219.5714
18	16452006.6190454	82256576.2929479	164513151.585896	822565756.929479	1645131514.85896	3290263029.71792	6580526074.43583	9870789112.15375	13161052149.8717	16451315148.5896
19	18268583.9889249	91339230.7988817	182678460.597763	913392301.988817	1826784604.97763	3653569209.95527	7307138434.91054	10960707652.8658	14614276870.8211	18267846049.7763
20	20123073.3285137	100611440.304354	201222879.608709	1006114397.04354	2012228795.08709	4024457590.17418	8048915195.34835	12073372793.5225	16097830391.6967	20122287950.8709
21	22016265.8606198	110077160.822206	220154320.644413	1100771602.22206	2201543205.44413	4403086410.88825	8806172836.7765	13209259255.6647	17612345674.553	22015432054.4412
22	23948969.320871	119740430.927266	239480860.854531	1197404303.27266	2394808607.54531	4789617215.09063	9579234445.18126	14368851668.2719	19158468891.3625	23948086075.4531
23	25922008.3023375	129605373.479418	259210745.958836	1296053728.79418	2592107458.58835	5184214917.17671	10368429849.3534	15552644774.5301	20736859699.7068	25921074585.8835
24	27936224.6073473	139676197.382633	279352393.765266	1396761967.82633	2793523936.65266	5587047873.30533	11174095761.6107	16761143642.916	22348191524.2213	27935239366.5266
25	29992477.6066427	149957199.380709	299914397.761418	1499571987.80709	2999143976.61417	5998287953.22835	11996575921.4567	17994863882.6851	23993151843.9134	29991439766.1417

earlier compared to the city of Gaoua. This is explained by the solar potential and climatic conditions that prevail in the localities. The return on investment in the locality of Gaoua happened around six month little later.

Fig. 4 shows the accumulated cash flows for a 10MWp installation with a purchase price of 90 Fcfa / kWh in the cities of Ouahigouya and Gaoua. It can be seen that the capital invested is recovered respectively around 7 ½ years after in Ouahigouya and around 8 years later in Gaoua. The benefits are felt therefore from the 8th year in Ouahigouya and the 9th year in Gaoua.

Table 8 shows the production of electricity in kWh, the inputs and outputs (the expenses) in a power plant of 10Wp according to the electric pricing in the localities of Ouahigouya and Gaoua on the lifespan of facilities that is taken on average equal to 25 years [17].

We can also see the electrical pricing that changes because of inflation and the energy produced per year. The first year for a purchase price of 90 Fcfa/kWh, the amount of outflows is 161 667 000 Fcfa for Ouahigouya and 154 802 340 Fcfa for Gaoua. Taking into account that the PV plant is degraded over time and loses its production capacity [17-26], Fig. 5 shows the production of a 10 MWp installation in Ouahigouya (black curve) and Gaoua (red curve) depending on the year. We notice that the production decreased with the year. In the first year of the investment, the cash flow amounts are 1 308 033 000 Fcfa for the installation in Ouahigouya and 1 252 491 660 Fcfa for the Gaoua plant.

3.2 Net Present Value (NPV) and Leveled Cost of Energy (LCOE)

Fig. 6 shows the net present value (NPV) for solar photovoltaic plants of 10MWp for an electricity pricing of 90 Fcfa / kWh, operating under the climatic conditions of cities of Ouahigouya and Gaoua. The NPV is calculated using equation (1) for several rates ranging from 1% to 25%.

For discount rates between 1 and 14.42%, (black curve) and between 1 and 13.72% (red curve), the NPV in Ouahigouya and Gaoua reaches positive values, which means that the PV installation provides advantages for the investors. For higher discount rates, (> 14.42% for Ouahigouya and > 13.72% for Gaoua) the value of the NPV is negative, which means that the photovoltaic installation would produce losses. The NPV value reaches zero when the discount rate corresponds to an internal yield of 14.42% for the locality of Ouahigouya and 13.72% for Gaoua (equation 2).

As defined in paragraph I.1.3, the IRR is the gross profitability of the investment. To achieve net profitability, the cost of capital must be considered for investors. Investors would obtain net benefits if the cost of their capital is less than 14.42% and 13.72%.

As indicated in equation (3) in paragraph I.1.4, the LCOE depends on the current discount rate. Table 9 shows the average updated cost of energy produced by solar photovoltaic systems studied for different values of the discount rate. According to REN 21, the average LCOE of photovoltaic production systems decreased by 73% between 2010 and 2017 due to the evolution of technology [27].

For a discount rate of 4% (Table 9), LCOE for photovoltaic solar energy from a plant installed in Ouahigouya, operational for 25 years is 59.56 Fcfa / kWh and 61.6 Fcfa / kWh at Gaoua. It is noted that this cost of electrical energy obtained from photovoltaic solar power plants represents around 50% of the current average electricity cost for domestic consumption, little and medium-sized enterprises in Burkina Faso (which is 119 Fcfa). The LCOE in Ouahigouya takes the value 90.038 Fcfa/kWh at a discount rate of 10.06% and 90.037 Fcfa/kWh at Gaoua for a discount rate of 9.46%. Note that these values are in agreement with the IRR (14.42% for Ouahigouya and 13.72% for Gaoua). These values also are in agreement with the average LCOE of PV systems in Africa which is between 50 and 120 Fcfa [5].

Table 8. Electric Tarif (ET), Energy Production (PE), Inputs (EV) and Total Expenditures (TE) in Ouahigouya and Gaoua

			Ouahigouya			Gaoua	
Year	ET(Fcfa/kWh)	EP(kWh)	EV (Fcfa)	TE (Fcfa)	EP(kWh)	EV (Fcfa)	TE (Fcfa)
0							
1	90	16330000	1469700000	161667000	15636600	1407294000	154802340
2	92.34	16248350	1500372639	165040990.29	15558417	1436664225.78	158033064.8358
3	94.74084	16167108.25	1531685415.97593	168485395.757352	15480624.915	1466647408.17203	161331214.898923
4	97.20410184	16086272.70875	1563651690.60735	172001685.966808	15403221.790425	1497256339.58058	164698197.353864
5	99.73140848784	16005841.3452062	1596285101.39032	175591361.152936	15326205.6814729	1528504079.38763	168135448.732639
6	102.324425108524	15925812.1384802	1629599571.45634	179255952.860197	15249574.6530655	1560403959.52445	171644435.547689
7	104.984860161345	15846183.0777878	1663609314.51263	182997024.59639	15173326.7798002	1592969590.15972	175226654.917569
8	107.71446652554	15766952.1623989	1698328840.90651	186816172.499716	15097460.1459012	1626214865.50635	178883635.205699
9	110.515042655205	15688117.4015869	1733772963.81623	190715026.019785	15021972.8451717	1660153969.74947	182616936.672442
10	113.38843376424	15609676.8145789	1769956805.57108	194695248.612818	14946862.9809458	1694801383.09814	186428152.140796
11	116.33653304211	15531628.4305061	1806895804.10334	198758538.451368	14872128.6660411	1730171887.9634	190318907.675974
12	119.361282901205	15453970.2883535	1844605719.53498	202906629.148848	14797768.0227109	1766280575.2652	194290863.279172
13	122.464676256636	15376700.4369118	1883102640.90168	207141290.499184	14723779.1825973	1803142850.87098	198345713.595808
14	125.648757839309	15299816.9347272	1922402993.01729	211464329.231902	14650160.2866843	1840774442.16866	202485188.638553
15	128.915625543131	15223317.8500536	1962523543.48156	215877589.782972	14576909.4852509	1879191404.77672	206711054.525439
16	132.267431807252	15147201.2608033	2003481409.83402	220382955.081743	14504024.9378247	1918410129.39441	211025114.233385
17	135.706385034241	15071465.2544993	2045294066.85726	224982347.354299	14431504.8131355	1958447348.79487	215429208.367436
18	139.234751045131	14996107.9282268	2087979354.03257	229677728.943583	14359347.2890699	1999320144.96422	219925215.946064
19	142.854854572304	14921127.3885856	2131555483.15123	234471103.146635	14287550.5526245	2041045956.38962	224515055.202859
20	146.569080791184	14846521.7516427	2176041046.0846	239364515.069306	14216112.7998614	2083642585.49947	229200684.404942
21	150.379876891755	14772289.1428845	2221455022.71638	244360052.498802	14145032.2358621	2127128206.25885	233984102.688473
22	154.289753690941	14698427.6971701	2267816789.04047	249459846.794452	14074307.0746828	2171521371.92347	238867350.911582
23	158.301287286905	14624935.5586842	2315146125.42775	254666073.797052	14003935.5393094	2216841022.95551	243852512.525107
24	162.417120756365	14551810.8808908	2363463225.06543	259980954.757197	13933915.8616128	2263106495.1046	248941714.461506
25	166.63996589603	14479051.8264864	2412788702.57254	265406757.28298	13864246.2823048	2310337527.65743	254137128.042317

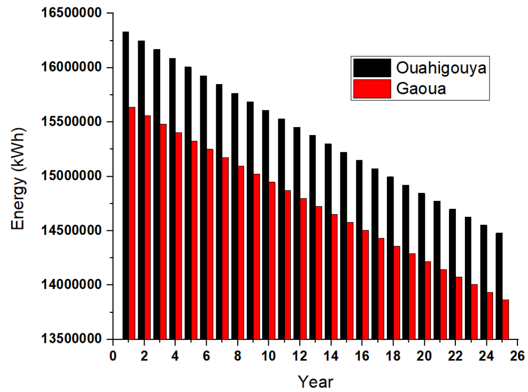

Fig. 5. Generation of electricity during the lifetime of the installation

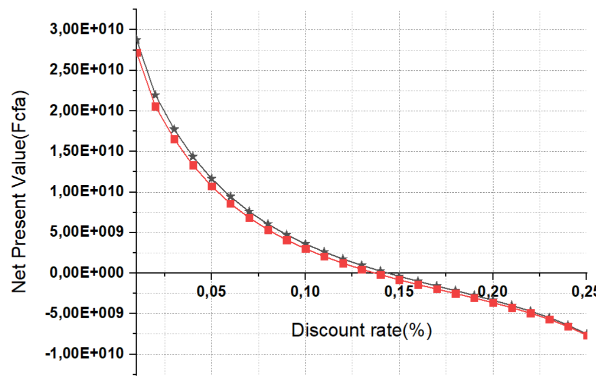

Fig. 6. Net present value of facilities in the localities of Ouahigouya and Gaoua

Table 9. Some values of LCOE for the localities of Ouahigouya and Gaoua

	LCOE (Fcfa/kWh)	
Discount rate (%)	**Ouahigouya**	**Gaoua**
4%	59.569	61.606
9.46%		90.037
10.06%	90.038	

4. CONCLUSION

In this article, we made a financial profitability study of a PV installation. Using cash flow data per year, we calculated net present value (NPV), internal rate of return (TRI or IRR) related to the expected return in terms of investment returns and evaluated the expected return on investment. We have evaluated the influence of the size of the facility and the purchase price of the kWh on the return on investment. For all the installations studied, we find that the size of the installation does not affect the return on investment. However, the higher the purchases price of kWh, the faster the return on investment. For the two localities studied, an IRR of 14.42% is obtained in Ouahigouya and an IRR of 13.72% is obtained in Gaoua. For a discount rate of 4%, as in most European countries, LCOE is about 59.569 FCFA / kWh in Ouahigouya and 60.61 FCFA / kWh in Gaoua, which is almost 50% less than the current price of energy in Burkina Faso. These values represent a significant benefit in terms of return on investments.

The plotting of accumulated cash flow over time made it possible to calculate the total investment payback, which is about 10 years for Ouahigouya and 12 years for Gaoua. This study helps to inform investors in terms of payback and strategic locations for PV investments. The guarantee on the reliability of the PV modules (25 years of life), the free availability of the solar resource makes it possible to perceive that to invest in the photovoltaic installations is low risk and should be encouraged in a country which knows a huge energy deficit. The use of real data for simulations and a study of the influence of climate (humidity for example) over the lifetime of the PV plant will determine the life of PV installations in Africa and particularly in Burkina Faso to improve this work.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kumar A, Kandpal TC. CO2 emissions mitigation potential of some renewable energy technologies in India. Energy Sources, Part A Recover. Util. Environ. Eff. 2007;29(13):1203-1214.
2. Kumar A, Kandpal TC. Potential and cost of CO2 emissions mitigation by using solar photovoltaic pumps in India. Int. J. Sustain. Energy. 2007;26(3):159-166.
3. Secrétariat de REN21. Report on the global status of renewable energies; 2016. Available:www.ren21.net/gsr
4. International Energy Agency (IEA). Energy technology perspectives 2008: Scenarios and strategies to 2050. Paris, France. International Energy Agency, IEA/OECD. 2008;1–650.
5. Branker K, Pathak MJM, Pearce JM. A review of solar photovoltaic levelized cost of electricity. Renewable & Sustainable Energy Reviews. 2011;15:4470-4482. Available:http://dx.doi.org/10.1016/j.rser.2011.07.104
6. Jackson J. Promoting energy efficiency investments with risk management decision tools. Energy Policy. 2010;38: 3865-3873.
7. Renewable Energy Policy Network for the 21st century (REN21). Renewables 2010 Global Status Report. Paris. 2010;1–80.
8. Mints P. The 12-step solar program: Towards an incentive-less future, Navigant Consulting January 19, 2011, on ElectoIQ; 2011. Available:http://www.electroiq.com
9. Kirkegaard JF, Hanemann T, Weischer L, Miller M. Toward a sunny future? Global integration in the solar PV industry. World Resources Institute (WRI) Working Paper Series. 2010;1–66.
10. Price S, Margolis R. Solar technologies market report. Energy Efficiency & Renewable Energy, US Department of Energy, 2010. 2008;1–131.
11. Organization for Economic Co-operation and Development (OECD), Nuclear Energy Agency/International Energy Agency (OECD/IEA). Projected costs of generating electricity: 2005 update. Paris, France: OECD Publishing. 2005;1–230.
12. National Energy Board (NEB). Canadian energy overview 2009—an energy market assessment. 2010;1–52.
13. Munasinghe M, Warford JJ. Electricity pricing: Theory and case studies. Washington, DC: International Bank for Reconstruction and Development. 1982;1–395. (Technical report).
14. YAMEOGO JDD. Expériences du Burkina Faso, Place des politiques, des financiers et des entreprises privées dans le développement de la filière solaire en Afrique. AFRICASOLAR; 2015.
15. Guaita-pradas I, Bartual-san Feliu I, Marí Soucase B. Profitability and sustainability of photovoltaic energy plants in Spain. International Journal of Sustainable Economy; 2015.
16. Evaluation rapideetanalysed'écart. Burkina_Faso_Gap Analysis_200313.doc. Available:Burkina_Faso_RAGA_FR_Released.pdf
17. Inmaculada Guaita-pradas et al. Energy production and financial analysis of photovoltaic energy plants in Ivory Coast. Sciences Direct. 2015;11(2):24-34.
18. Hegedus S, Luque A. Achievements and challenges of solar electricity from photovoltaics. In: Luque A, Hegedus S, Editors. Handbook of Photovoltaic Science and Engineering. 2nd Ed. John Wiley and Sons Ltd. 2011;1–38.

19. Velosa A III. What is inside your LCOE assumptions? SEMI PV group – the grid; 2010.
Available:http://www.pvgroup.org/NewsArchive/ctr 036226
20. Short W, Packey D, Holt T. A manual for economic evaluation of energy efficiency and renewable energy technologies. National Renewable Energy Laboratory. 1995;1–120.
21. Sevilgen SH, Erdem HH, Cetin B, Akkaya AV, Da˘gdas A. Effect of economic parameters on power generation expansion planning. Energy Convers Manage. 2005;46:1780–9.
22. Gibson RB, Winfield M, Markvart T, Gaudreau K, Taylor J. An analysis of the Ontario Power Authority's consideration of environmental sustain-ability in electricity system planning. Studies in Ontario Electricity Policy Series Paper No. 2. University of Waterloo and York University. 2008;1–173.
23. Hydro-Quebec. 2010 comparison of electricity prices in major north Americancities. 2010;1–79.
24. Hern_andez-Moro J, Martínez-Duart JM. CSP electricity cost evolution and grid parities based on the IEA roadmaps. Energy Policy. 2012;41:184e92.
25. Guaita-Pradas I, Marí Soucase B. Endorse of renewable energy plants, still an alternative investment in Spain? SOP Transactions on Economics Research (ER) Scientific Online Publishing. Scientific Online Publishing. 2014;1(2):1-9.
26. Available:http://pubdocs.worldbank.org/en/882431460465176053/Morocco-MEM-FR-2.pdf
27. Renewable Energy Policy Network for the 21st century (REN21). Renewable Global Status Report. Paris. 2018;41.

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