Feasibility of Substitution of the Conventional Street Lighting Installation by the Photovoltaic Case Study on a Municipality in Agadir in Morocco

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Article Info	ABSTRACT
	In this work, we present a technical and economic study of the solar powered street lighting system of a municipality in the south of Morocco. The state of the conventional street lighting system is first analyzed in a substation of street lighting. Then a sizing method is applied to the photovoltaic installation in the testing area. A financial study, by comparison between conventional and PV-based lighting, is carried out showing the feasibility of the PV street lighting.).

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1. INTRODUCTION

The techno-economic study for solar street lighting system have been developed in many scientific research works [1-3]. These studies confirmed that the energy consumption in street lighting system is considerably reduced with PV power source. However, these works focused only on the technical feasibility [4-11], and it's much difficult to find studies on the sustainable and exhaustive feasibility in literature which require an analysis of electrical quality of power supply installation in accordance with EN50160 standard [12,13], and the quality of the electrical network consistent with the standards CE161000-2-2 [14] and CEI61000-3-4 [15].

In India, a study has been carried out in order to evaluate the energy and economic efficiency of the street lighting by the "Lithonia Visual Software" and "Homer Software" [16]. The first software is used in order to simulate the graphic structure of light points and the maximum luminous flux by adjusting the tilt angle and height of mast; the second one is used in for the conception and analysis of hybrid power generation systems.

Another study [2], fulfilled in Taiwan, has concerned an economic comparison between three types of systems: Solar street lighting with LED lamp, conventional street lighting with on the one hand LED lamp and mercury-vapor-lamp on the other hand. This study has shown that, despite a higher installation cost, the solar powered LED system is more economical due to an energy savings of up to 75% compared to the mercury lamp lighting system.

In the case studied in this work, the street lighting of Dcheira El-Jihadia municipality, located in the suburb of Agadir city in Morocco, has consumed 3 364 300 kWh during the year 2015. This meant to the municipality a bill of around 4 178 750 MAD that represent 20% of its total budget. This was the main reason that led the municipality to move towards solutions to optimize the electricity consumption in street lighting, including solutions using PV energy.

Indeed, in the field of street lighting, the solar street light is a kind of street light which is supplied by the solar PV energy, that is, it's equipped with solar panels that collect sunlight throughout the day and transform it to electricity. Then, it insures the energy storage in batteries via a circuitry. Finally, to provide lighting, electrical energy is restored at night. This kind of street light thus becomes self-sufficient in energy. it will greatly contribute to reducing consumption costs as well as greenhouse gas emissions.

In this context, together with the great sunshine in the region of Agadir estimated at 3 144 kWh/m^2 [17], we have proposed to this municipality to study the feasibility of substitution of the conventional street lighting installation by the photovoltaic in order to minimize electrical energy consumption.

The present paper is organized as follows: after this introduction, we present in section 2 the tools of investigation used. Then, in section 3, we analyze different measurements carried out in one of the conventional street lighting substations in an area of Dcheira El Jihadia municipality. Then, we describe in section 4 a sizing method applied to the PV installation of street lighting in the testing area. Section 5 concludes the sizing with a financial study of the installation by comparison between the use of conventional and PV-based lighting. Then, the technical and economic study results will be presented, compared and discussed in section 6. Finally, a conclusion and references close this paper.

2.   DEVELOPMENT TOOLS

A portable network analyzer [18] was used to study the state of a post of the street lighting. This device allows to make measures and to record certain electrical quantities as well as the parameters which identify the quality of an electrical network.

Otherwise, for sizing the proposed solar street lighting system, the tools used are:
- PVSyst is a software dedicated to sizing photovoltaic systems [19].
- DiaLux software is used to calculate optimum brightness in public lighting installation [20].
- MapInfo which is a computer tool giving a representation of geographic data of light points on geographical/satellite maps [21].

3.   MEASUREMENT ANALYSIS OF CONVENTIONAL STREET LIGHTING SYSTEM

Prior to study and size of the proposed solution, we present the state of one of the street lighting substation, named "Substation 9", in the Dcheira El-Jihadia municipality.

The measurements were carried out as follow: Firstly, some electrical quantities characterizing the substation, such as voltage, current, power factor and fundamental frequency. Secondly, the parameters identifying the electrical grid quality of the conventional substation, such as total harmonic distortion, harmonic spectrum of the voltage and the current, and their compatibility levels. Finally, the power consumption involved in this conventional substation.

3.1. Tracing and tracking of the installation

Using MapInfo software, we have tracked coordinates of the different light points supplied by the "Substation 9" that was chosen for this study. This Substation is located in the region whose GPS coordinates are 30°21'46.8" North and 9°31'42.2" West (Latitude 30.363 and Longitude -9.5284). Figure 1 presents the geographical distribution of 70 light points of various powers that "Substation 9" serves. These light points are listed in Table 1.

Table 1. Tracking symbols of light points in figure 1

Reference	Designation	Power (W)	Number of light points
P	"Substation 9"	--	--
🟡	Underground outgoing feeder C	250	20
🔵	Overhead outgoing feeder B + Streetlights	150 et 250	11 et 15
🔴	Overhead outgoing feeder A	150 et 250	11 et 1
☆	Projector MI	400	12
		Total light points	**70**

Figure 1. Area supplied by the "Substation 9" with the tracking summarized in table 1

As an illustration, to evaluate the values of electrical quantities, as well as the electrical performance quality of "Substation 9", we make use of quantities adopted by EN50160 standard [12] summarized in Table 2.

Table 2. The limit values according to the EN50160 standard [12]

Quantity		Values		
		Min.	Max.	Tolerance (%)
Voltage	(V)	207	253	±10% (of 230 V)
Fundamental frequency	(Hz)	49.5	50.5	±1% (of 50 Hz)
Imbalance	(V)		4,6	2% (of 230 V)
THD_f in voltage	(%)	---	---	0 to 5
THD_f in current	(%)	---	---	0 to 10

3.2. Electrical quantities evolution U, I, Ψ et F
3.2.1. Phases voltage U
Figure 2 shows the evolution of the voltage U of the three phases during one day; between 13h of 08 July 2015 and 15h of 09 July 2015.
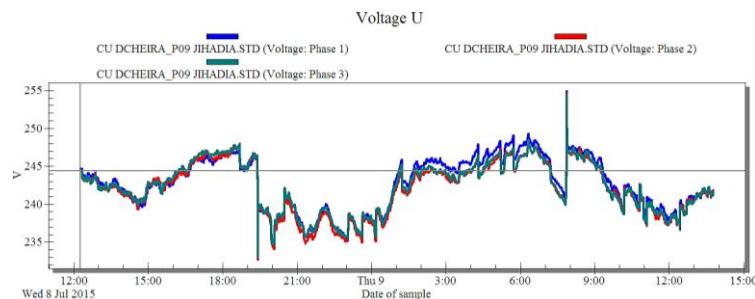

Figure 2. Evolution of the three phases voltage U supplying the "Substation 9"

Following analysis of the above parameter, we find that the voltage U of the three phases is lower than ±10% of nominal voltage 230 V as stipulated by the standard EN50160 [12]. Indeed, according to this figure, the maximum value is approximately 250 V (< 253 V) and the minimum value is about 233 V (> 207 V) leading to a non-overloaded electricity network.

We also note, in figure 2, a voltage imbalance between phases. But this imbalance does not exceed the EN50160 standard [12] limit of 2%. For example, on 09 July 2015 about 3h30, $\Delta U_{max} = U_1 - U_3 = 245.5 - 244 = 1.5$ V < 4.6 V.

3.2.2. Phases current *I*

Figure 3 shows the temporal variation of the current *I* in the three phases of the "Substation 9" power supply. We observe that the three curves corresponding to phase currents present current peaks during starting of the street lighting lamps, at 19h45 of 08 July 2015 as shown in Figure 3. At around 11h00 of the following day, the lighting was forced to determine the light points supplied by the substation 9. These current peaks are approximately 1.4 times the nominal current I_n ($I_{n1} = 28$ A, $I_{n2} = 48$ A, $I_{n3} = 72$ A). the various pulses occurring on the curves of phases 1 and 2 in the range of 10 A at 14h40 of 08 July 2015 shown in figure 3, are due to another additional load supplied by the phases 1 and 2. It corresponds to temporary supplying of maintenance engines by the "Substation 9".
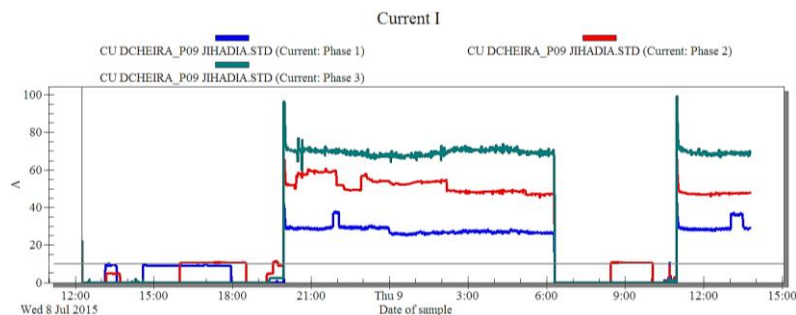

Figure 3. Variation of the three phases current *I* supplying the "Substation 9"

We also note that load current is stable throughout the lighting period, especially for phase 3 for which $I_3 \approx 72$ A. For the other two phases, the mean value of the currents I_1 and I_2 are respectively about 28 A and 48 A. the imbalance between I_1, I_2 and I_3 is due to the light points inequality supplied by these lines. Indeed, the phases 1 and 2 supply 12 and 26 streetlights respectively, while the phase 3 alone supplies 32 streetlights. In order to correct this imbalance, the municipality must balance the three phases by charging them almost identically.

3.2.3. Power factor Ψ

The statements issued by network analyzer include the evolution of power factor ψ, as shown in Figure 4 for the three phases of the "Substation 9". We find that, for the two phases 1 and 3, ψ_1 and ψ_3 evolve almost in the same direction with an average value of about 0,7. On the contrary, ψ_2 is unstable due to defect in the phase line 2, and possibly due to flickering street light, and also to temporary supplying of maintenance engines. Otherwise, the average total power factor measured in the installation of street lighting is approximately 0,7, which is not really optimal since most lamps installed don't have a power correction capacitor. The municipality must install capacitors in order to reach a power factor close to 0,95.
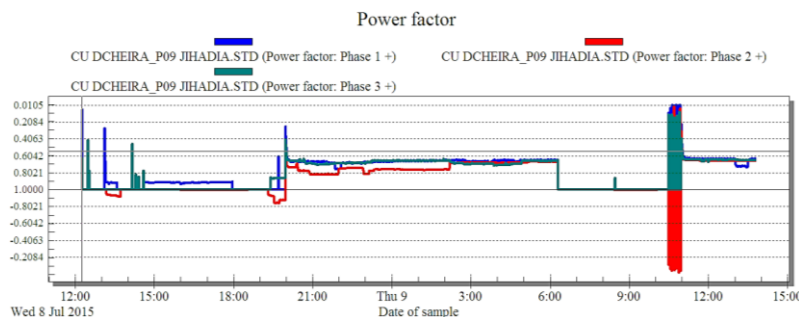

Figure 4. Evolution of the phases power factor ψ of "Substation 9"

3.2.4. Network frequency

Among the electrical quantities in the "Substation 9", we illustrate in figure 5 the fundamental frequency F measured and that is less than ±1% of the nominal value 50 Hz imposed by the standard EN50160 [12]. Indeed, the measured values, F_{max} and F_{min} are equal to 50.06 Hz < 50.5 Hz and 49.95 Hz > 49.5 Hz respectively, which represents the acceptable variations.
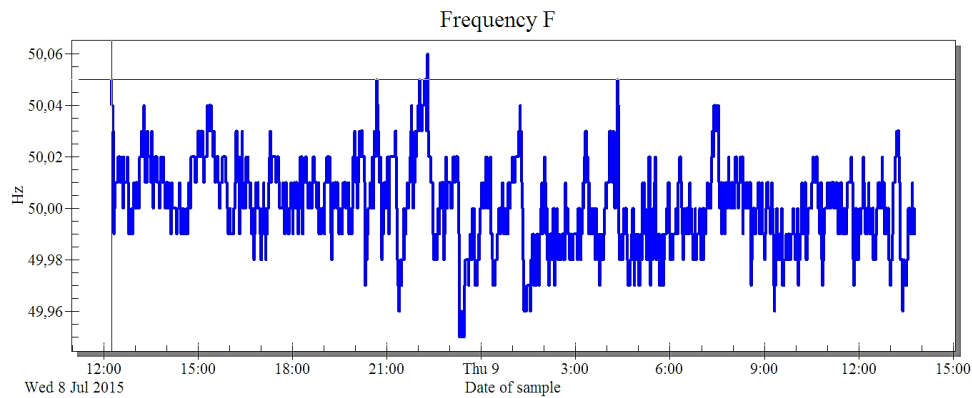

Figure 5. Fundamental frequency F of the supply voltage on the "Substation 9"

3.3. Parameters identifying the electricity network quality
3.3.1. Total harmonic distortion factor

In order to assess the electricity network quality of "Substation 9", we use one of the dedicated parameters, named total harmonic distortion THD_f. This is defined as the ratio between the total effective value of the harmonics of signal U or I, and the effective value of its fundamental component. This is a parameter defining the overall distortion of the periodic quantity.

The THD_f reflects substantially increase of Joule effect in the lines and devices. We distinguish two total harmonic distortion:

- THD_V corresponding to the total harmonic distorsion in voltage.
- THD_I representing the total harmonic distorsion in current.
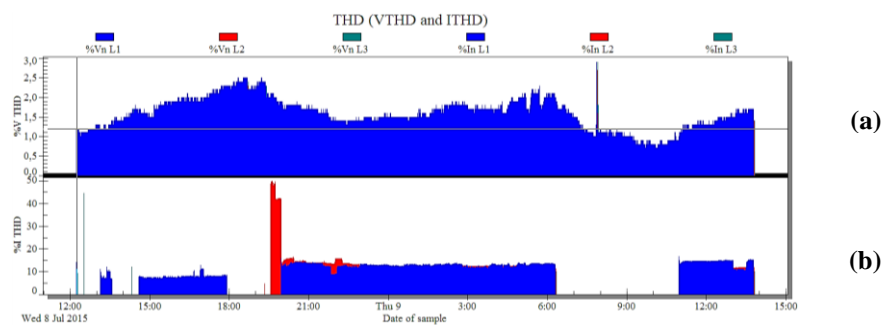

Figure 6. Variation of the total harmonic distortion of fundamental :
(a) voltage and *(b)* current, concerning the supply of "Substation 9"

According to measurement results shown in figure 6-a, we find that the total harmonic distortion in voltage *VTHD* is less than 5%, which is acceptable under the EN50160 [12]. Thus, this electrical grid is environmentally non-polluting in voltage, which is not the case for current. Indeed, the spectrum on figure 6-b shows that the total harmonic distortion in current *ITHD* is about 13,8% from 20h to 06h15 of 09 July 2015, exceeding 10% required by the standard. To minimize the *ITHD*, we must set up a passive harmonic filter [22-24], which is envisaged in the near future by the municipality.

There is also a high *ITHD* between 19h30 and 20h which is not due to the street lighting: Since the lighting begins only at 20h, then the *ITHD* is not caused by the ignition of the lamps, but by an impact of other loads supplied by the phase 2; namely the maintenance works near the "Substation 9".

3.3.2. Harmonic spectrum of voltage and current

The lamps used in street lighting are a non-linear load corresponding to a deformed current draw, and then to an harmonic rich current.

From the measurements taken on three phases L1, L2 and L3 of "Substation 9", as shown in figure 7, the current harmonics H_{In} are more predominant than the voltage harmonics H_{Vn}. This is due to the impact of loads whose current exceeds 16 A. The spectral lines H_{In} as will as H_{Vn} correspond to the odd harmonics ranks of order 3, 5, 7, 9, 11, etc. In fact, the harmonics are characterized by their odd/even rank. The even harmonics are often negligible in industry, because they are cancelled by the signal symmetry. In addition, these even harmonics only exist in the presence of a DC component, contrary to the odd harmonics (3, 5, 7) which are ampler on the public electricity grid.
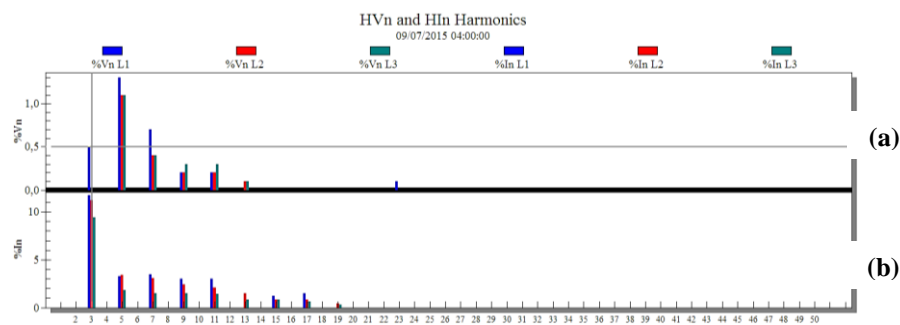

Figure 7. Spectrum of the set of harmonics: *(a)* H_{Vn} and *(b)* H_{In} of the grid in case of "Substation 9"

Following the spectrum analysis in figure 7, we summarize in table 2 and 3, the values of measured amplitudes (A_{HVn-m} and A_{HIn-m} in %) corresponding to the spectral lines H_{Vn} and H_{In} for different ranks. The A_{HVn-n} and A_{HIn-n} tolerable levels for the amplitudes of lines H_{Vn} and H_{In}, according to CEI61000-2-2 [14] for low voltage grid 50 Hz, are presented in Table 3 and Table 4.

Table 3. Compatibility levels for H_{Vn} on the grid supplying the "Substation 9"

Orders *n* odd non-multiples of 3			Orders *n* odd multiples of 3		
n	A_{HVn-m} (%)	A_{HVn-n} (%) [14]	*n*	A_{HVn-m} (%)	A_{HVn-n} (%) [14]
5	1.3	6	3	0.5	5
7	0.7	5	9	0.3	1.5
11	0.3	3.5	15	0	0.3
13	0.1	3	21	0	0.2
17	0	2	>21	0	0.2
19	0	1.5			
23	0.1	1.5			
25	0	1.5			
>25	0	0.2 + 12.5/*n*			

From these tables 3 and 4, we conclude on one hand, that the levels of harmonics H_{Vn} and H_{In} of the station under test, largely meet the standard, except the two current harmonics H_{I15} and H_{I17}. On the other hand, as shown in Figure 7, the current harmonics H_{I3} as well as the voltage harmonics H_{V5} [13] are ampler than the others. Indeed, H_{I3} and multiples of 3 are generated by single-phase loads since, in this case, the HPS lamps (High Pressure Sodium) are powered by one phase line. These H_{In} are particularly damaging to three-phase power at the station, because of the high current produced in the neutral conductor leading to production of an excessive heating of neutral wire.

Table 4. Compatibility levels for H_{In} demanded by the "Substation 9"

Orders n odd non-multiples of 3			Orders n odd multiples of 3		
n	$A_{HIn\text{-}m}$ (%)	$A_{HIn\text{-}n}$ (%) [15]	N	$A_{HIn\text{-}m}$ (%)	$A_{HIn\text{-}n}$ (%) [15]
5	3.3	10.7	3	11.5	21.6
7	3.5	7.2	9	3	3.8
11	3	3.1	15	1.2	0.7
13	1.7	2.0	21	0	0.6
17	1.7	1.2	27	0	0.6
19	0.7	1.1	33	0	0.6
23	0	0.9	≥39	0	0.6
25	0	0.8			
29	0	0.7			
31	0	0.7			
≥35	0	0.6			

3.4. Energy consumption

The power consumption E_c (en kWh) is the basis data for improvement work of a street lighting system. It's related to the lighting time and equipments state.
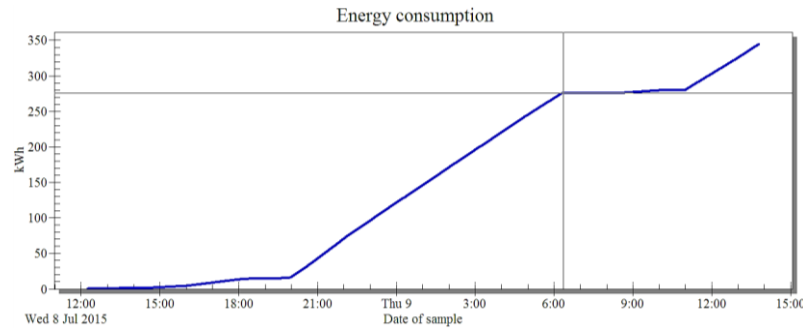

Figure 8. Evolution of the energy consumed by the "Substation 9" during the night

As shown in figure 8, the power consumption increases linearly from 20h of 8 July 2015 up to about 6h on the next day. The power analyzer providing the cumulative energy, we note that the amount of this energy E_c consumed during the night, is 275 kWh. This is reached when E_c stabilizes around 6h of 09 July 2015 on the curve. In fact, if we divide by 92 days, $Ec_{3,2015} = 19\,206$ kWh corresponding to the consumed cumulative energy and charged during the third quarter of 2015. This leads to a daily consumption of about 210 kWh which is slightly close to that measured (275 kWh) and shown in figure 8 for a day.

4. PV SYSTEM DESIGN

Hereinafter, we propose a sizing method of a stand-alone PV system, which will provide electricity to various lines supplied by the "Substation 9".

The method consists of dimensioning, in PVsyst 5.0 software [19], the PV panels to be installed in this solar street lighting system. This software requires some characteristics of the study area, such as; geographical data, photometric data and the energy requirement. Subsequently, the software generates a type of PV module and of suitable battery.

The approach to be taken for the sizing is as follows [25]:
- Tracking and tracing of the installation;
- Sizing of the lamps;
- Definition of the energy requirement;
- Determination of the peak power of the photovoltaic panels;
- Calculation of the battery capacity;
- Choice of charge controller.

Sizing a PV system requires knowledge of daily average irradiance I_{rd} at the place of installation. Table 5 presents the meteorological data in the testing area. These data are obtained using simulation tool PVgis-CMSAF [26], incorporating irradiance data I_{rd}, during the period from 1998 to 2011.
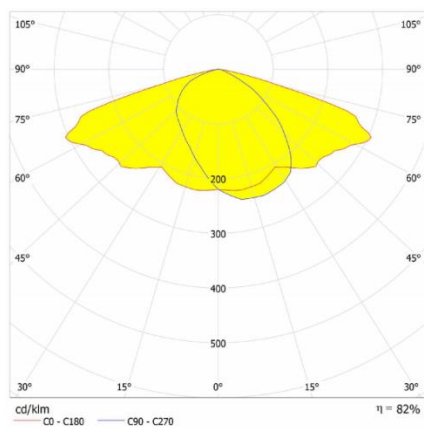
Figure 9. Photometric curve of the lamp Philips SGS453 C GB 1Son-Tpp150W SGR CR P6 [27]
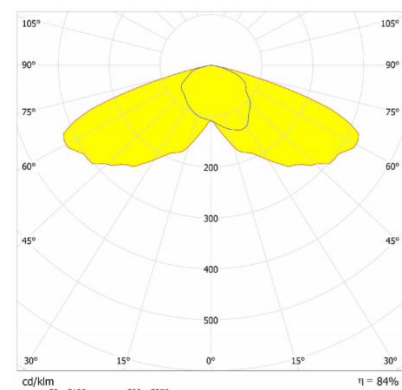
Figure 10. Photometric curve of the Led lamp of the Model EL3000-DC, Philips, Ecolite [28]

Table 5. Average daily irradiance I_{rd} in the testing area from 1998 to 2011

Month	Juna.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Irradiance I_{rd} (kWh/m²/d)	3,89	4,72	6,27	7,07	7,67	7,50	7,54	6,94	6,06	5,11	4,11	3,45

4.1. Sizing light fixtures

In the case of the conventional street lighting, the loads to be supplied are mainly lamps in powers of 150, 250 and 400 W. For our solution, both for environmental and economic reasons, we opt for LEDs lamps (*Light Emitting Diode*) replacing conventional lamps. These LEDs lamps were chosen by means of the DiaLux 4.12 software [20]. Figures 9 and 10 show a comparative example, given by the manufacturers [27], between the photometric results of a conventional HPS lamp in power of 150 W and that of equivalent LEDs lamp [28].

With respect to photometric properties given in Figures 9 and 10, the manufacturers define on the one hand, two "C-plane"; C0-C180 named the transverse plane perpendicular to the light fixture axis and the longitudinal plane C90-C270 passing through the axis of light fixture. On the other hand, they define the parameter γ which represents the viewing angle wherein we can observe the light fixture.

Figures 9 and 10 illustrate the luminous intensity distribution in Cd/kLm, emitted in a given direction within the two planes C0-C180 and C90-C270. We note that the light fixture efficiency η of the HPS lamp in power of 150 W up to 82%, is closer (84%) to that of the light fixture of equivalent LEDs lamp. This efficiency is defined as the ratio of the luminous flux emitted by the light fixture and that of the lamp.

Following our comparative study of different types of HPS lamps used in conventional street lighting, table 6 summarizes the simulation results obtained in the DiaLux software.

Table 6. Comparison of some parameters of selected LEDs substituting lamps used in conventionnel street lighting

Replacement LEDs	Conventional lamp	Light efficiency (Lm/W)	Luminous flux (Lm)	Power (W)
EL3000-DC Philips [28]	SHP 150 W [27]	91 Against 104	3000 Against 17 500	33 Against 169
UP2 Sunna Design [29]	SHP 250 W [31]	112 Against 121	5600 Against 33 300	50 Against 276
YY-ST90W Sama Technologie [30]	SHP 400 W [32]	110 Against 130	9900 Against 56 500	90 Against 433

4.2. Calculation of the electrical energy requirement

This energy is required for the design of photovoltaic generator (PVG) and the storage capacity of the battery with an adequate series/parallel mode selected for their interconnections. Considering the light point that consumes 33 W, for an average of 13 h/day, the electrical energy requirement is approximately $E_c = 430$ Wh/d.

4.3. Sizing of the PV Modules

With the data in the previous paragraph, it is possible to know the number of PV modules needed to cover electricity demand. This involves firstly calculating energy which the PV modules have to produce every day [25]-[33]:

4.3.1. Energy produced by a PV panel

According to the influence of several parameters, for an expected energy requirement E_c to supply a single light point, the energy E_p to produce by a single PV module is given by the following relation.

$$E_p = \frac{E_c}{k} \tag{1}$$

Where k represents a coefficient dependent on the meteorological uncertainty, the uncorrected tilt of the PV modules according to the season, the operating point of the modules that is rarely optimal, the performance of charge-discharge of the batteries (80%), the cable losses, etc. For the stand-alone systems, that is with storage unit such as batteries, this coefficient k is generally between 0.55 and 0.75 [34]. Considering in our case, an average value $k = 0.65$, this allows us to estimate the value of E_p at 660 Wh/d.

4.3.2. Calculation of the peak power of the PVG to install

The peak power P_c of a single PV module is calculated by the following relation:

$$P_c = \frac{E_p}{I_r} \, G \tag{2}$$

Where I_r is the average annual daily irradiation and $G = 1$ kW/m^2 is the radiation in standard measurement conditions (STC: Standard Test Conditions). In our study, according to data of the table 5, I_r is about 5.86 kWh/m^2/d, which gives us a peak power P_c of approximately 113 Wp (Peak Watt).

4.3.3. Determination of number of solar panel

Our choice went to polycristalline PV modules type SPP81-12, whose technical specifications are given in Table 7 [28].

As the radiation G does not reach 1 kW/m^2 and that these PV panels have a peak power P_{MPP} of 80 Wp, a single module will be sufficient to supply a light point of power 33 W according to equation (3).

$$N = \frac{P_c}{P_{MPP}} \tag{3}$$

Table 7. Characteristics of the selected PV module (SPP81-12) [28]

Kind of cells		Poly-crystalline
Number of cells connected in series		36
Dimensions (mm)		915 x 670 x 35
Weight (Kg)		8
Electrical characteristics (STC)	P_{MPP} (W)	80
	V_{MPP} (V)	18
	I_{MPP} (A)	4.6
	V_{OC} (V)	21.6
	I_{SC} (A)	5.06

4.4. Calculation of the capacity of battery

For PV based systems, storage batteries are needed. In order to design them, we proceed as follows:
- Determination of the number of days battery life required N_j
- Evaluation of the depth of discharge D (en %) acceptable for the type of chosen battery
- Calculation of battery capacity C (Ah) to implement whose voltage is U (V),

$$C = \frac{E_c \, N_j}{D \, U} \tag{4}$$

For daily energy consumption E_c of about 430 Wh with autonomy N_j estimated 2 days, for a voltage $U = 12$ V, there should be a battery capacity C of about 90 Ah admitting a depth of discharge D in the order of 80%. In our case, we opted for the battery of the type GEL/12V of a capacity of 90 Ah [25, 35].

4.5. Design of the charge controller

Any stand-alone photovoltaic system requires a charge/discharge regulation of the batteries. It's the role of the solar controller which ensures the protection of batteries against surcharge as well as deep discharge. It also allows to be protected against a reverse current while ensuring the temperature control; this is why the charge controller should always be installed next to the batteries. This charge controller will be sized according to the following parameters:

- The nominal voltage U: is the battery voltage: 12 V.
- The maximum current of the charge controller I_e: is the maximum operating current of the generator. It must be backed easily by the charge controller. To estimate the current, we take a coefficient of 1,5 to ensure a safety margin. As a result, for the maximum current $I_{max} = 4.6$ of the PV panel, I_e is nearly 7 A. As standard value, we choose $I_e = 10$ A [36].
- The output current $I_s = 10$ A [36].

Considering the above, we opted for the type of charge controller STECA PRS 1010 Solarix 10A-12V whose technical specifications are summarized in table 8 [36].

Table 8. Characteristics of the selected charge controller STECA PRS 1010 Solarix 10A-12V [36]

Parameters	Voltage of the system	Own consumption	Open-circuit voltage of PVG	Input current	Battery voltage	Output current
Value	12 V	< 4 mA	< 47 V	10 A	9 à 17 V	10 A
Parameters	End-of-charge voltage	Fast charge voltage	Equalisation charge	Reclose reference point (LVR)	Deep discharge protection (LVD)	
Value	13.9 V	14.4 V	14.7 V	12.4 to 12.7 V	11.2 to 11.6 V	

5. ECONOMIC EVALUATION OF THE PROJECT

In order to carry out and to justify the chosen solution in our technical study of the street lighting system of Dcheira-El Jihadia municipality, an economic study is required. This is covered in some detail in this section.

In order to get a sense for the amount of the investment for the PV system, we start by calculating the original investment. This calculation is based on the price of each component of the installation while integrating the installation cost of the lights. Then, we determine the annual cost of energy consumption using basic data. In fact, this data is the product of operating hours, the power consumption and the unit cost. Finally, we estimate the annual operating cost after calculating the annual cost of maintenance.

5.1. Original Investment

It is defined as the sum of the acquisition cost and the labour cost for the installation. Indeed, the PV system materials is about 905 830 MAD, while the labour is approximately 5 250 MAD. Whereas the cost of equipment of the conventional installation did not exceed 391 700 MAD, with a labour cost of the installation of approximately 15 750 MAD.

5.2. Annual cost of the energy consumption

The cost of annual energy consumption is the product of total power of the lamps by the lighting hours per year (4530h) and the price of the Kilowatt-hour (1,11071 MAD). This average annual cost for the conventional installation is about 69 200 MAD. In the case of PV system where consumption is free, the equivalent of annual cost is about 18 000 MAD.

5.3. Annual operating cost

It includes the annual cost of energy consumption C_a and the annual cost of maintenance C_m which corresponds to the replacement cost. The conventional system has generated a significant cost of about 73 280 MAD, which C_m is about 4 080 MAD. On the contrary, the operating cost for the PV system is only 14 250 MAD corresponding only to the annual cost of maintenance.

5.4. Total operating cost for 25 years

The operating cost is calculated for a given period. This period is considered as the maximum lifetime of PV panels, which is equal to 25 years [33-37]. For that purpose, we proceed first to update the prices according to the following equation [38]:

$$S_n = S_0 (1 + \tau)^n \tag{5}$$

with:

> S_n: The future value in year n.
> S_0:   The present value (here = 1.11071 MAD).
> n: Number of years to the future value.
> τ.   Discount rate (8%).

The total operating discounted cost will be 570 400 MAD for the conventional installation for a period n of 25 years and a discount rate τ of 8%. While for the PV system, it does not exceed 167 400 MAD. Table 9 summarizes the results of different cost calculation.

Table 9. Various components of the economic study of the project

Cost		Conventional installation (MAD)	PV installation
Of the annual energy consumption C_a		$E_c = 54\ 200.00$ kWh $p_{kWh} = 1.11071$ DH 69 200.00	0.00
Annual of maintenance	C_m	4 080.00	14 250.00
Total annual of operation	C_e	73 280.00	14 250.00
Total of operation for 25 years	C_{e25}	570 400.00	167 400.00

6.   RESULTS AND DISCUSSION

The technical and financial studies of street lighting system presented above have allowed us to compare the quantities of energy operated in the PV and conventional installations, which will lead us to substantial gain by substituting PV cells supply for conventional electricity supply. The results thus obtained are summarized in table 10. The energy consumed during 2015 for the conventional installation is in fact 54 200 kWh, whereas for PV system it does not exceed 16 300 kWh.

Table 10. Energy and financial gains obtained

	Annual consumption C_a	Total cost for 25 years C_{e25} (MAD)
Conventional installation	$E_{conv} = 54\ 200$ kWh	$C_{conv} = 570\ 400$
PV installation	$E_{PV} = 16\ 300$ kWh	$C_{PV} = 167\ 400$
Energy and cost savings	$(E_{conv} - E_{PV}) = \mathbf{37\ 900}$ kWh $(E_{conv} - E_{PV}) / E_{conv} = \mathbf{70\%}$	$C_{conv} - C_{PV} = \mathbf{403\ 000}$

According to table 10, we note that the solar street lighting system generates, during a 25 years period, a large gain of about 403 000 MAD corresponding to 70% of the budget and of energy savings compared to conventional system.

7.   CONCLUSION AND PERSPECTIVES

The investigations presented in this paper allowed us to study, analyze, design and compare the annual energy consumption, then the cost of two types of street lighting installation implemented or envisaged in a municipality of Agadir in Morocco. The two types are the conventional street lighting and that based on solar energy, especially the photovoltaic. According to the results, we can confirm the feasibility of substituting conventional street lighting technology for renewable energy sources such as PV. In fact, it's far more cost-effective both on the energy and economic levels. Indeed, following our study, the solar street lighting solution provides for the municipality, a large gain of about 70% of the public lighting budget, and of energy savings, compared to the conventional street lighting. In perspective, a monitoring application of energy efficiency of the solar street lighting installation will be developed.

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