Sustainable Energy Technologies and Assessments

Optimal design of grid-connected rooftop PV systems: An overview and a new approach with application to educational buildings in arid climates

--Manuscript Draft--

Manuscript Number:	
Article Type:	Full Length Article
Keywords:	Grid-connected Rooftop PV Systems; Optimal Design; Multi-criteria Decision Making; Geographical Information System; Techno-economic Assessment
Corresponding Author:	Charafeddine Mokhtara ALGERIA
First Author:	Charafeddine Mokhtara
Order of Authors:	Charafeddine Mokhtara
	Belkhir Negrou
	Noureddine Settou
	Abdessalem Bouferrouk
	Yufeng Yao
Abstract:	This paper presents a new design approach, for a robust design and evaluation of the techno-economic potential of grid-connected rooftop PV (GCR-PV) systems, focusing on educational buildings in arid environments. A university campus in Ouargla province in Algeria is selected as a test-bed in this work. The main objectives of this work are to reduce the cost of energy (COE), grid dependency and CO2 emissions, and even contribute to limit grid blackouts in the building location. Ecotect software, ArcGIS, and HOMER optimizer were therefore used to achieve the contributions of this work. The findings reveal that 60 % of the overall roof area is optimally suitable for hosting PV panels. Considering only this optimal area, multi-crystalline PV panels with an inclination of 17 ° yield the highest annual electricity output (2333.11 MWh/year). Based on this configuration, a sensitivity analysis is then performed to study the effects of feed-in tariffs (FITs) and the cost of components in the system outcomes. It is observed that with FITs less than those applied to large-scale PV projects in Algeria (0.11 $/kWh), the analyzed GCR-PV system has fulfilled high self-sufficiency, reaching grid parity (COE 0.043 $/kWh) and exporting significant amounts of electricity to the grid.
Suggested Reviewers:	JAVIER DOMINGUEZ BRAVO Javier.Dominguez@ciemat.es
	Mohamed Samy mohamed_227@hotmail.com
	Rui Castro rcastro@tecnico.ulisboa.pt
	Ramon Zamora ramon.zamora@aut.ac.nz
	Amanda D. Smith amanda.d.smith@utah.edu
Opposed Reviewers:	

To my dear the Editor-in-Chief of the Journal:

The authors wish to submit a new manuscript entitled **“Optimal design of grid-connected rooftop PV systems: An overview and a new approach with application to educational buildings in arid climates”**

We would like to have the manuscript considered for publication in *Sustainable Energy Technologies and Assessments Journal.*

The authors are confirming that this work is an original and has not been published elsewhere nor is it currently under consideration for publication elsewhere.

This paper presents a new design approach, which combines spatial analysis with techno-economic optimization for a robust design and evaluation of the technical and economic potential of grid-connected rooftop PV (GCR-PV) systems, focusing on educational buildings in arid environments. A university campus in Ouargla province in Algeria is selected as a test-bed in this work. The main objectives of this work are to reduce the cost of energy (COE), grid dependency and CO_2 emissions, and even contribute to limit grid blackouts in the building location. Ecotect software, ArcGIS, and HOMER optimizer were therefore used to achieve the contributions of this work.

The findings reveal that 60 % of the overall roof area is optimally suitable for hosting PV panels. Considering only this optimal area, multi-crystalline PV panels with an inclination of 17 ° yield the highest annual electricity output (2333.11 MWh/year). Based on this configuration, a sensitivity analysis is then performed to study the effects of feed-in tariffs (FITs) and the cost of components in the system outcomes. It is observed that with FITs less than those applied to large-scale PV projects in Algeria (0.11 $/kWh), the analyzed GCR-PV system has fulfilled high self-sufficiency, reaching grid parity (COE 0.043 $/kWh) and exporting significant amounts of electricity to the grid. Accordingly, the feasibility of the developed approach and the techno-economic viability of the GCR-PV system are both demonstrated.

Thank you for receiving our manuscript and considering it for review. We appreciate your time and looking forward to your response.

The corresponding author information:

Mr: Charafeddine Mokhtara

Tel.: +2136 59 70 41 66

E-mail address: mokhtara.chocho@gmail.com; charafeddine.mokhtara@univ-ouargla.dz; charaf92eddine@gmail.com

Highlights

- A robust design of a grid-connected rooftop PV system is performed.
- The impacts of key parameters on economic performance are investigated.
- Ccomparison between incentive policies is discussed.
- Sensitivity analysis on FIT and components' costs is investigated.

Graphical Abstract

Optimal design of grid-connected rooftop PV systems: An overview and a new approach with application to educational buildings in arid climates

Word Count (7421)

Charafeddine Mokhtara[a,b*], Belkhir Negrou[a], Noureddine Settou[a], Abdessalem Bouferrouk[c], Yufeng Yao[c]

[a] Laboratory Promotion et Valorisation des Ressources Sahariennes (VPRS), Kasdi Merbah Ouargla University, BP 511, 30000 4 Ouargla, Algeria.

[b] Department of Mechanical Engineering, Kasdi Merbah Ouargla University, BP 511, 30000 4 Ouargla, Algeria.

[c] Department of Engineering Design and Mathematics, University of the West of England, Bristol BS16 1QY, U.K.

The corresponding author information:

Mr: Charafeddine Mokhtara

Tel.: +213659704166

E-mail address: mokhtara.chocho@gmail.com; charaf92eddine@gmail.com; mokhtara.charafeddine@univ-ouargla.dz

Optimal design of grid-connected rooftop PV systems: An overview and a new approach with application to educational buildings in arid climates

Charafeddine Mokhtara[a,b*], Belkhir Negrou[a], Noureddine Settou[a], Abdessalem Bouferrouk[c], Yufeng Yao[c]

[a] Laboratory Promotion et Valorisation des Ressources Sahariennes (VPRS), Kasdi Merbah Ouargla University, BP 511, 30000 4 Ouargla, Algeria.

[b] Department of Mechanical Engineering, Kasdi Merbah Ouargla University, BP 511, 30000 4 Ouargla, Algeria.

[c] Department of Engineering Design and Mathematics, University of the West of England, Bristol BS16 1QY, U.K.

The corresponding author information: Mr: Charafeddine Mokhtara

Tel.: +213659 70 41 66; E-mail address: mokhtara.chocho@gmail.com, charaf92eddine@gmail.com, mokhtara.charafeddine@univ-ouargla.dz

ABSTRACT

Recently, rooftop photovoltaic (PV) systems are widely deployed due to their technical, economic and socio-environmental benefits. This paper presents a new design approach, which combines spatial analysis with techno-economic optimization for a robust design and evaluation of the technical and economic potential of grid-connected rooftop PV (GCR-PV) systems, focusing on educational buildings in arid environments. A university campus in Ouargla province in Algeria is selected as a test-bed in this work. The main objectives of this work are to reduce the cost of energy (COE), grid dependency and CO2 emissions, and even contribute to limit grid blackouts in the building location. Ecotect software, ArcGIS, and HOMER optimizer were therefore used to achieve the contributions of this work. The findings reveal that 60 % of the overall roof area is optimally suitable for hosting PV panels. Considering only this optimal area, multi-crystalline PV panels with an inclination of 17 ° yield the highest annual electricity output (2333.11 MWh/year). Based on this configuration, a sensitivity analysis is then performed to study the effects of feed-in tariffs (FITs) and the cost of components in the system outcomes. It is observed that with FITs less than those applied to large-scale PV projects in Algeria (0.11 $/kWh), the analyzed GCR-PV system has fulfilled high self-sufficiency, reaching grid parity (COE 0.043 $/kWh) and exporting significant amounts of electricity to the grid. Accordingly, the feasibility of the developed approach and the techno-economic viability of the GCR-PV system are both demonstrated.

Keywords: Grid-connected PV Systems; Rooftop; Optimal Design; Multi-criteria Decision Making; Geographical Information System; Techno-economic Assessment.

Abbreviations

AC	Alternative current
CAD	computer-aided design
CO2	Carbon dioxide
COE	Cost of electricity
C_T	Investment costs
DC	Direct current
FIT	Feed-in tariffs
FS	First solar company
FS	First Solar Company
GCR-PV	Grid-connected rooftop PV
GIS	Geographical information system
HRES	hybrid renewable energy system
HVAC	Heat ventilation and air conditioning
LiDAR	Light (Laser Imaging) Detection And Ranging
MOPSO	multi-objective particle swarm optimization
PV	Photovoltaic
SC	Self-consumption
S_{PV}	Net savings with PV only
S_{PV-BS}	Net savings with PV and Battery
TS	Trina solar company
TS	Trina Solar Company
USA	United States of America
WT	Wind turbine

1.Introduction

1.1.Background and motivation

Today, buildings use more than 40 % of the global generated energy [1]. In Algeria, in specific in last decade, the electricity demand of the building sector has been increased rapidly, by 8.3 % annually, which makes this sector account for 43% of total electricity consumption [2]. The main reasons are the rapid growth of consumers, whose total number has exceeded 9.6 million by 2018[3]. Besides, as 97 % of the generated electricity is derived from natural gas (fossil fuel) [4], buildings responsible for a high fraction of CO2 emissions. The Algerian Government must therefore act quickly in order to face up to the coming technical, economic and environmental challenges, in particular to guarantee the necessary demand for electricity and to prevent a power outage[5] specifically in arid environments where the strong use of air conditioners in very hot periods in Summer [6]. In the meantime, they will save their fossil fuel reserves and reduce their carbon footprint. With a rapid decrease in the cost of PV modules [7] versus an increase in their efficiency[8] and assuming that 99 % of Algerian buildings have been connected to the grid [9], grid-connected rooftop PV (GCR-PV) systems could be the key solution for sustainable energy transition in the country. However, the optimal design of such systems is a major challenge, especially for existing buildings that did not consider the integration of renewable based-supply systems in their first stage of design.

1.2.Bibliometric analysis of GCR-PV systems

In this paper, a Bibliometric analysis is first carried out on the design optimization of GCR-PV systems. Such a type of analysis is not used before by researchers in this field of research. The authors have done this research on the Elsevier Database (the only free source available to authors) by introducing three keywords (Grid connected PV system, rooftop and optimal design). After the research has been completed, 930 papers, including original and review papers, have been found. However, after doing filtering (after reading their titles and abstract), only 120 papers are selected and exported to the VOS viewer and Gephi software as RIS format for performing the analysis. It is observed that most papers have been published in the journal Renewable and Sustainable Energy Reviews (26), followed by Renewable Energy (20), Solar Energy (18), Applied Energy (12) and Energy (10). In addition, only three papers are published before 2010 and 95 of them after 2015. The maps obtained from the VOS viewer are given in Fig.1 and Fig.2.

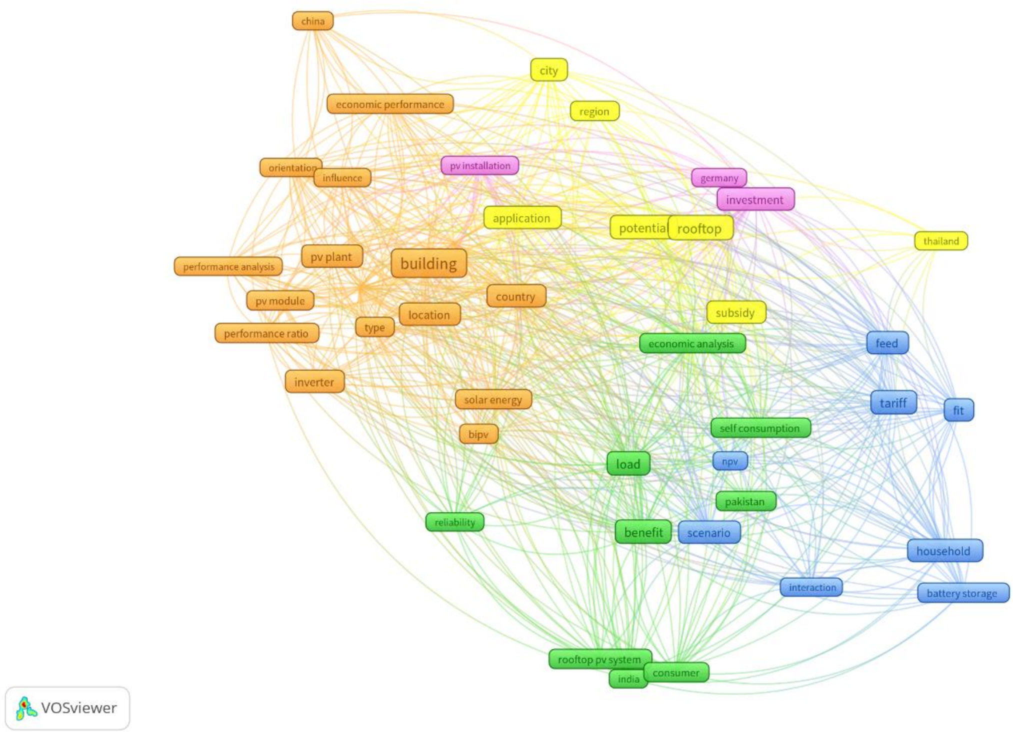

Fig. 1 Bibliometric analysis results (from VOS Viewer).

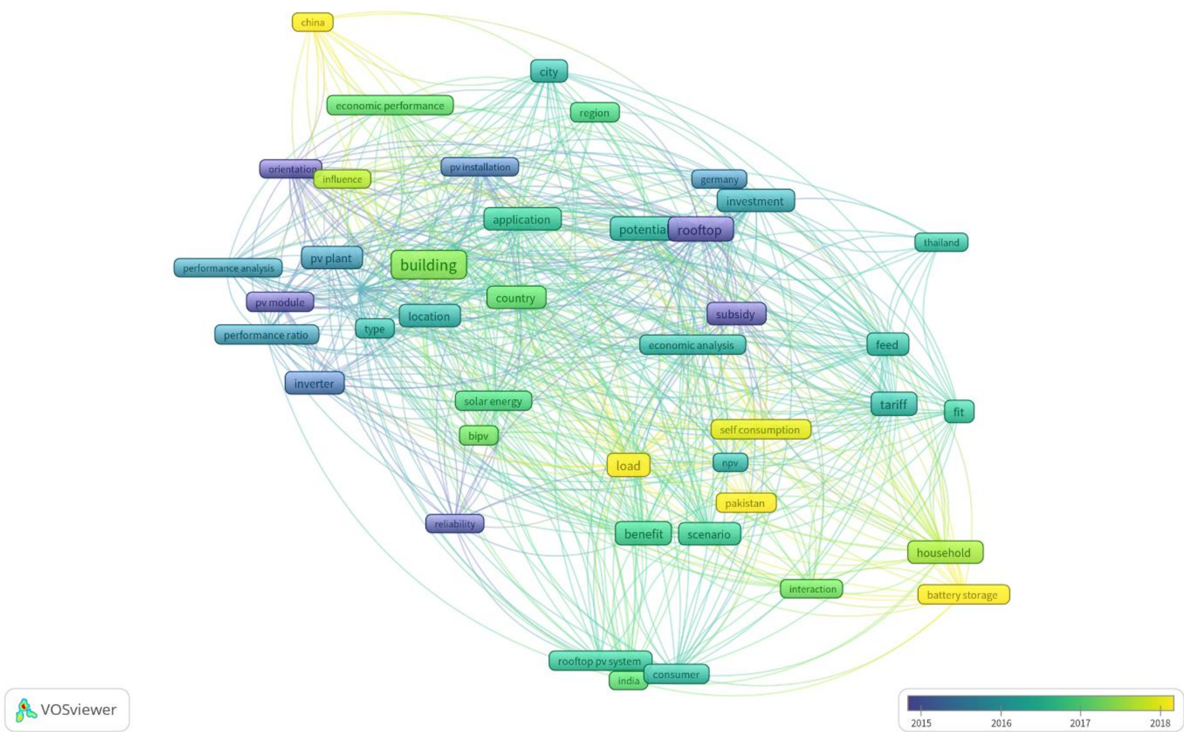

Fig. 2 Bibliometric analysis results with time evolution (from VOS Viewer).

According to the obtained maps (from VOS Viewer), the design optimization of rooftop PV systems includes mainly the evaluation of their technical potential (as presented by keywords like performance analysis, orientation, type of PV module, location, building load, reliability, and grid interaction), and assessing their economic potential (concluded from key words like economic analysis, investment, net present value (NPV), subsidy (including self-consumption and feed-in tariffs)). In addition, rooftop PV systems are discussed at building-scale (mostly for households) and city-scale, and in developed countries (as Germany and China) or developing countries (Pakistan, Thailand, and India). Besides, recently (from 2018), there is a transition from feed-in tariffs policy (that is firstly applied in some developed countries as Germany) to self-consumption schemes (as in Pakistan) by using battery storage. Hence, after reading the most important papers accordingly, the literature review section is developed to point the reader gradually to the main research gap.

1.3.Literature review on GCR-PV systems' design

1.3.1.Technical potential assessment of GCR-PV systems

The technical potential assessment of GCR-PV systems involves, in particular, the selection of suitable roofing areas for PV panel mounting and then the improvement of the PV system energy output [10]. The majority of recent works are dedicated to the implementation of rooftop PV systems on a city level (also called solar cities) rather than for an individual building. A review of the concept of solar cities and techniques used for assessing roof solar potential in cities is given [11]. For instance, the Light Detection and Ranging data (LiDAR) is used in[12,13] to estimate the technical potential of a roof-mounted PV system in urban areas. Similar work is carried out in[14–16], but geographic information systems (GIS) based-approaches are used instead of LiDAR. As an alternative to costly LiDAR methods, alternative methods for estimating the performance of roof-mounted PV installations is proposed in [17,18]. Contrary, in [19], both GIS and LiDAR data are used in combination. It is concluded in some previous works as in [20] that estimating the potential of a rooftop PV system within a city level is necessary to make best decisions in primary design stages. However, accurate estimations cannot be attained without making deep analysis at each type of building separately. In this context, the performance of the building- PV roofing system located in Italy is carried out in[21]. The design optimization of rooftop PV installation at existing building is carried out in [22], considering shading effects and PV module's orientation. The authors in [23] examined the technical performance of roof-mounted PV systems for school buildings in Kuwait. Besides, the economic analysis of a solar PV system at residential buildings roofs is undertaken in[24]. A GIS-based optimization approach is proposed in [25] to optimally design of a rooftop PV system for a campus building. Similarly, the potential evaluation of a GCR-PV system for a University building is carried out by [26].

1.3.2.Economic potential assessment of GCR-PV systems

The economic potential assessment includes the determination of the size of the PV system, evaluate its energy costs and compare it to conventional sources, investigating local incentives (grid purchase and sell back costs, interest rates), etc. [10]. Until now, there have been different incentive policies adopted in many countries to promote GCR-PV systems, such as feed-in tariffs (FIT) and self-consumption (SC). Under the FIT policy that is mostly adopted in case of low electricity purchase rates, the consumers intend to reach grid parity and feed maximum surplus electricity into the grid [27]. Overview of rooftop residential installations with performance assessment of a GCR-PV system at a Palestinian residence case study is performed in [28]. In [29] the PV-battery system for an Australian residential home was economically assessed under the FIT policy. Similarly, the economic feasibility study of grid-connected GCR-PVs for residences with FIT policy is performed in [30] using HOMER software. The research conducted in [31]explores how FITs affect GCR-PV systems in Australian's buildings. The study of [32] investigated the techno-economic viability of GCR-PV systems for residential buildings in Thailand considering different incentives schemes. In [33], a techno-economic analysis was carried out for optimal design of a PV system considering Net Metering and FIT support mechanisms. In [34], the viability study of a rooftop PV system at a case study Mosque in KSA is carried out considering a FIT scheme. Recently, due to the increasing prices of electricity purchase rates in some countries, SC policies gained an increased interest [35,36]. In this case, we would have a Prosumers, which consume the maximum of their onsite produced electricity by GCR-PV and then feed excess electricity back to the grid [37]. Authors in [38] studied the feasibility of Prosumers with rooftop PV systems up to 2050. Meanwhile, [36] analyses the economic feasibility of electricity SC of the GCR-PV system in Thailand for different customers. The economic assessment of residential GCR-PV SC with batteries in French case until 2030 is investigated in [39]. A techno-economic feasibility analysis of three small GCR-PV SC systems located in different cities of Peru is undertaken in [40]. The technical and economic feasibility study of a rooftop PV system under the SC-policy for different building categories is investigated in [41]. Thermo-economic study of grid-connected rooftop photovoltaic systems for residential sector is performed in [42].

From the above literature, it is observed that the performance of GCR-PV systems can be influenced by many factors, including spatial factors (available area, shape, slope, and direction of rooftops, shading over roofs and between rows [43–45]), environment parameters (including solar radiation, wind speed, ambient temperature, and dust) and technical factors (the setting of PV rows, including their inclination angle, orientation, and arrangements). Also, selecting the PV technology, thin-film or crystalline silicon modules [8,46–48] has a significant effect on the performance of GCR-PV systems. The robust configuration of these systems is indeed important to achieve high reliability and minimize energy costs. Outside of this, none research is conducted in our knowledge to evaluate both the technical and economic potential of GCR-PV systems for non-residential buildings. Further, many factors that could affect the performance of GCR-PV systems are not taken into account in their analysis. Moreover, the majority of papers are performed at a city-scale rather than at the building level. In which, GIS tools and LiDAR data based approaches [49] are mostly used. However, carry out of spatial analysis on 3D buildings is difficult if using only GIS tools. Besides, LiDAR data are unavailable for many countries. Hence, the combination of GIS tools with CAD software [50] is suggested in such cases. On the other side, the economic assessment of GCR-PV systems is mostly performed for residential buildings. However, GCR-PV systems for residential consumers was found costly unattractive for developing countries (like Algeria) [51], because of many barriers, mainly, the high capital cost of small scale PV systems (less than 10 kW) [52], low retail prices and lack of FITs for small scale systems. Besides that, as residential buildings use more electricity outside of PV output periods, a large size of batteries that still very cost [53,54] is needed to enhance their SC [55]. Thus, more researches to foster deployment of GCR-PV systems should be conducted.

1.4.Novelty and contributions

This research article presents a new approach to the optimal design and the techno-economic potential assessment of GCR-PV systems for education buildings in arid climates, choosing a university campus in Algeria as a test-bed. The novelty of this work is the combination of spatial analyses with the technical-economic assessment to make the best decisions. Besides, this work is the first to make Bibliometric analysis and undertaken a sensitivity study to determine appropriate FITs for commercial-scale PV systems in Algeria. Minimizing the overall system cost, reaching grid parity, reduce power from the grid as well as CO_2 emissions, and the contribution of the studied building on limiting power blackouts in the location area during peak periods (Summer) are all investigated. Hence, this study has the following contributions:

1) Identify feasible rooftop zones for hosting PV panels.
2) Determine the best PV technologies for the building based on the simulation results.
3) Techno-economic feasibility assessment of the grid-connected PV system with sensitivity analysis on FIT and components' costs.
4) Determine the required incentive policies to promote GCR-PV systems in Algeria.

2.Methodology and case study inputs

In this study, a new approach is developed for the optimal design of a GCR-PV system for a university campus in Ouargla, Algeria. First, a map of the building (from Google-Earth) is exported, separately, to ArcGIS to perform spatial analysis, and to sketch up to create a 3D model of the building. Based on the developed 3D model, Ecotect software is used to evaluate shading effects and sunlight hours at each rooftop's zone for a one-year simulation. Hence, based on multi-criteria decision-making analysis carried out on ArcGIS software [56], the best zones for hosting PV panels are identified. Thus, the optimal PV system's configuration among various candidates is determined. Finally, the optimal sizing and techno-economic assessment of the GCR-PV system is performed using HOMER. Fig.3 shows the flow chart of the proposed approach.

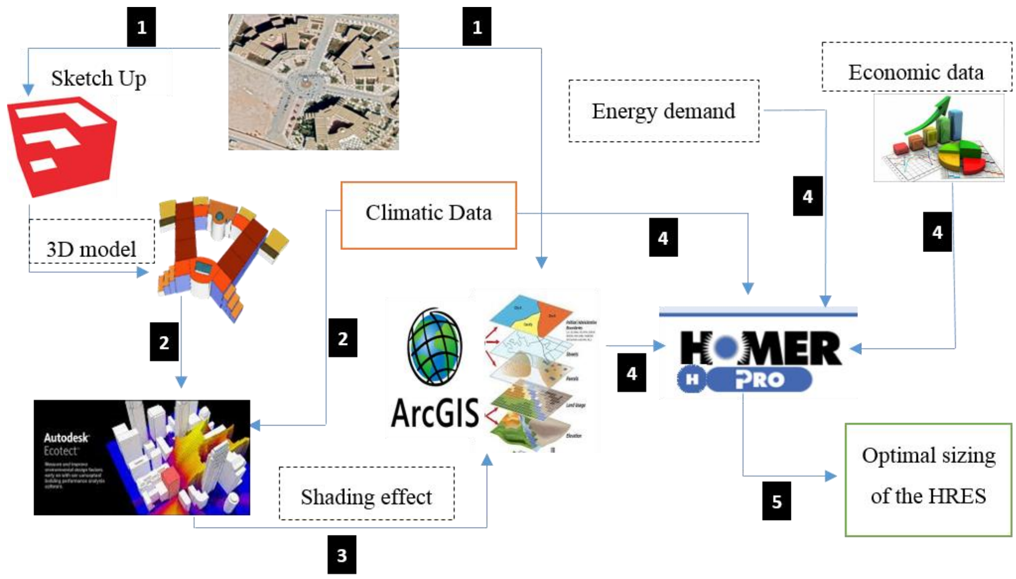

Fig. 3 Flowchart of the proposed approach.

2.1.Building description and climatic data

The education building under study (University campus) is located in an arid environment (hot dry climate), in Ouargla, south-east of Algeria [57]. The building constitutes of three faculties and has a total roof area of 18209 m² and annual energy demand of 1487.35 MWh/year. Fig. 4 and Fig. 5 shows the map of the building (from Google earth) and its load profile (as supplied by Sonelgas Company), respectively. The required climatic data for the building are collected from Meteonorm 7 database. Fig.6 gives the daily global radiation and hourly ambient temperature at Ouargla.

Fig. 4 Map of the University campus (from Google earth)

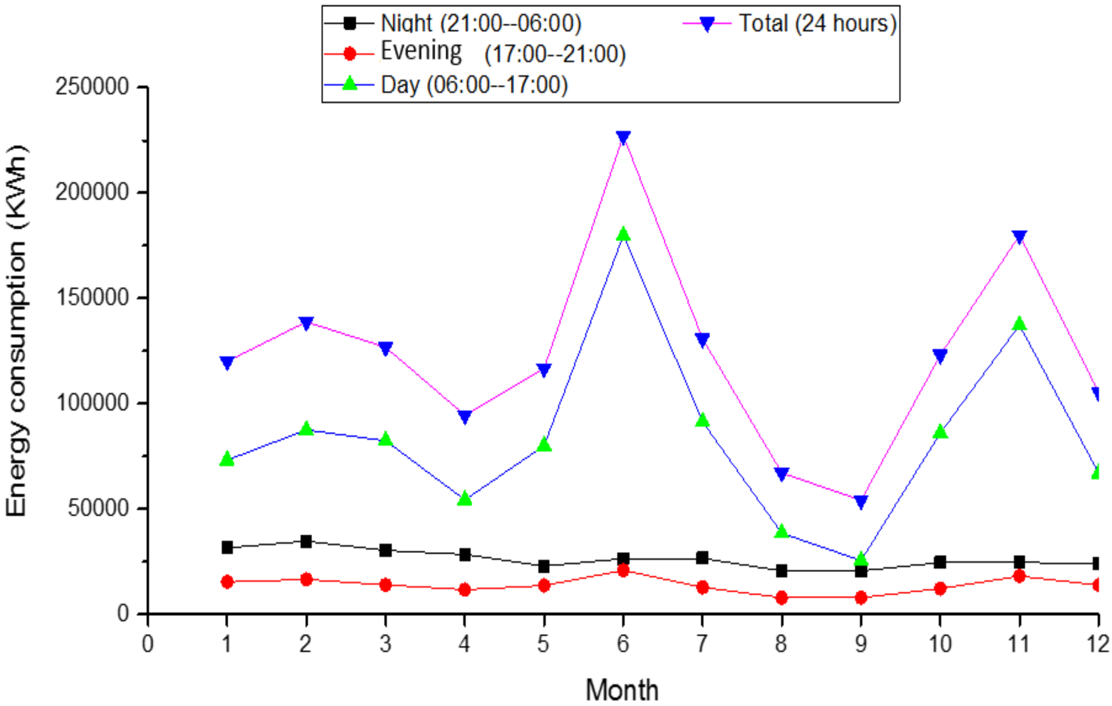

Fig. 5 Monthly load profile for the Building (from the Algerian electricity supplier, Sonelgas Company).

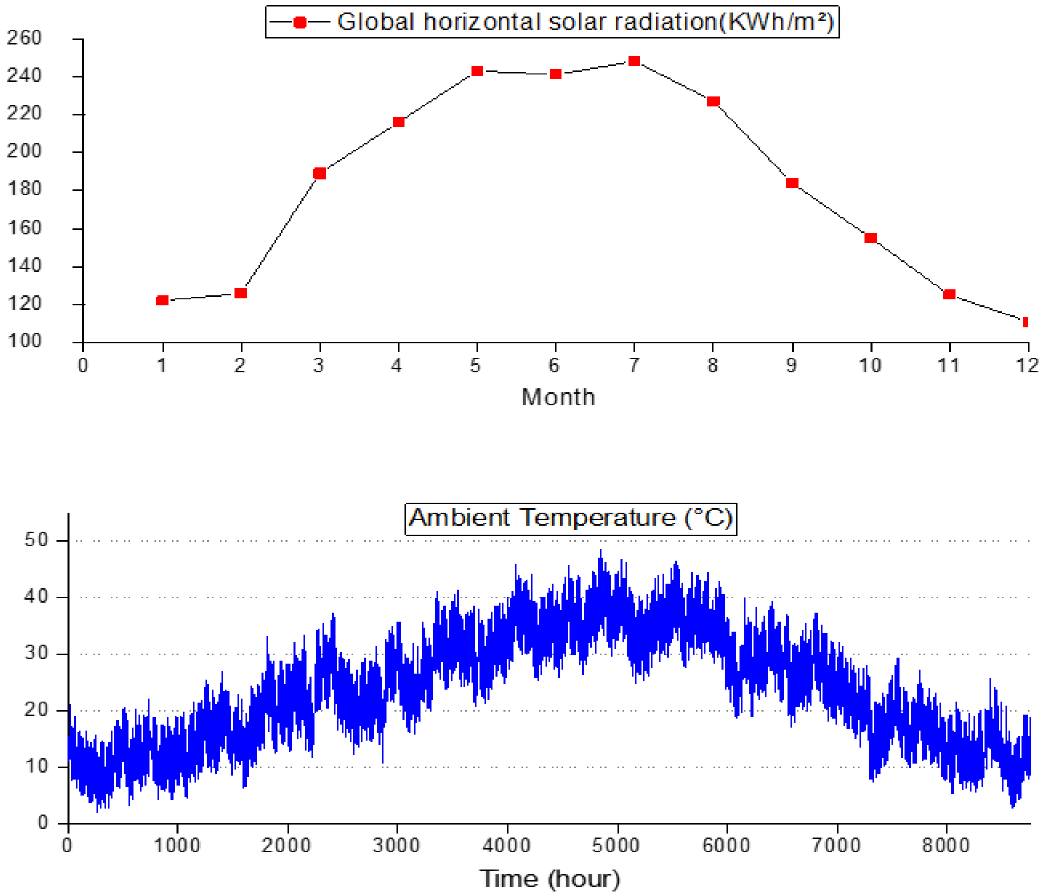

Fig. 6 Climatic data at Ouargla, Algeria (Extracted from Meteonorm 7).

2.2.Technical potential Assessment of the GCR-PV system

Solar potential represents the theoretical maximum amount of PV that can be deployed on the rooftop of buildings, which depends on different factors [58]. In the literature it is found that GIS and LiDAR methods are frequently used to assess the technical viability of city-level rooftop PV systems (macro scale), but CAD software are more effective in case of small spatial entities (building level) [59]. In addition, as many determining factors should be taken into account in the classification of spatial alternatives, a multi-criteria decision making (MCDM) analysis is often required to solve the problem. Hence, the combination of both tools, GIS and CAD software is a powerful technique to evaluate the technical potential of rooftop PV systems at building level, which is suggested in this work. The explanation for this developed approach is given as follows.

2.2.1.Sunlight duration and shading effect assessment

Owing to the existence of shading issue on building roofs, it is important to assess its impact on the availability of solar radiation in order to deduce the technical potential of rooftop PV systems[59]. Ecotect software that is mainly created for the design of zero energy buildings [59,60], it is used here to evaluate sunlight hours (i.e. number of hours when the zone is exposed to the sun) and exposer ratio (i.e. the percentage of maximum exposed area to the total area) at the building's roof for the whole year. For assessing these parameters, Ecotect is based on the created 3D model of the building (by Sketch up), solar radiation data and geographical information of the building. Besides, the inter rows shading effect is also evaluated in this work by calculating the minimum distance to avoid inter rows shading and to guarantee the ventilation (cooling) of the PV modules [61]. A simplified model based on PV module dimensions and sun height is used to evaluate the minimum distance, as shown in Fig. 7 [62].

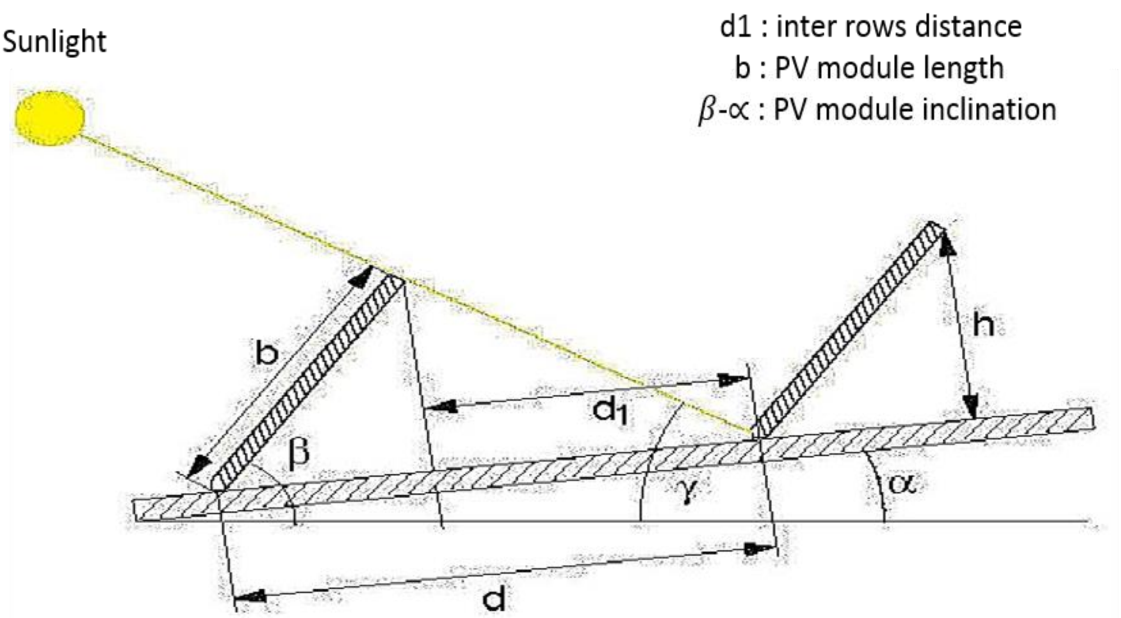

Fig. 7 Calculation of the minimum distance to avoid inter rows shading

2.2.2.Identifying optimal rooftop zones

Geographic information system software plays a key role in future analyses ; it enables us to monitor, evaluate and view the spatial distribution of all types of geographically referenced data [63]. ArcGIS software (V. 10.2) was used to select the best rooftop zones to install PV panels considering five evaluating criteria. Table 1 provides the description and weights of the five investigated criteria. After creating the raster maps of the five criteria, and based on their weights, a MCDM analysis [64] is performed using the Raster calculation toolbox on ArcGIS to solve the MCDM problem and hence classify and select best roof zones [65].

Table 1
Summary of evaluating criteria and their definition and weights.

Criteria	Definition	Weight (%)
Exposer Ratio	Is the ratio of the area exposed to the sun per entire area of the zone	30
Sunlight hours	Is the number of hours when the zone is exposed to sunlight	30
Shape Factor	Or architectural suitability of roof areas to install PV panels, which influenced by the shape of the zone, and what includes inside (Domes…)	20
Available Area	Is the area available for use in the zone	15
Wind speed intensity	Wind speed is needed for refreshing PV panels, as the performance of PV panels is reduced with high temperatures. As known, wind speed is a function of the zone's height.	5

2.2.3.Select best configurations

To select the best PV system installation, many factors are considered in this work, including PV panels' technology, the inclination angle of PV panels and the available area on the obtained optimal zone as found in the previous sub-section. Two different PV technologies are considered, multi-crystalline and CdTe thin-film modules, as mentioned above. The second factor is the inclination angle of PV panels, in which, three inclination angles are considered: 17°, 47°, and 32°; these represent the optimum tilt angles (in which the highest energy can be produced by PV modules) at the studied location in the summer period, winter period, and the overall year, respectively. The last parameter is the total area of the obtained optimal zone, which only considered for hosting PV panels. Hence, the maximum allowed capacity that can be installed in the obtained optimal zone is determined for each configuration. Finally, the best installation for the PV system (That yields to the highest annual energy produced) is determined.

2.3. Economic potential assessment of the GCR-PV system

2.3.1. HOMER simulation

HOMER is a powerful tool developed for optimizing energy supply systems design in all sectors and for both off-grid and grid-connected applications [66–68] by determining the optimal size of components through carrying out the techno-economic analysis. HOMER performs the calculations according to three levels [69], starts by simulating energy systems, shows system configurations optimized by cost, and provides sensitivity analyses.

2.3.2. Simulation of the GCR-PV system in HOMER

The investigated GCR-PV system as shown in Fig. 8, includes PV modules, battery, electricity grid, and an inverter which is designed using HOMER to meet the electricity demand of a University campus.

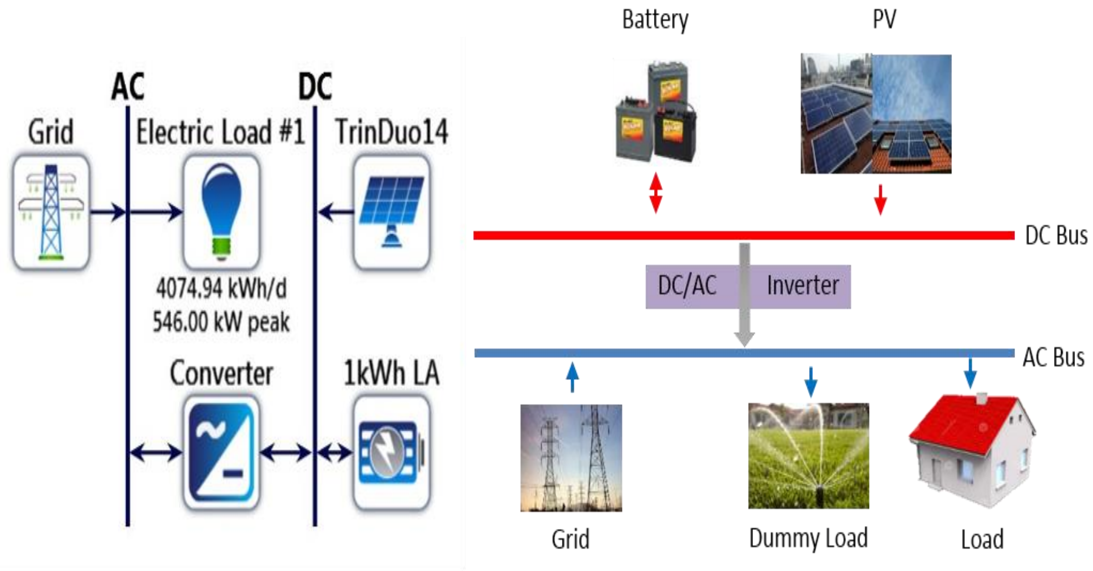

Fig. 8 Schematic of the GCR-PV system.

In this work, the system is simulated and optimized based on the parameters of the case study building, and based on the results of previous sections. Here, the system was evaluated based on many technical, economic and environmental criteria. Besides that, a sensitivity analysis was carried out on components costs and electricity sell price to study their effect on system feasibility and the achievement of grid parity. The main steps of the techno-economic assessment of the system under study in this work are presented in Fig. 9.

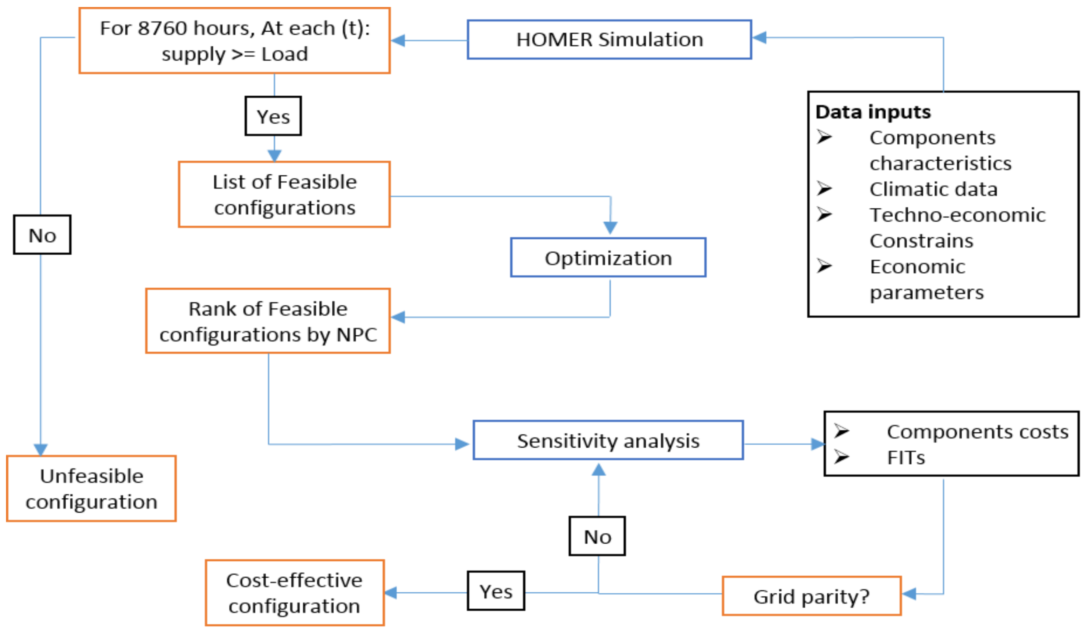

Fig. 9 Main steps of the applied strategy for techno-economic assessment of the Grid-connected PV system.

As mentioned before, only the best PV system (i.e. ranked first) from the discussed configurations, is considered for this analysis. Three, different scenarios are investigated to achieve the objectives of this work. To control the energy flows between systems components and organize the operation between them, the Load following (LF) dispatch control strategy was used in this work. Under the LF control strategy, supply sources, including storage components, are required to generate sufficient energy to meet the required demand at the lowest possible cost. Within this dispatch strategy, the PV system can export excess electricity to the grid if it is financially beneficial.

The description and modelling of the evaluating criteria and system components are provided in following parts.

2.4.Components modelling

2.4.1.Solar PV

The electric output power of the PV module is evaluated using eq.1 as follows [70].

$$P_{pv} = P_{Npv} \times \frac{G}{G_{STC}} \times \left[1 + K_t \times \left(\left[T_{amb} + \frac{NOCT-20}{800}\right] \times G - T_{STC}\right)\right] \qquad (1)$$

where Ppv and PNpv are the output power and rated power of PV module respectively, G and Tamb are the solar radiation and ambient temperature at a time step of the simulation, Gref (1 kW/m²) and Tref (25°C) are solar radiation and ambient temperature at standard conditions, Kt is the temperature coefficient of power which depends on PV's panel technology, and NOCT (nominal operation cell temperature). Two different technologies are considered including thin-film modules of First-Solar (FS) and multi-crystalline modules of Trina-Solar (TS)). These two technologies are provided by manufacturers listed on the top ten PV manufacturers in the world [8]. The characteristics of the selected PV modules are given in Table 2.

Table 2
The manufacturer's datasheet of selected modules.

Manufacturer	Trina Solar (TS)	First Solar (FS)
Model	DuoMax PEG14-320	FS-4107A-2
Technology	Multi-crystalline	CdTe
Efficiency (%)	16,3	14,9
Nominal Power (Wp)	320	107,5
Temperature coefficient of Power (%/°C)	-0,41	-0,34
Length (m)	1,96	1,2
Width (m)	0,992	0,6

2.4.2.Battery storage (BS)

Batteries are used to store excess electricity from PV panels. The state of charge of BS is evaluated according to discharge and charge mode and can be assessed by eq.2-3 respectively [71,72].

$$E_b(t+1) = E_b(t) \times (1-\sigma) - \left(\frac{E_l(t)}{\eta_{cnv}} - E_g(t)\right) \times \eta_{BD} \quad (2)$$

$$E_b(t+1) = E_b(t) \times (1-\sigma) + \left(E_g(t) - \frac{E_l(t)}{\eta_{cnv}}\right) \times \eta_{BC} \quad (3)$$

The operation of BS depends on charging and discharge limits, depth of discharge (DOD) and solar energy availability. This means that the BS must operate according to the permissible SOC limits specified by each manufacturer and for a DOD that depends on battery technology. The operation of the BS can be expressed by eq.4 as follows:

$$Eb_{min} \leq Eb(t) \leq Eb_{max} \quad \text{Or} \quad Eb_{min} = (1 - DOD) \times Eb_{max} \quad (4)$$

where El(t) and Eg(t) are the energy demand and the generated power by renewable sources (solar PV), respectively, $\boldsymbol{\eta}$BD and $\boldsymbol{\eta}$BC represent the discharge and charge efficiencies of the battery. The term σ is the self-discharge of the battery which is neglected in this study, and $\boldsymbol{\eta}$cnv is the converter's efficiency.

In this study, Lead-acid (L-acid) batteries are used as there large availability in the Algerian local market and can be used for large scale applications. L-acid batteries are the oldest and most widely used rechargeable electrochemical devices. Besides, Lead-acid batteries have a low cost ($300–600/kWh), and high reliability and efficiency (70–90%) [73].

2.4.3.Grid

When the PV system and storage devices are not sufficient to supply the load, the grid is used to supply the deficit power. In Algeria, the purchase price of electricity (EPR) is 0.045 $/kWh. However, there is no incentive schemes for commercial and residential scale PV systems. Therefore, we have suggested different values for FITs similar or less than existing FITs in Algeria for large scale applications.

2.4.4.Inverter

An inverter converts the DC power from solar PV array output into 50 or 60 Hz AC power [74].

2.5.Economic evaluating criteria

In order to assess the economic viability of the GCR-P system under investigation and to compare the feasible configurations, the following economic indices, including the net present costs (NPC), cost of energy (COE), internal rate of return (IRR), return on investment (ROI) and the payback period (PB) have been used..

2.5.1.NPC and COE

HOMER computes the total net present cost (NPC) by determining the present value of all costs associated by the system throughout its working life, minus present value of all revenues gained (including grid sales income and salvage) by the system at the same period. Costs involve capital investment, replacement, operation and maintenance (O&M) expenses and grid buying costs t. HOMER is based on the NPC to optimise to system and rank the possible solutions. Besides, based on the total annualized cost and NPC or CRF (capacity recovery factor), the cost of energy (COE) was calculated by dividing the total annualized cost by the total electric load served. NPC and COE are defined by the eqs. 5-13 [75–78].

$$NPC_{tot}(\$/KWh) = \frac{C_{A\_tot}}{CRF} \quad (5)$$

$$C_{A\_tot}(\$/year) = C_{A\_cap} + C_{A\_O\&M} + C_{A\_rep} + C_{Grid\_purchase} - C_{Grid\_sold} \quad (6)$$

$$C_{A\_tot}(\$/year) = C_{A\_cap} + C_{A\_O\&M} + C_{A\_rep} + C_{Grid\_purchase} - C_{Grid\_sold} \quad (7)$$

$$C_{A\_cap}(\$) = (P_{Npv} \cdot C_{PV} + Eb_{max} \cdot C_{BS} + P_{Cnv} \cdot C_{Cnv}) \times CRF \quad (8)$$

$$C_{A\_O\&M}(\$) = 0.02 \times (C_{PV} + C_{BS}) \times \sum_{k=1}^{T} \frac{1}{(1+j)^k} \times CRF \quad (9)$$

$$C_{A\_rep}(\$) = \left(Eb_{max} \times C_{BS} \sum_{k=10}^{T} \frac{1}{(1+j)^k} + P_{Cnv} \times C_{Cnv} \sum_{k=15}^{T} \frac{1}{(1+j)^k} \right) \times CRF \quad (10)$$

$$C_{Grid\_purchase} = EPR \times E_{Grid\_purchase} \times CRF \quad (11)$$

$$C_{Grid\_sold} = ESR \times E_{Grid\_sold} \times CRF \quad (12)$$

$$CRF = \frac{i(1+i)^T}{(1+i)^T - 1} \quad (13)$$

Here, $E_{Grid\_purchase}$ and E_{Grid_sold} are the energy purchased and sold from/to the grid, respectively. $C_{Grid\_purchase}$ and C_{Grid_sold} are the prices of electricity purchased and sold from/to the grid, respectively. EPR and ESR are the electricity purchase rate and the electricity sell rate (FIT), respectively. C_{PV}, $C_{BS,}$ and C_{Cnv} are the capital cost of PV, BS, and converter, respectively. C_{A_cap}, $C_{A\_O\&M}$, $C_{A\_rep,}$ and C_{A_tot} are the annualized capital, operation, and maintenance, replacement cost, and total annualized cost, respectively. P_{Npv}, P_{Cnv} is the rated capacity of PV and converter, respectively. CRF is the capacity recovery factor, T and i are the project lifetime and the real interest rate, respectively. E_{served} [kWh/year] is the total electrical load served (includes the energy served the primary load as well as the energy sold to the grid).

2.5.2.Return on investment

Return on investment (ROI) is a profitability ratio that calculates the profits of an investment as a percentage of the original cost. RIO can be calculated by using the simple formula of eq. 14.

$$ROI\ (\%) = \frac{\text{Investement revenue} - \text{Investement cost}}{\text{Investement cost}} \quad (14)$$

2.5.3.Internal rate of return

The interest rate of return (IRR) is an economic indicator that has always had to compare the profits of projects. The IRR is the interest rate that renders the NPC zero, as specified in eq. 15. The most beneficial project to be undertaken is that of the highest IRR.

$$NPC = \sum_{n=1}^{N} \frac{C_n}{(1+IRR)^N} - C_0 = 0 \quad (15)$$

Given that Cn are the future cash flows from an investment, C_0 is the initial investment, n is the number of year, N the project lifetime.

2.5.4.Simple payback

HOMER calculates payback (PB) for comparing one system with another. In general, payback tells you how many years it takes to recover an investment. In other words, PB is the number of years it takes for the cumulative income to equal the value of the initial investment. For our system, the payback period is the time required to recover the investment on the solar PV and BESS project [29].

The PB period for only grid-PV systems can be calculated by the eq.16 as follows:

$$PBP_{PV}(year) = \frac{C_T}{S_{PV}(T)} \quad (16)$$

And that of for the grid-PV-battery systems can be calculated by the eq.17:

$$PBP_{PV-BS}(year) = \frac{C_T}{S_{PV-BS}(T)} \quad (17)$$

Where SPV or SPV-BS (expressed in $/year) are the cost of the annual energy saving resulting from the utilization of PV or PV-Battery electrical energy instead of the electricity bought from the utility grid [79]. CT is the initial cost of the PV or PV-Battery system.

2.6.Techno-environment evaluating criteria

2.6.1.Capacity shortage fraction

HOMER uses the capacity shortage fraction to evaluate the reliability of the system. The capacity shortage fraction is equal to the total capacity shortage (E_{CS_tot}) divided by the total electrical demand (E_{demand}) as given by eq.18. HOMER considers a system feasible (or acceptable) only if the capacity shortage fraction is less than or equal to the maximum annual capacity shortage (MACS). The value of the MACS is defined by the user and must be low as possible (mostly less than 1-5 %).

$$CSF(\%) = \frac{E_{CS\_tot}}{E_{demand}} \quad (18)$$

2.6.2.Renewable fraction

The renewable fraction is the fraction of the energy supplied to the load from renewable energy sources. In the present case study system, the renewable fraction (RF) is estimated using the eq.19.

$$RF(\%) = 1 - \frac{E_{Grid\_purchase}}{E_{served}} \quad (19)$$

2.6.3.Self-sufficiency

Consumers aim to improve this rate to limit grid dependency and then ensure they are self-sufficient in terms of electrical energy. Hence, the Self-sufficiency ratio (SSR) was defined as given by the eq.20.

$$SC(\%) = \frac{\text{Used generated renewable energy}}{\text{Energy consumption}} \quad (20)$$

2.6.4.Net energy purchased and net CO2 emission

This parameter represents the balance between the energy sold and purchased from the grid. To evaluate their value, HOMER subtracts the amount of electricity sold to the grid from those purchased from it. Therefore, its value is negative if the system export higher electricity to the grid than import from it. In this case, an energy plus balance was achieved, we would have energy plus building [80].

2.6.5.Grid parity

Grid parity is defined as the threshold at which a grid connected renewable energy-based system supplies electricity to the end-user at the same price as grid-supplied electricity [81]. This factor was taken into account to evaluate the economic feasibility of the GCR-PV system under study.

2.7.Simulation scenarios

2.7.1.First scenario

In this first scenario, we have used the characteristics of components, which are currently available as reported in the literature [82–87]. In addition, we have to assume that electricity sell price (ESP) or FIT equal to EPR (0.045 $/kWh) as there are no FITs for commercial-scale PV systems in our country. In this situation, we have followed a Net-metering option. The characteristics of the system components that are used in this work are summarized in Table 3.

Table 3
Characteristics of system components (first scenario).

Generation source	Parameters	Specification
Solar PV	Capital cost ($/kW)	1500
	O&M cost (% of Capital cost)	2
	Temperature coefficient of power (%/°C)	-0.41
	Lifetime (Year)	20
Battery (L-acid)	Capital/replacement cost ($/kW)	300
	O&M cost (% of Capital cost)	2
	DOD (%)	80
	Discharge efficiency	90%
	Charge efficiency	100%
	Lifetime (Year)	10
Converter	Capital/ Replacement cost ($/kW)	300
	Efficiency (%)	96
	Lifetime (Year)	15
Economic parameters	Project lifetime (Year)	20
	i (real interest rate) (%)	5.88
	EPR($/kWh)	0.045
	ESR($/kWh)	0.045

2.7.2.Second scenario

This scenario represents sensitivity analysis applied to the investment cost of components, including PV modules and batteries. This scenario is suggested as the costs of these components was rapidly decreased in the last years. Here, we consider that the capital cost of the battery is expected to decline by half in the future to be 150 $/Kwh by 2030. Similarly to solar PV panels, we have assumed that the capital cost of the PV panels will be reduced with half to be 750$/kW next year. Besides that, ESR was set (0.03 $/kWh) lower than the EPR.

2.7.3.Third scenario

Here, using the same characteristics of the components that have been used in the first scenario, a sensitivity analysis is carried out on FITs rates to study their effect on COE and to determine the rates that reach grid parity in these buildings. Here, only the grid-PV system was investigated as grid-PV-battery was found not cost-effective higher rates of FITs (Higher than the EPR). The values of FITs that are used in this scenario are 0.045, 0.065, 0.085, and 0.095. These values are less than the minimum value of FITs for large scale (1-5 MW) consumers as launched by the Algerian government in 2014, which are in range (11.8 to 20.08 DZD/kWh or 0.10 to 0.17 $/kWh) [88]. It is noted that the conversion from DZD to USD is performed according to average exchange rates in 2019.

3.Results and discussion

3.1.GCR-PV system's technical potential assessment

3.1.1.Maps of evaluation criteria for assessing GCR-PV technical potential

Before doing MCDM, the maps for the five evaluating criteria are developed. In Fig. 10, the distribution of exposer ratio and sunlight hours (Hrs) are presented, which obtained by Ecotect software. Besides, Fig. 11 presents the maps for the available area, shape factor, and wind-speed intensity, which are developed in ArcGIS.

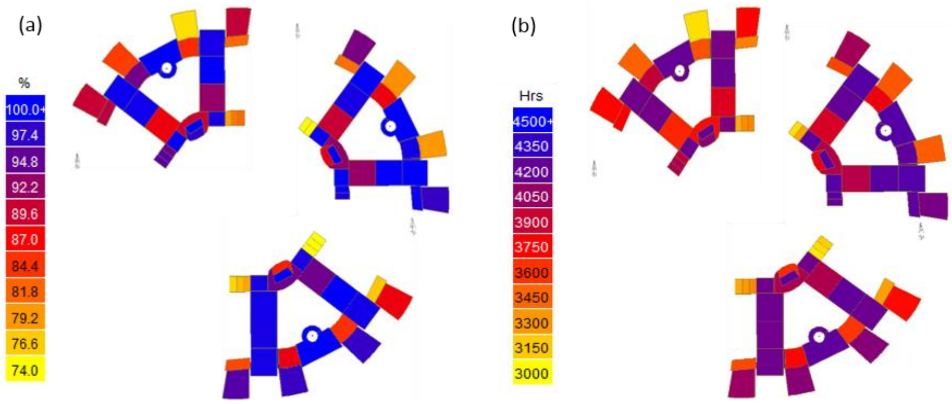

Fig. 10 Evaluating criteria; (a): Exposer ratio; (b) sunlight hours (from Ecotect).

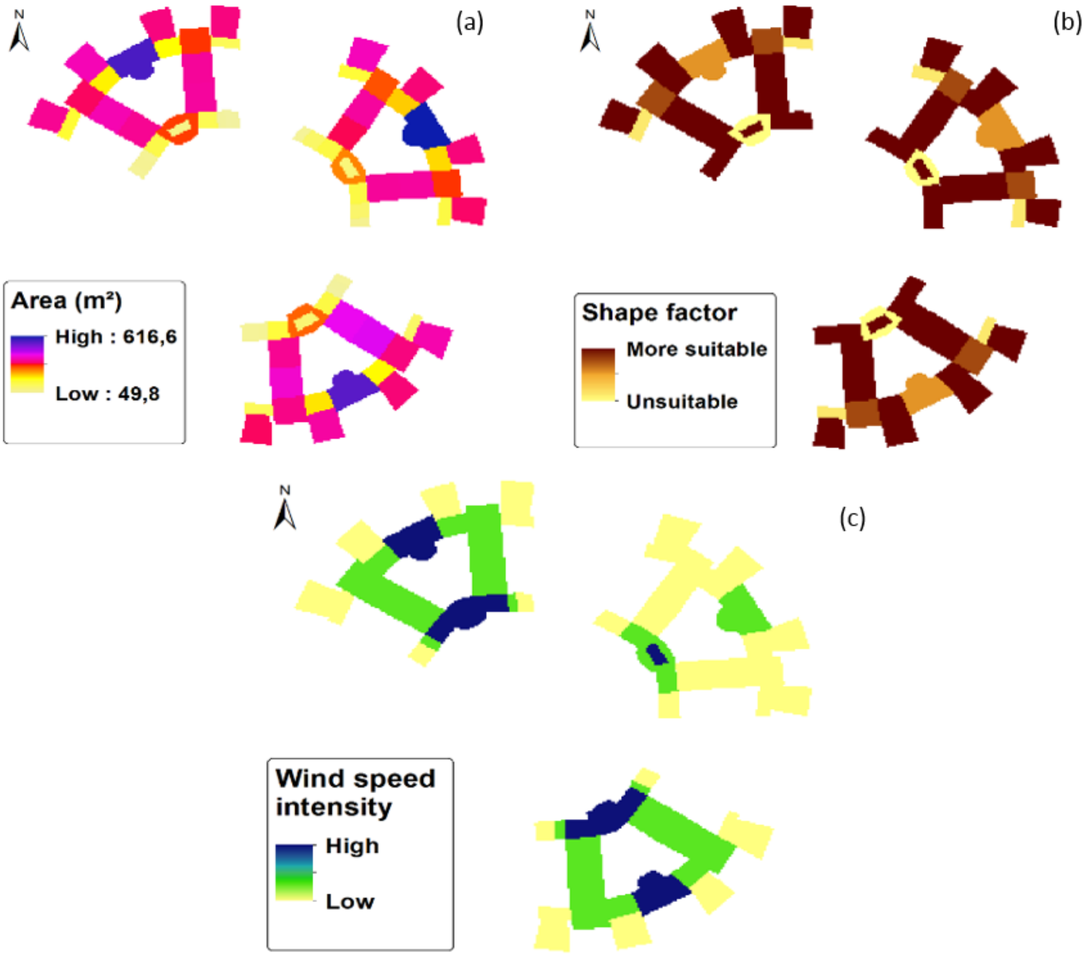

Fig. 11 Evaluating criteria; (a): area; (b) shape factor; (c) wind speed intensity (from ArcGIS).

It is shown that the exposer ratio and sunlight hours are not similar for all roof zones, because these zones have different height and orientation. The high rise zones can reach a value of exposer ratio of 100 % and sunlight hours above 4500 hours, which makes them the best among the other zones taking into account these two factors. However, some of these zones have small area and could present unsuitable shape. Thus, there are no zones dominant over other zones. Therefore, multi-criteria decision analysis is proposed to select the best zones for installing PV panels considering the above criteria.

3.1.2.Area suitability classification

Based on the created raster maps of the five evaluating criteria (influencing factors on PV modules' performance and setting) and their weights, an MCDM analysis for area classification within the building is carried out and the results are presented in Fig. 12.

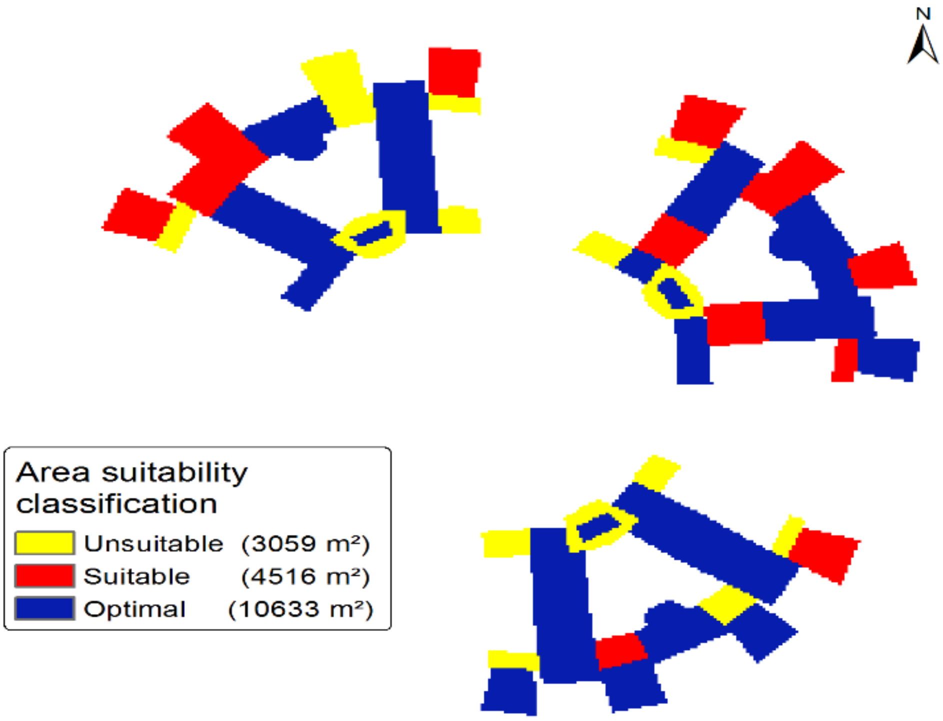

Fig. 12 Area suitability for installing PV panels on three buildings of the campus (from ArcGIS).

Results clearly show three categories of areas, with the optimal zones (of area 10633 m²) representing more than half of the total area of the building. These best zones are classified first among other rooftop zones, as they are better to other zones for the majority of the most influencing criteria such as shading effect and area characteristics (area and shape). Here, only the optimal zone area is selected for installing PV panels to benefit from its advantages and avoid energy and cost losses. Therefore, the maximum capacity of GCR-PV depends on the available area from this optimal zone. This information will be used in the following subsection to select the best PV system installation.

3.1.3.Selecting the best PV system installation results

Based on the results of area suitability, and as already mentioned before, only the optimal zone area is considered for installing PV panels. The results of the allowed capacity of each configuration, their annual generated electricity, and their ranking are presented In Table 4.

Table 4
Ranking of PV system installations.

Configuration	Required area per KW	Maximum allowable PV capacity (optimal zone) (KW)	PV output per KW (KWh/year)	PV total power (optimal zone) (MWh/year)	Rank
TS_17°	**8,12**	**1310**	**1781**	**2333.11**	**1**
FS_17°	9,04	1176	1804	2121.50	2
TS_32°	9,5	1119	1800	2014.20	3
TS_47°	10,22	1040	1743	1812.72	4
FS_32°	10,83	982	1828	1795.10	5
FS_47°	11,67	912	1759	1604.21	6

From the results of Table 3, multi-crystalline PV panels at 17° inclination represent the optimal installation for the case study building. This is because it provides the largest annual electricity production by exploiting the entire area of the optimal zone. We can see that considering the effect of inter-rows shading (must be avoided), the required area for installing 1 KW is changed, and therefore, the output power of the PV system is affected. Comparing results to other results that are obtained without considering the effect of inter-rows shading, PV panels at 32° (optimum inclination at Ouargla) presents the best option. Therefore, it is recommended to take 17° as the optimal inclination angle for Ouargla. By taking into account the inter-rows shading effect, multi-crystalline PV modules provide better results than thin-film modules for the three inclinations. Therefore, we recommend using multi-crystalline PV modules in a hot dry climate.

In this work, only the best configuration (that is ranked first) is the one that will be investigated in the economic assessment section. This information is the link between the technical assessment and economic assessment of the GCR-PV system under study in this work. Because it will define the maximum capacity of the PV system that cannot be exceeded in the optimization of the grid-connected PV system with HOMER. This information is the main input (constraint) for making the optimization and analysing the feasibility of the proposed system.

3.2.Economic assessment results

As mentioned before, Multi crystalline PV panels at an inclination angle of 17° were selected for performing the techno-economic analysis, as it is ranked first among other configurations. This information is the main input for doing techno-economic assessment and optimal sizing of the GCR-PV system under study. The obtained results for the three different scenarios are presented and discussed as follows.

3.2.1.First scenario results

The results of the optimal sizing of the first scenario are presented in Table 5. The hourly electricity generation of the selected configuration is presented in Fig. 13. In addition, the monthly energy sold to the grid, and the net energy purchased for the three configurations (grid, grid-PV, and grid-PV-battery) are provided in Fig. 14 and Fig. 15, respectively.

Table 5
Results of optimal sizing of the PV system (first scenario).

Configuration	Grid	Grid-PV	Grid-PV-Battery
PV capacity (kW)	/	1310	1310
Battery capacity (kWh)	/	/	7
Converter capacity (kW)	/	881	818
Renewable Fraction (%)	0	77.95	77.53
CO2 (kg/year)	940006.3	-426405.1	-393885.7
Annual Energy Purchased (kWh)	1487352	611506	611506
Annual Energy Sold (kWh)	0	1286198	1234743
Annual Net Energy Purchased (kWh)	1487352	-674692	-623237
Initial capital ($)	0	2229450	2212640
NPC ($)	775077.4	2388958	2396094
COE ($/kWh)	**0.045**	**0.0743**	**0.0760**
Ranking (According to COE)	1	2	3

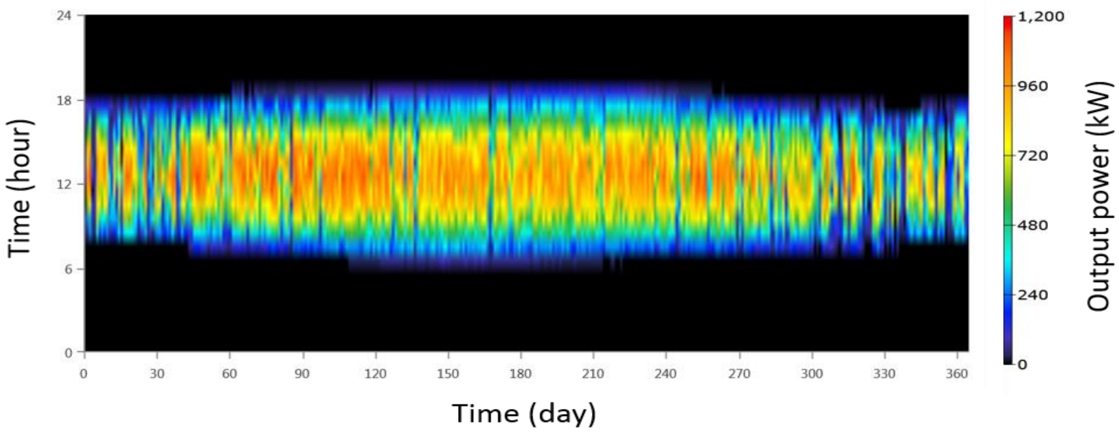

Fig. 13 The daily output power of the PV system at the building location (from HOMER results).

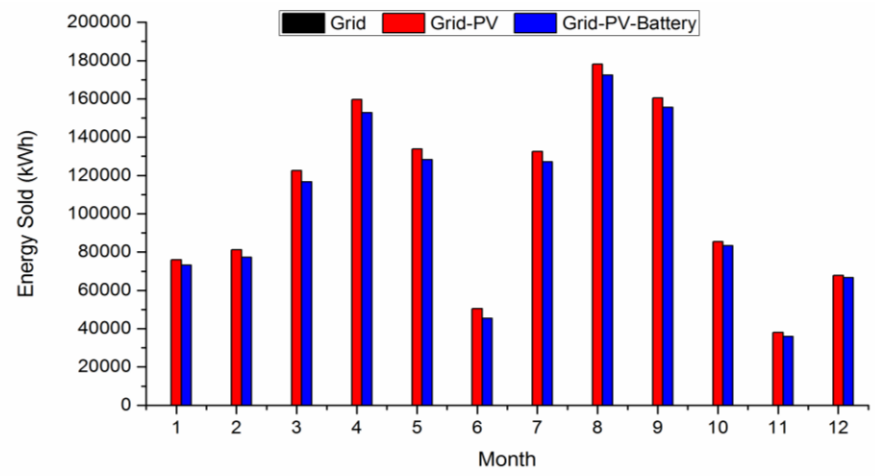

Fig. 14 Monthly energy sold to the grid.

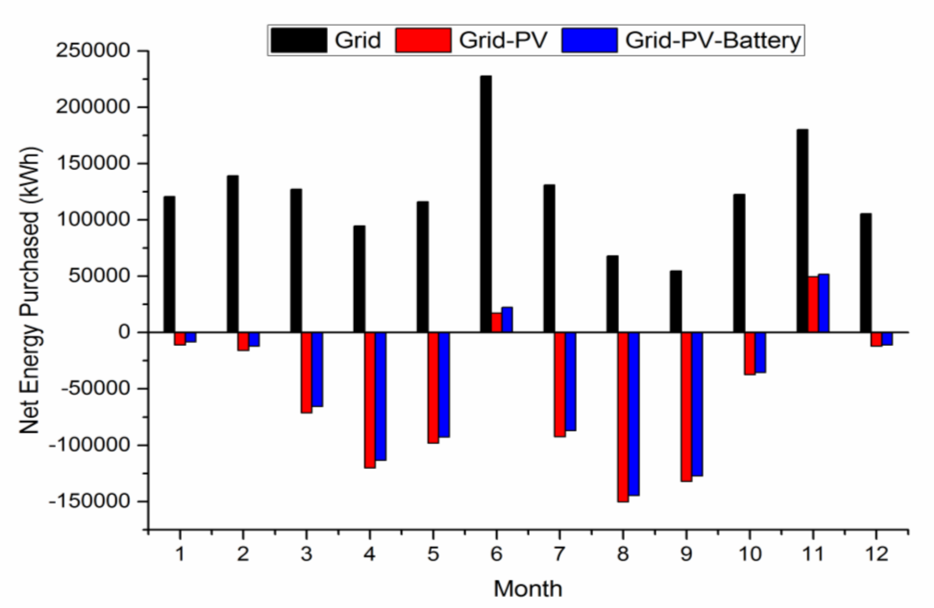

Fig. 15 Monthly net energy purchased.

The results show that both configurations (grid-PV and grid-PV-battery) cannot reach grid parity within the inputs of this scenario. Furthermore, grid-PV presents better results than grid-PV-battery in terms of COE, NPC and renewable fraction. We can see that the grid-PV system can sell (export) to the grid an important amount of electricity, which can supply an equivalent of 394 residential building, assuming that the average annual electricity consumption of a residential building in Algeria is 3262 KWh [2]. Moreover, large electricity can be exported to the grid in peak periods (July to 15 September), which can help reducing power shortage or grid blackouts in the case study location. In April also there is large energy exported to the grid, because of the low energy consumed and the high energy produced this month. However, in some months (June and November), the net energy purchased is positive, which represents that the energy sold to the grid is less than the energy purchased from the grid. Because of the energy demand of the campus in these two months (for cooling in June and for heating in November). Although, the annual balance still a net plus, it means, an energy plus building target was achieved in these buildings without taking any enhancements on building components (no energy efficiency measures are introduced before integrating such renewable system). Finally, we can conclude that GCR-PV system FIT similar to electricity purchase rates can achieve plus energy targets with low COE. However, grid parity still unachieved within this scenario. The following scenarios have been discussed the possible ways to achieve grid parity in these buildings.

3.2.2.Second scenario results (FIT less than the EPE)

The results of optimal sizing for the second scenario are presented in Table 6.

Table 6
Result of the second scenario (Sensitivity analysis on components costs).

Configuration	Grid-PV	Grid-PV-BS
PV (kW)	1310	1310
LA (kWh)	/	18
Converter (kW)	796	801
COE ($/kWh)	**0.0446**	**0.0447**
NPC ($)	1397097	1401331
Initial capital ($)	1221581	1225691
Renewable Fraction (%)	77.35	77.39
CO2 (kg/year)	-379990	-383080
Energy Purchased (kWh)	611506	611506
Energy Sold (kWh)	1212757	1217646
Net energy purchased (kWh)	-601251	-606140
Return on investment (%)	4.3	4.3
Simple payback (year)	n/a	n/a

From the study of [89] increasing electricity pricing, decreasing PV feed-in tariff and falling cost in battery can provide the residential PV-battery system more attractiveness. However, in the case of low electricity pricing it still difficult to make residential PV-battery systems cost-effective. From the results, we can see that even within half reduction on battery costs, the grid-PV system still more cost-effective than grid-PV-Battery. Therefore, grid-PV systems are the most cost-effective solution for education buildings in Algeria. In this scenario, grid parity was achieved within FIT lower than EPR by half reduction on the investment cost of PV and battery storage. However, this scenario represents future assumptions, which cannot be applied currently. But if subsidies can be devoted to reducing investment costs of PV panels with half, the investment on GCR-PV systems in education buildings will be more attractive especially within the problem of power shortage in arid environments in peak periods.

3.2.3.Third scenario results

In this scenario, the only grid-PV system was investigated, because grid-PV-battery is found not competitive to the grid –PV configuration for the investigated building even with a half reduction on battery cost (as obtained from the second scenario). The results of this scenario (third scenario) are presented in Table 7. Further results for this scenario are presented in Fig. 16, Fig. 17 and Fig. 18.

Table 7
Result of optimal sizing of the Grid-PV system (third scenario).

FIT rate	FIT_0.045	FIT_0.065	FIT_0.085	FIT_0.095	Grid
Solar PV (kW)	1310	1310	1310	1310	/
Converter (kW)	882	928	957	961	/
Renewable Fraction (%)	77.95	78.17	78.26	78.28	/
Initial capital ($)	2229450	2243544	2252000	2253410	/
NPC ($)	2161406	1859601	1553752	1400102	/
Simple payback (year)	n/a	n/a	19	17	/
COE ($/kWh)	0.067	0.057	0.047	**0.043**	0.045

n/a is result in case of the time value exceeded project life time or can be applicable only with time less than the project lifetime

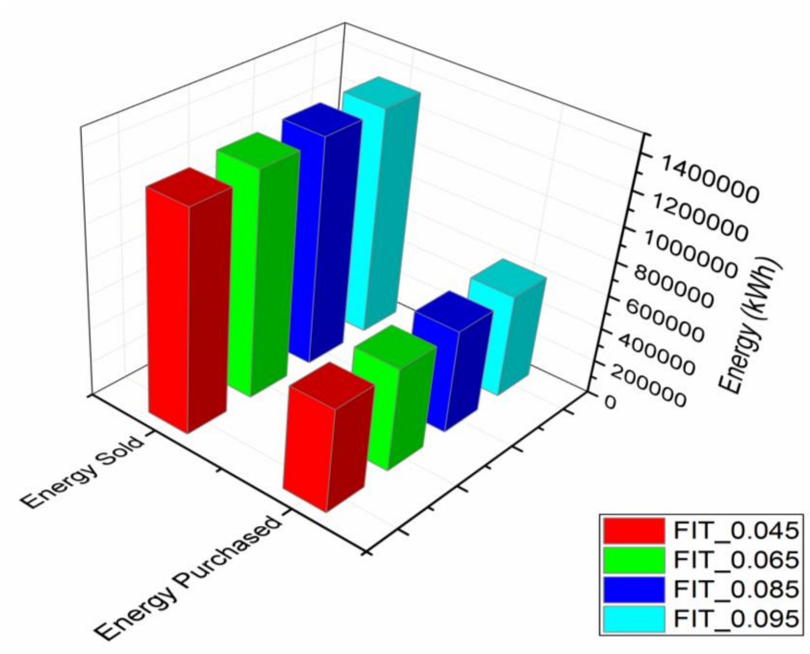

Fig. 16 Annual energy Purchased and Sold to the electricity grid.

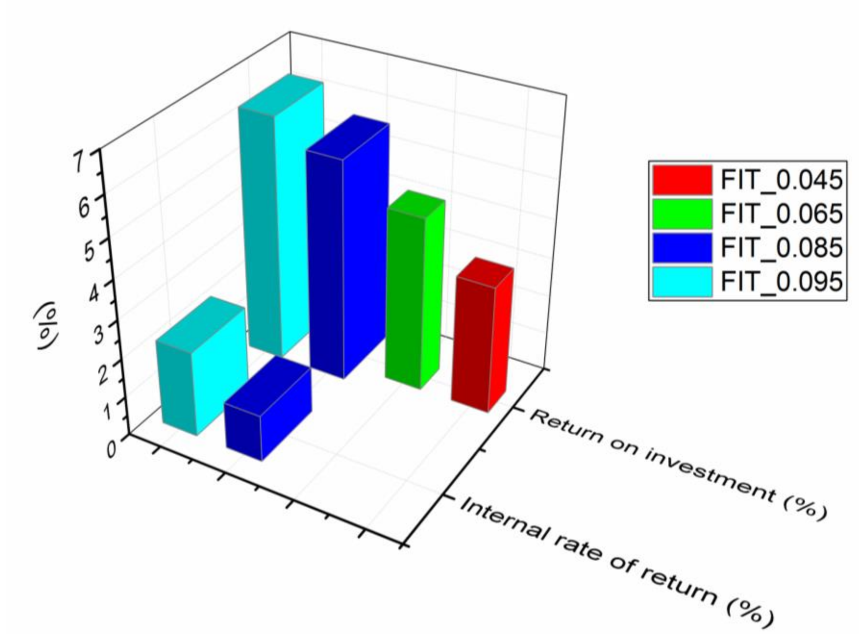

Fig. 17 Return on investment and internal rate of return.

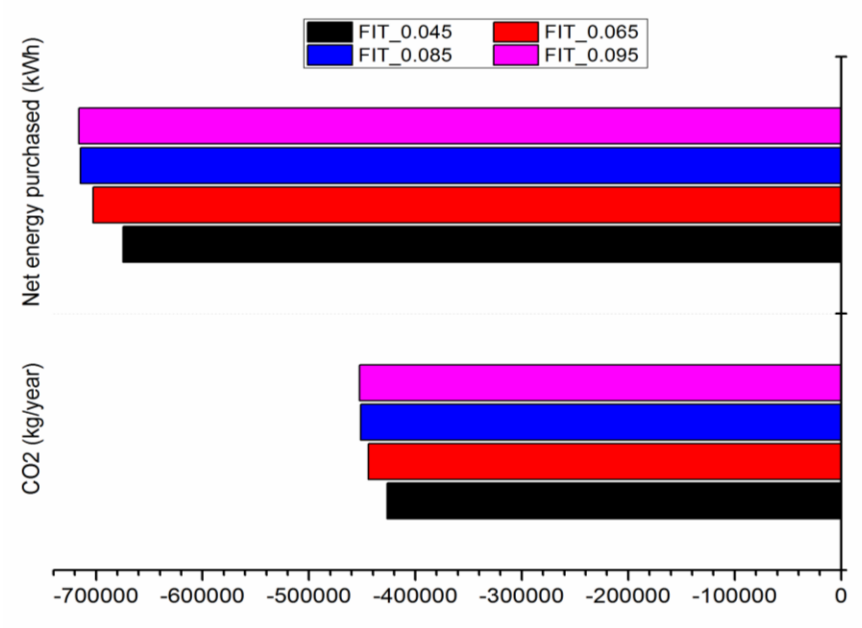

Fig. 18 Annual net energy purchased and CO2 emission.

The results of this scenario show that grid parity can be achieved with a sell electricity price of 0.095 $/kWh, which is slightly smaller than the minimum sell electricity price devoted to large scale PV systems. Therefore, FIT-0.095 is the minimum FIT rate that allows education buildings to reach grid parity. The detailed results for this grid parity option are presented in the following figures. Fig. 19 shows the hourly energy purchased and sold from/to the grid. In addition, Fig. 20 provides the instantaneous SC of the building.

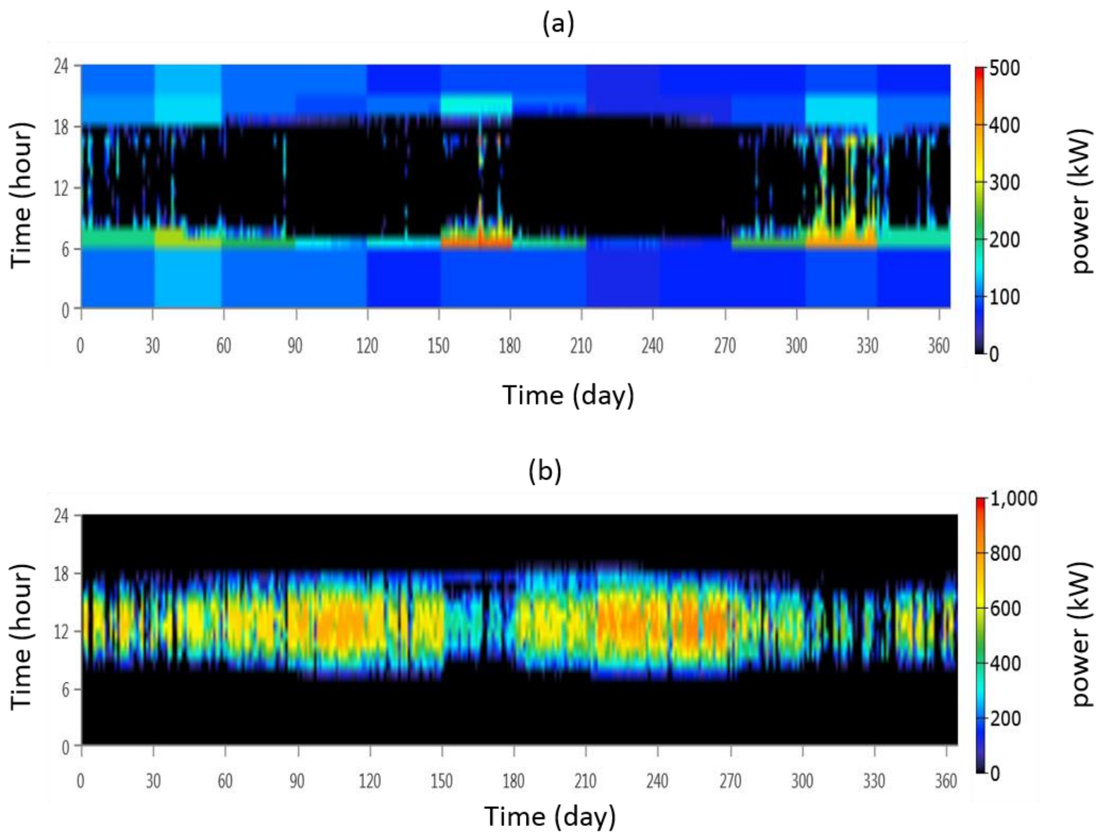

Fig. 19 (a) Energy Purchased From Grid (kW); (b) Energy Sold To Grid (kW).

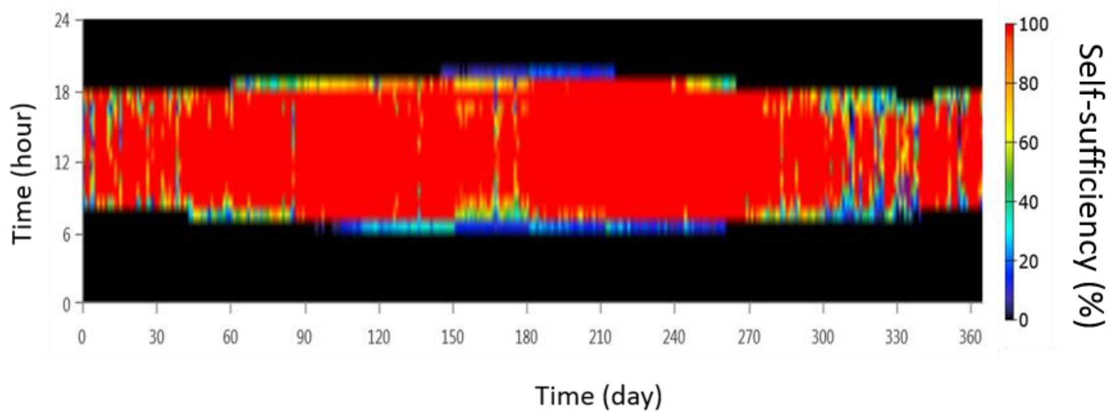

Fig. 20 Instantaneous self-sufficiency.

As the university campus operated from 8:00 until 18:00, the PV system can provide near to 100% of the total lead on this period expect in June (150-180) and in November (300-330) where the campus import some amount of electricity from the grid, due to high demand in these two months. Hence, high self-sufficiency (more than 90 %) levels can be achieved. Meanwhile, the system can export a high amount of electricity to the grid. Hence, a large number of buildings, which are located near to the campus location can be supplied by this excess electricity, which can help to reduce significantly peak loads in these regions. In addition, grid parity is also fulfilled with acceptable FIT rates. We can conclude that GCR-PV systems installed on education buildings in arid climates is beneficial for both consumers and suppliers. Because, it able to ensure high self-sufficiency, reach grid parity, and feed into grid large amounts of electricity that allows electricity companies to reduce the hours of blackouts or blackout problems definitely in the building location.

3.2.4.Comparison of Grid parity results

As shown, grid parity is achieved in two different ways. In the second scenario by applying a half reduction on components costs and with FIT 0.03 $/kWh lower than EPR (0.045$/kWh), and in the third scenario with FIT 0.095 $/kWh (which is higher than EPR). The comparison of the results between these two options is given in Table 8.

Table 8
Comparison between the second and third scenarios within grid parity fulfilment.

Configuration	Grid-PV (2nd scenario)	Grid-PV (3rd scenario)
COE ($/kWh)	**0.0446**	**0.043**
Initial capital ($)	1221581	2253410
NPC ($)	1397097	1400102
Renewable Fraction (%)	77.35	78.28
CO2 (kg/year)	-379990	-452607
Net energy purchased (kWh)	-601251	-716151
Return on investment (%)	4.3	6.3
Internal rate of return (%)	n/a	2.2
Simple payback (year)	n/a	17

From the results, if considering investment (initial capital) cost as the determinant parameters, in this case, the second scenario is more cost-effective as the capital cost of the grid-PV system is about half of the investment cost of the same system in the third scenario. Moreover, the rates of FIT used in the second scenario is more attractive for supplier companies. In this regard, the third scenario is more advantageous for both sides (consumers and Supplier Company). However, if we consider other parameters as net energy purchased (related to power shortage as mention above), CO2 emissions and other economic indices as payback time, we can see that the second scenario can bring better results than the second scenario. However, both scenarios still attractive for education buildings. Accounting that there has been an important number of education buildings in each small community including university buildings, high schools, elementary schools, and other categories, large electricity surplus can be exported to the grid, and therefore, reducing power shortage even with high energy demand in summer periods.

4.Conclusions

In this work, a GCR-PV system at a university campus (common types of education buildings in Algeria) is optimally designed. Contrary to previous work, here, a combined approach is developed, that enables to carry out the technical and economic potential assessment of the proposed grid connected system. Based on the obtained results, and with a sensitivity analysis performed on component cost and feed-in tariffs, the key conclusions of the study are presented as follows:

- The simulation results reveal that only 60 % of the overall roof area is optimally suitable for hosting PV panels. In which, standard multi-crystalline PV panels at an inclination angle of 17° were found the most suitable configuration for the studied building. By considering only the obtained suitable roof area, this optimal installation yields an annual electricity production of 2333.11 MWh/year.
- It is observed that the Shading effects can reduce dramatically the potential of PV systems on rooftop installations.
- GCR-PV systems without battery storage are technically and economically viable solution than grid-PV-battery systems for education buildings in arid climates of Algeria.
- In Algeria, for the GCR-PV system at education buildings, it is found that with high FITs rates but less than existing FITs for large scale PV systems (0.11$/kWh), the grid parity is fulfilled, with the cost of energy 0.043 $/kWh. In addition, education buildings can reach grid parity with even low FITs rates (if achieving half reduction on PV panels costs).

The findings of this study have proven the techno-economic feasibility of GCR-PV systems in education buildings in the arid environments of Algeria. It also ensures the efficiency of the developed approach to design such complex renewable-based systems.

Acknowledgement

The first author of this work would like to thank the University of Kasdi Merbah Ouargla for their financial support for this work. Thanks also to the University of the West of England Bristol, UK. University for their collaboration in this research.

References

[1] Charafeddine Mokhtara, Belkhir Negrou, Noureddine Settou, Belkhir Settou MMS. Design Optimization of Off-grid Hybrid Renewable Energy Systems Considering the Effects of Building Energy Performance and Climate Change: Case Study of Algeria. Energy 2020:104743. https://doi.org/10.1016/j.energy.2020.119605.

[2] APROU. LA CONSOMMATION ÉNERGÉTIQUE FINALE. 2017.

[3] MINISTERE DE L'ENERGY. Bilan Energetique National Année 2018. Algeria: 2019. https://doi.org/https://www.energy.gov.dz/?article=bilan-energetique-national-du-secteur.

[4] Mokhtara C, Negrou B, Settou N, Gouareh, Abderrahmane BS. Pathways to plus-energy buildings in Algeria : design optimization method based on GIS and multi-criteria decision-making. Energy Procedia 2019;162:171–80. https://doi.org/10.1016/j.egypro.2019.04.019.

[5] Alramlawi M, Gabash A, Mohagheghi E, Li P. Optimal operation of hybrid PV-battery system considering grid scheduled blackouts and battery lifetime. Sol Energy 2018;161:125–37. https://doi.org/10.1016/j.solener.2017.12.022.

[6] Dondariya C, Porwal D, Awasthi A, Kumar A. Performance simulation of grid-connected rooftop solar PV system for small households : A case study of Ujjain , India. Energy Reports 2018;4:546–53. https://doi.org/10.1016/j.egyr.2018.08.002.

[7] Karneyeva Y, Wüstenhagen R. Solar feed-in tariffs in a post-grid parity world: The role of risk, investor diversity and business models. Energy Policy 2017;106:445–56. https://doi.org/10.1016/j.enpol.2017.04.005.

[8] Honrubia-Escribano A, Ramirez FJ, Gómez-Lázaro E, Garcia-Villaverde PM, Ruiz-Ortega MJ, Parra-Requena G. Influence of solar technology in the economic performance of PV power plants in Europe. A comprehensive analysis. Renew Sustain Energy Rev 2018;82:488–501. https://doi.org/10.1016/j.rser.2017.09.061.

[9] L'Energie M de. Bilan des réalisation du sector de l'Energie 2018. https://doi.org/http://www.energy.gov.dz/francais/uploads/MAJ_2018/Stat/Bilan_des_Realisations_du_secteur_2017_%C3%A9dition_2018.pdf.

[10] Bódis K, Kougias I, Jäger-Waldau A, Taylor N, Szabó S. A high-resolution geospatial assessment of the rooftop solar photovoltaic

potential in the European Union. Renew Sustain Energy Rev 2019;114:109309. https://doi.org/10.1016/j.rser.2019.109309.
[11] Byrne J, Taminiau J, Kurdgelashvili L, Kim KN, Nam K. A review of the solar city concept and methods to assess rooftop solar electric potential, with an illustrative application to the city of Seoul. Renew Sustain Energy Rev 2015;41:830–44. https://doi.org/10.1016/j.rser.2014.08.023.
[12] Lukač N, Seme S, Dežan K, Žalik B, Štumberger G. Economic and environmental assessment of rooftops regarding suitability for photovoltaic systems installation based on remote sensing data. Energy 2016;107:854–65. https://doi.org/10.1016/j.energy.2016.04.089.
[13] Jurasz JK, Dąbek PB, Campana PE. Can a city reach energy self-sufficiency by means of rooftop photovoltaics? Case study from Poland. J Clean Prod 2019;245. https://doi.org/10.1016/j.jclepro.2019.118813.
[14] Assouline D, Mohajeri N, Scartezzini JL. Quantifying rooftop photovoltaic solar energy potential: A machine learning approach. Sol Energy 2017;141:278–96. https://doi.org/10.1016/j.solener.2016.11.045.
[15] Assouline D, Mohajeri N, Scartezzini JL. Large-scale rooftop solar photovoltaic technical potential estimation using Random Forests. Appl Energy 2018;217:189–211. https://doi.org/10.1016/j.apenergy.2018.02.118.
[16] Aboushal EA. Applying GIS Technology for optimum selection of Photovoltaic Panels "Spatially at Defined Urban Area in Alexandria, Egypt." Alexandria Eng J 2018;57:4167–76. https://doi.org/10.1016/j.aej.2018.11.005.
[17] Li Y, Ding D, Liu C, Wang C. A pixel-based approach to estimation of solar energy potential on building roofs. Energy Build 2016;129:563–73. https://doi.org/10.1016/j.enbuild.2016.08.025.
[18] Hong T, Lee M, Koo C, Jeong K, Kim J. Development of a method for estimating the rooftop solar photovoltaic (PV) potential by analyzing the available rooftop area using Hillshade analysis. Appl Energy 2017;194:320–32. https://doi.org/10.1016/j.apenergy.2016.07.001.
[19] Verso A, Martin A, Amador J, Dominguez J. GIS-based method to evaluate the photovoltaic potential in the urban environments : The particular case of Miraflores de la Sierra. Sol Energy 2015;117:236–45. https://doi.org/10.1016/j.solener.2015.04.018.
[20] Lee M, Hong T, Jeong K, Kim J. A bottom-up approach for estimating the economic potential of the rooftop solar photovoltaic system considering the spatial and temporal diversity. Appl Energy 2018;232:640–56. https://doi.org/10.1016/j.apenergy.2018.09.176.
[21] Cucchiella F, Dadamo I. Estimation of the energetic and environmental impacts of a roof-mounted building-integrated photovoltaic systems. Renew Sustain Energy Rev 2012;16:5245–59. https://doi.org/10.1016/j.rser.2012.04.034.
[22] Martinez-Rubio A, Sanz-Adan F, Santamaria J. Optimal design of photovoltaic energy collectors with mutual shading for pre-existing building roofs. Renew Energy 2015;78:666–78. https://doi.org/10.1016/j.renene.2015.01.043.
[23] Al-Otaibi A, Al-Qattan A, Fairouz F, Al-Mulla A. Performance evaluation of photovoltaic systems on Kuwaiti schools' rooftop. Energy Convers Manag 2015;95:110–9. https://doi.org/10.1016/j.enconman.2015.02.039.
[24] Haegermark M, Kovacs P, Dalenbäck JO. Economic feasibility of solar photovoltaic rooftop systems in a complex setting: A Swedish case study. Energy 2017;127:18–29. https://doi.org/10.1016/j.energy.2016.12.121.
[25] Zhong Q, Tong D. Spatial layout optimization for solar photovoltaic (PV) panel installation. Renew Energy 2020;150:1–11. https://doi.org/10.1016/j.renene.2019.12.099.
[26] Talavera DL, Muñoz-Cerón E, De La Casa J, Ortega MJ, Almonacid G. Energy and economic analysis for large-scale integration of small photovoltaic systems in buildings: The case of a public location in Southern Spain. Renew Sustain Energy Rev 2011;15:4310–9. https://doi.org/10.1016/j.rser.2011.07.119.
[27] Thakur J, Chakraborty B. A study of feasible smart tariff alternatives for smart grid integrated solar panels in India. Energy 2015;93:963–75. https://doi.org/10.1016/j.energy.2015.09.100.
[28] Omar MA, Mahmoud MM. Grid connected PV- home systems in Palestine : A review on technical performance , e ff ects and economic feasibility. Renew Sustain Energy Rev 2018;82:2490–7. https://doi.org/10.1016/j.rser.2017.09.008.
[29] Akter MN, Mahmud MA, Oo AMTT. Comprehensive economic evaluations of a residential building with solar photovoltaic and battery energy storage systems: An Australian case study. Energy Build 2017;138:332–46. https://doi.org/10.1016/j.enbuild.2016.12.065.
[30] Duman AC, Güler Ö. Economic analysis of grid-connected residential rooftop PV systems in Turkey. Renew Energy 2019. https://doi.org/10.1016/j.renene.2019.10.157.
[31] Poruschi L, Ambrey CL. Energy justice, the built environment, and solar photovoltaic (PV) energy transitions in urban Australia: A dynamic panel data analysis. Energy Res Soc Sci 2019;48:22–32. https://doi.org/10.1016/j.erss.2018.09.008.
[32] Tongsopit S. Energy for Sustainable Development Thailand ' s feed-in tariff for residential rooftop solar PV systems : Progress so far. Energy Sustain Dev 2015;29:127–34. https://doi.org/10.1016/j.esd.2015.10.012.
[33] Górnowicz R, Castro R. Optimal design and economic analysis of a PV system operating under Net Metering or Feed-In-Tariff support mechanisms: A case study in Poland. Sustain Energy Technol Assessments 2020;42. https://doi.org/10.1016/j.seta.2020.100863.
[34] Elshurafa AM, Alsubaie AM, Alabduljabbar AA, Al-hsaien SA. Solar PV on mosque rooftops : Results from a pilot study in Saudi Arabia. J Build Eng 2019;25. https://doi.org/10.1016/j.jobe.2019.100809.
[35] Ossenbrink J. How feed-in remuneration design shapes residential PV prosumer paradigms. Energy Policy 2017;108:239–55. https://doi.org/10.1016/j.enpol.2017.05.030.

[36] Tongsopit S, Junlakarn S, Wibulpolprasert W, Chaianong A, Kokchang P, Hoang NV. The economics of solar PV self-consumption in Thailand. Renew Energy 2019;138:395–408. https://doi.org/10.1016/j.renene.2019.01.087.

[37] Thakur J, Chakraborty B. Impact of increased solar penetration on bill savings of net metered residential consumers in India. Energy 2018;162:776–86. https://doi.org/10.1016/j.energy.2018.08.025.

[38] Keiner D, Ram M, Barbosa LDSNS, Bogdanov D, Breyer C. Cost optimal self-consumption of PV prosumers with stationary batteries, heat pumps, thermal energy storage and electric vehicles across the world up to 2050. Sol Energy 2019;185:406–23. https://doi.org/10.1016/j.solener.2019.04.081.

[39] Jin H, Yu J. A prospective economic assessment of residential PV self-consumption with batteries and its systemic e ff ects : The French case in 2030. Energy Policy 2018;113:673–87. https://doi.org/10.1016/j.enpol.2017.11.005.

[40] Aguilera J, Espinoza R. Feasibility evaluation of residential photovoltaic self-consumption projects in Peru. Renew Energy 2019;136:414–27. https://doi.org/10.1016/j.renene.2019.01.003.

[41] Lang T, Ammann D, Girod B. Profitability in absence of subsidies: A techno-economic analysis of rooftop photovoltaic self-consumption in residential and commercial buildings. Renew Energy 2016;87:77–87. https://doi.org/10.1016/j.renene.2015.09.059.

[42] Tran TTD, Smith AD. Thermoeconomic analysis of residential rooftop photovoltaic systems with integrated energy storage and resulting impacts on electrical distribution networks. Sustain Energy Technol Assessments 2018;29:92–105. https://doi.org/10.1016/j.seta.2018.07.002.

[43] Tanesab J, Parlevliet D, Whale J, Urmee T. Energy and economic losses caused by dust on residential photovoltaic (PV) systems deployed in different climate areas. Renew Energy 2018;120:401–12. https://doi.org/10.1016/j.renene.2017.12.076.

[44] Lydon GP, Hofer J, Svetozarevic B, Nagy Z, Schlueter A. Coupling energy systems with lightweight structures for a net plus energy building. Appl Energy 2017;189:310–26. https://doi.org/10.1016/j.apenergy.2016.11.110.

[45] Shukla AK, Sudhakar K, Baredar P. Design, simulation and economic analysis of standalone roof top solar PV system in India. Sol Energy 2016;136:437–49. https://doi.org/10.1016/j.solener.2016.07.009.

[46] Shukla AK, Sudhakar K, Baredar P. Simulation and performance analysis of 110 kW p grid-connected photovoltaic system for residential building in India : A comparative analysis of various PV technology. Energy Reports 2016;2:82–8. https://doi.org/10.1016/j.egyr.2016.04.001.

[47] Hamza A, Ali H, Abdelrasheed H, Zeid S, Alfadhli HMG. Energy performance , environmental impact , and cost assessments of a photovoltaic plant under Kuwait climate condition. Sustain Energy Technol Assessments 2017;22:25–33. https://doi.org/10.1016/j.seta.2017.05.008.

[48] Ali H, Khan HA. CIS Thin-Film Based PV Rooftop Systems in Pakistan. Renew Energy 2019. https://doi.org/10.1016/j.renene.2019.12.144.

[49] Romero L, Duminil E, Sánchez J, Eicker U. Assessment of the photovoltaic potential at urban level based on 3D city models : A case study and new methodological approach 2017;146:264–75. https://doi.org/10.1016/j.solener.2017.02.043.

[50] Desthieux G, Carneiro C, Camponovo R, Ineichen P, Desthieux G. Solar Energy Potential Assessment on Rooftops and Facades in Large Built Environments Based on LiDAR Data, Image Processing, and Cloud Computing. Methodological Background, Application, and Validation in Geneva (Solar Cadaster). Front Built Environ 2018;4. https://doi.org/10.3389/fbuil.2018.00014.

[51] Enongene KE, Abanda FH, Otene IJJ, Obi SI, Okafor C. The potential of solar photovoltaic systems for residential homes in Lagos city of Nigeria. J Environ Manage 2019;244:247–56. https://doi.org/10.1016/j.jenvman.2019.04.039.

[52] Pillai GG, Putrus GA, Georgitsioti T, Pearsall NM. Near-term economic bene fi ts from grid-connected residential PV (photovoltaic) systems. Energy 2014;68:832–43. https://doi.org/10.1016/j.energy.2014.02.085.

[53] Li J. Optimal sizing of grid-connected photovoltaic battery systems for residential houses in Australia. Renew Energy 2019;136:1245–54. https://doi.org/10.1016/j.renene.2018.09.099.

[54] Shaughnessy EO, Cutler D, Ardani K, Margolis R, O'Shaughnessy E, Cutler D, et al. Solar plus: A review of the end-user economics of solar PV integration with storage and load control in residential buildings. Appl Energy 2018;228:2165–75. https://doi.org/10.1016/j.apenergy.2018.07.048.

[55] Dietrich A, Weber C. What drives pro fi tability of grid-connected residential PV storage systems ? A closer look with focus on Germany. Energy Econ 2020;74:399–416. https://doi.org/10.1016/j.eneco.2018.06.014.

[56] Mokhtara C, Negrou B, Settou N, Gouareh A, Settou B. Pathways to plus-energy buildings in Algeria: Design optimization method based on GIS and multi-criteria decision-making. Energy Procedia 2019;162:171–80. https://doi.org/10.1016/j.egypro.2019.04.019.

[57] Mokhtara C, Negrou B, Settou N, Bouferrouk A, Yao Y. Design optimization of grid-connected PV-Hydrogen for energy prosumers considering sector-coupling paradigm: Case study of a university building in Algeria. Int J Hydrogen Energy 2020. https://doi.org/10.1016/j.ijhydene.2020.10.069.

[58] Kurdgelashvili L, Li J, Shih CH, Attia B. Estimating technical potential for rooftop photovoltaics in California, Arizona and New Jersey. Renew Energy 2016;95:286–302. https://doi.org/10.1016/j.renene.2016.03.105.

[59] Freitas S, Catita C, Redweik P, Brito MC. Modelling solar potential in the urban environment: State-of-the-art review. Renew Sustain Energy Rev 2015;41:915–31. https://doi.org/10.1016/j.rser.2014.08.060.

[60] Koutra AS, Ioakimidis CS, Gallas M, Becue V. Towards the Development of a Net-Zero Energy District Evaluation Approach: A Review of Sustainable Approaches and Assessment Tools. Sustain Cities Soc 2018. https://doi.org/10.1016/j.scs.2018.03.011.

[61] Hernández-Callejo L, Gallardo-Saavedra S, Alonso-Gómez V. A review of photovoltaic systems: Design, operation and

maintenance. Sol Energy 2019;188:426–40. https://doi.org/10.1016/j.solener.2019.06.017.
[62] Peng J, Lu L. Investigation on the development potential of rooftop PV system in Hong Kong and its environmental benefits. Renew Sustain Energy Rev 2013;27:149–62. https://doi.org/10.1016/j.rser.2013.06.030.
[63] Rahmouni S, Negrou B, Settou N. Prospects of hydrogen production potential from renewable resources in Algeria. Int J Hydrogen Energy 2016:1–13. https://doi.org/10.1016/j.ijhydene.2016.07.214.
[64] Sadiq R, Karunathilake H, Hewage K. Renewable energy selection for net-zero energy communities : Life cycle based decision making under uncertainty. Renew Energy 2019;130:558–73. https://doi.org/10.1016/j.renene.2018.06.086.
[65] Settou B, Settou N, Gouareh A, Negrou B, Mokhtara C, Messaoudi D. A high-resolution geographic information system-analytical hierarchy process-based method for solar PV power plant site selection: a case study Algeria. Clean Technol Environ Policy 2020. https://doi.org/10.1007/s10098-020-01971-3.
[66] Kemausuor F, Sedzro MD, Osei I. Decentralised Energy Systems in Africa: Coordination and Integration of Off-Grid and Grid Power Systems—Review of Planning Tools to Identify Renewable Energy Deployment Options for Rural Electrification in Africa. Curr Sustain Energy Reports 2018;5:214–23. https://doi.org/10.1007/s40518-018-0118-4.
[67] Bahramara S, Moghaddam MP, Haghifam MR. Optimal planning of hybrid renewable energy systems using HOMER: A review. Renew Sustain Energy Rev 2016;62:609–20. https://doi.org/10.1016/j.rser.2016.05.039.
[68] Anoune K, Bouya M, Astito A, Abdellah A Ben, Ben A. Sizing methods and optimization techniques for PV-wind based hybrid renewable energy system : A review. Renew Sustain Energy Rev 2018;93:652–73. https://doi.org/10.1016/j.rser.2018.05.032.
[69] Zou H, Du H, Brown MA, Mao G. Large-scale PV power generation in China : A grid parity and techno- economic analysis. Energy 2020;134:256–68. https://doi.org/10.1016/j.energy.2017.05.192.
[70] Kumar A, Singh AR, Deng Y, He X, Kumar P, Bansal RC. Integrated assessment of a sustainable microgrid for a remote village in hilly region. Energy Convers Manag 2019;180:442–72. https://doi.org/10.1016/j.enconman.2018.10.084.
[71] Mokhtara C, Negrou B, Bouferrouk A, Yao Y, Settou N, Ramadan M. Integrated supply–demand energy management for optimal design of off-grid hybrid renewable energy systems for residential electrification in arid climates. Energy Convers Manag 2020;221:113192. https://doi.org/10.1016/j.enconman.2020.113192.
[72] Mokhtara C., Negrou B., Settou N., Gouareh A., Settou B. CMA. Decision-making and optimal design of off-grid hybrid renewable energy system for electrification of mobile buildings in Algeria: case study of drilling camps in Adrar. Alger J Env Sc Technol 2020.
[73] Akbari H, Browne MC, Ortega A, Huang MJ, Hewitt NJ, Norton B, et al. Efficient energy storage technologies for photovoltaic systems. Sol Energy 2019;192:144–68. https://doi.org/10.1016/j.solener.2018.03.052.
[74] Mahela OP, Shaik AG. Comprehensive overview of grid interfaced solar photovoltaic systems. Renew Sustain Energy Rev 2017;68:316–32. https://doi.org/10.1016/j.rser.2016.09.096.
[75] Maleki A. Design and optimization of autonomous solar-wind-reverse osmosis desalination systems coupling battery and hydrogen energy storage by an improved bee algorithm. Desalination 2018;435:221–34. https://doi.org/10.1016/j.desal.2017.05.034.
[76] Das BK, Zaman F. Performance analysis of a PV/Diesel hybrid system for a remote area in Bangladesh: Effects of dispatch strategies, batteries, and generator selection. Energy 2019;169:263–76. https://doi.org/10.1016/j.energy.2018.12.014.
[77] Padrón I, Avila D, Marichal GN, Rodríguez JA. Assessment of Hybrid Renewable Energy Systems to supplied energy to Autonomous Desalination Systems in two islands of the Canary Archipelago. Renew Sustain Energy Rev 2019;101:221–30. https://doi.org/10.1016/j.rser.2018.11.009.
[78] Gharibi M, Askarzadeh A. Size and power exchange optimization of a grid-connected diesel generator-photovoltaic-fuel cell hybrid energy system considering reliability, cost and renewability. Int J Hydrogen Energy 2019;44:25428–41. https://doi.org/10.1016/j.ijhydene.2019.08.007.
[79] Allouhi A, Saadani R, Kousksou T, Saidur R, Jamil A, Rahmoune M. Grid-connected PV systems installed on institutional buildings : Technology comparison , energy analysis and economic performance. Energy Build 2016;130:188–201. https://doi.org/10.1016/j.enbuild.2016.08.054.
[80] Missoum M. Impact of a grid-connected PV system application in a bioclimatic house toward the zero energy status in the north of Algeria. Energy Build 2016. https://doi.org/10.1016/j.enbuild.2016.07.005.
[81] Ramírez-sagner G, Mata-torres C, Pino A, Escobar RA. Economic feasibility of residential and commercial PV technology : The Chilean case. Renew Energy 2017;111:332–43. https://doi.org/10.1016/j.renene.2017.04.011.
[82] Fodhil F, Hamidat A, Nadjemi O. Potential , optimization and sensitivity analysis of photovoltaic-diesel-battery hybrid energy system for rural electri fi cation in Algeria. Energy 2019;169:613–24. https://doi.org/10.1016/j.energy.2018.12.049.
[83] Guzmán L, Lake M, Vasquez R, Yan Y. Modelling autonomous hybrid photovoltaic-wind energy systems under a new reliability approach. Energy Convers Manag 2018;172:357–69. https://doi.org/10.1016/j.enconman.2018.07.025.
[84] Mandal S, Das BK, Hoque N. Optimum sizing of a stand-alone hybrid energy system for rural electri fi cation in Bangladesh. J Clean Prod 2018;200:12–27. https://doi.org/10.1016/j.jclepro.2018.07.257.
[85] Jafari M, Armaghan D, Seyed Mahmoudi SM, Chitsaz A. Thermoeconomic analysis of a standalone solar hydrogen system with hybrid energy storage. Int J Hydrogen Energy 2019;44:19614–27. https://doi.org/10.1016/j.ijhydene.2019.05.195.
[86] Zhao G, Ravn E, Troncoso E, Hyde K, Diderich M. Life cycle cost analysis: A case study of hydrogen energy application on the Orkney Islands. Int J Hydrogen Energy 2018:1–12. https://doi.org/10.1016/j.ijhydene.2018.08.015.
[87] Han Y, Zhang G, Li Q, You Z, Chen W. Hierarchical energy management for PV/hydrogen/ battery island DC microgrid. Int J

Hydrogen Energy 2018;4:0–9. https://doi.org/10.1016/j.ijhydene.2018.08.135.

[88] IEA. Feed-in tariff for solar PV installations. IEA 2014.

[89] Li Y, Gao W, Ruan Y. Performance investigation of grid-connected residential PV-battery system focusing on enhancing self-consumption and peak shaving in. Renew Energy 2018;127:514–23. https://doi.org/10.1016/j.renene.2018.04.074.

Conflict of Interest

The authors wish to tell the editor in chief and the editorial board of the **Sustainable Energy Technologies and Assessments** Journal that the new manuscript entitled **"** ***Optimal design of grid-connected rooftop PV systems: An overview and a new approach with application to educational buildings in arid climates***" has no Conflict of interest with any one or organization

Thank you for receiving our manuscript and considering it for review. We appreciate your time and looking forward to your response.

The corresponding author of the manuscript:

Mr: Charafeddine Mokhtara

Tel.: +2136 59 70 41 66

E-mail address: mokhtara.chocho@gmail.com; charafeddine.mokhtara@univ-ouargla.dz; charaf92eddine@gmail.com