

## Lessons learned from the field analysis of PV installations in the Saharawi refugee camps after 10 years of operation



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### ABSTRACT

Energy access at refugee camps is one of the main challenges to address in humanitarian response actions, especially on long-term situations. The lack of access to electricity depends, among other factors, on the local natural resources and available technologies. In this sense, solar photovoltaic is one of the most appropriate technologies, especially now with the decrease of the photovoltaic costs. But long-term performance, reliability and social acceptance must be ensured to facilitate the introduction of the technology and its rapid widespread in these humanitarian context. This work presents the results of a field study conducted at the Saharawi refugee camps, inspecting the photovoltaic systems installed in the health institutions after 10 years of use. Results show how despite the good initial system design and high quality of the PV components, the lack of training on operation and maintenance of the PV installations have led to a dramatic reduction of the lifetime of the systems. Strong training programs on basic photovoltaic concepts and operation and maintenance of systems are required to solve this problem and guarantee the long-term functioning of the installations.

### 1. Introduction

Energy access at refugee camps is one of the main challenges to address in humanitarian response actions, especially on those populations that are in a ‘protracted situation’ (refugee or displaced population major than 25,000 for more than 5 years in asylum in another country), which are long-term situations. In their recent review of 2016, Lehne et al. [1] showed that as many as 7 million displaced people in camps have access to electricity for less than 4 h a day, and that energy is not considered a key in humanitarian actions as it is regarded as a long-term investment. However, the population of refugees trapped in protracted situations is increasing, and according to the United Nations High Commissioner for the Refugees (UNHCR), ‘6.7 million refugees were in a protracted situation by the end of 2015’, plus 5.2 million Palestinian registered with the United Nations Relief and Works Agency (UNRWA), about 12 million in total [2]. On the other hand, some of these protracted situations last now for decades, such as the refugee camps of the Palestinian population in Gaza, Jordan, Lebanon and the West Bank (1948, > 65 years), the Sudanese in Ethiopia (since 1950), the Burundians in Tanzania (1971) and the Saharawi camps in Algeria (1975, > 40 years). In these cases, the short-term humanitarian actions are not valid and provision for energy needs to be ensured.

One of the main problems regarding access to energy in refugee camps is the lack of access to natural resources and freedom of movement [3]. In general, the access to energy is firewood collection or fuel acquisition for lighting (kerosene for lamps), but the displaced population is often in areas where the firewood is limited or inexistent, and the possibilities of accessing to fuels are very restricted. As the report from Lyytinen from the UNHCR states: ‘Solutions to the problems related to the links between livelihoods and household energy can be found in innovative projects that address both the environmental challenges and the lack of economic options’.

In this regard, solar energy can be one of the innovative technologies to be used in refugee camps, and as such, it has been already used in several cases: a) the UNHCR has introduced solar street lights to new camps (in Bangladesh), which has had a positive impact on the overall security situation, b) solar home systems have been implemented in Dadaab refugee camps in Kenya [4], providing power for lighting and equipment such as televisions, radios and mobile phone chargers, and although they have been widely used for the camp operations, they have been implemented without a long-term plan (pilot experiences) and at household level the social acceptance is still low; and c) a solar farm is being funded by the UNHCR with several partners outside the camp of Azraq (Jordan) as a legacy for the country after the refugees

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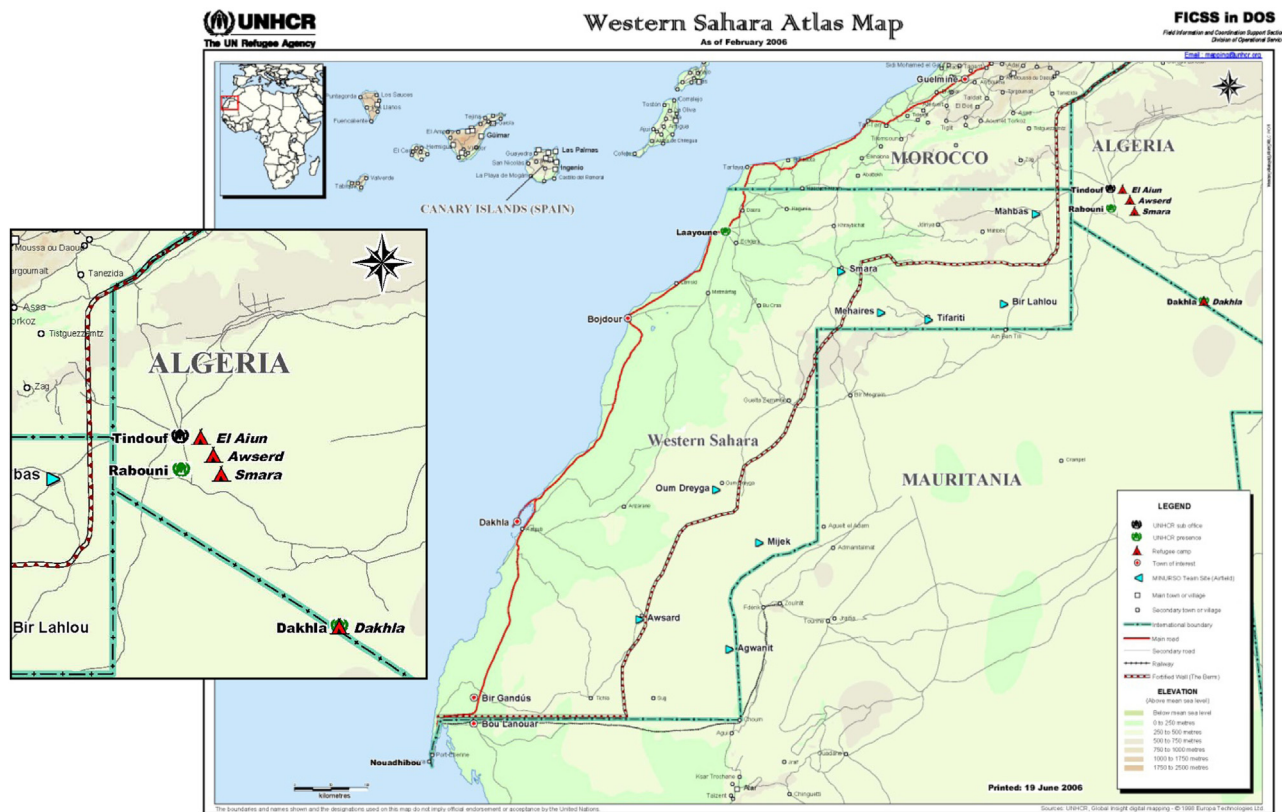


Fig. 1. Map of Western Sahara (UNHCR 2006) and detail of the Saharawi camps area, showing the location of the four different wilayas and the institutional centre of Rabouni.

leave. Other refugee camps using solar are Buramino camp in Ethiopia, Goudoubo in Burkina Faso [5], Kobe in Ehtiopia, Kutupalong in Bangladesh, Kakuma in Kenya, [6] and the Saharawi refugee camps in Algeria. Main identified technical issues that are hampering the widespread of the solar technology in humanitarian actions are often associated to poor training, lack of reliability, insufficient social acceptance or lack of appropriate funding [7]. For example, in the refugee camps of Goudoubo in Burkina Faso [5], it was found that while many households were still using solar lamps, others had sold the lanterns or stopped using them because they were broken, and in some cases the lanterns had been modified to charge two mobile phones instead of one (overloading), so they were no longer been used as lanterns. Another recent example is the installation of a biogas system and a photovoltaic minigrd system for street lighting in the relocation camp of Santo 17 in Haiti after the 2012 earthquake [8], a project that failed due to the technical failures regarding the biogas and lights and the poor socio-cultural context assessment. Also in 2015, solar-powered shelters were installed in Kawergosk (Iraq) for lighting and phone charging, but the lack of funding prevented a further development of the project [6].

No examples of clear success of solar programs in refugee camps or emergency situations have been found in the literature, and so one must look up for the keys to success in the long-term solar programs in rural electrification [9,10], where solutions for a practical implementation of solar energy with the focus on the final user needs have been often linked to a major implication of these final users: when the final user is the owner and has to pay a fee and care for the system, the program works. There are multiple examples of this solution in the literature, as the experience from Aguilera and Lorenzo between 1988 and 1993 in the Bolivian High Plateau [11], where they achieved a high degree of satisfaction in the final users by providing local maintenance and repair capabilities along with a local production of solar components (Balance of Systems – BOS, essentially), obtaining a high degree of self-sufficiency. Each family had to get involved additionally with the system

itself, paying an initial and monthly fee. Another key example is the Grameen Shakti solar home system program in Bangladesh [12], which uses the mini-credit concept of the Nobel Laureate Muhammad Yunus. Of course the payment of a fee might be problematic on a refugee situation, but the solutions that have been worked in rural electrification should be studied in detail and applied (with the appropriate modifications) to humanitarian contexts.

Regarding the advance of the solar photovoltaic technology and its application to refugee situations, the UNHCR report from Lahn and Grafhm states [6] that the rapid falling of prices of solar photovoltaics and light-emitting diodes is introducing changes in the humanitarian system, as ‘sustainable energy solutions are now more cost-effective than traditional technologies in many countries’. In places where the technology supply chains and financial systems are already established, solar energy is spreading rapidly even without assistance. But it is necessary to guarantee the long-term performance, reliability and social acceptance [13] of the photovoltaic systems installed in these new settlements (refugee camps) to ensure the rapid widespread of this clean energy into the humanitarian sector so it can make an impact in the living conditions of the refugee population.

This work presents the results of a field study conducted at the Saharawi refugee camps, inspecting the photovoltaic systems installed in the health institutions after 10 years of use. The main objective of the work has been to identify the technical and social issues related to the adequate operation of the photovoltaic systems at the health institutions within the camps so the electricity access can be guaranteed. A comparison with the situation in other camps or rural areas has been conducted in order to analyse the potential problems and most suitable solutions.

## 2. The Saharawi refugee camps

The Saharawi refugee population is one of the longest international



Fig. 2. Saharawi dwellings: typical tent ('jaima') next to an adobe house, with no electricity access.

conflicts with no resolution yet. It has been more than 40 years now, with a population of about 165,000 -according to local authorities- living under the harsh conditions of the Sahara desert, with very limited access to basic needs such as electricity.

Saharawi refugee camps were established in 1975 in the initial stages of the international conflict in Western Sahara in Tindouf, Algeria (Fig. 1) [14]. They are currently composed by one institutional centre (Rabouni) that comprises mainly the ministries and administrations; and five refugee camps that correspond to the five administrative regions ('wilayas') separated physically between them: El Aiun, Awserd, Smara, Dakhla and Boujador (Boujador is near Rabouni, not shown in the Figure). Then each wilaya is organised in smaller communities or districts called 'dairas'. Most of the Saharawi population live in these dairas in tents ('jaimas') and/or rudimentary adobe houses that usually do not have access to electricity (Fig. 2). Only in the last years, the government of Algeria has slowly started to provide connection to the electricity grid to the refugee camps, and Smara and Boujador have some access to the grid, as well as the institutional centre of Rabouni. But the majority of the population is still 'in the dark'.

This is particularly critical for the case of health centres, which require electricity for their normal operation, not only for lighting but also for fridges that keep medicines and for powering specific medical equipments. In fact, it has already been stated that the lack of access of energy in the health centres has serious effects on the overall population health [10,15], and [16]. Regarding the specific organisation of the health centres at the Saharawi camps, it is as follows: there is a national-level hospital located in Rabouni, then each wilaya has a regional hospital (except Boujador), and finally each दौरا has a community medical centre. In total, there is 1 national hospital, 4 regional hospitals and about 29 medical centres disseminated amongst the refugee camps. From all these medical institutions, only the national hospital has access to the electrical grid, and in the last years the Smara regional hospital. The rest, 3 regional hospitals and 29 medical centres, lack from an appropriate access to energy, which added to the lack of other basic resources such as an adequate health system (number of doctors, access to equipment, medicines, etc.) and drinking water [17], make the situation of these centres very precarious and vulnerable. The situation is often worse in the smaller community medical centres, where one of the problems reported by the local authorities is the lack of electricity at night during births.

A multidisciplinary team from the University of Jaén (Spain) and IMDEA Water (Spain) is currently working in the fields of health, education, energy and water, with a special focus on the health institutions, with the final aim of improving the lives of the Saharawi population by improving access to basic needs while promoting local autonomous management. The project is funded by the Andalusian Agency for International Cooperation and Development (AACID). During 2015 and 2016, several visits have been conducted to work on

the different areas and their interrelationship.

For the case of the energy team, the objective of the work has been to assess the current state of the electricity access provided by photovoltaic systems at the health institutions from the Saharawi refugee camps, identifying potential problems and exploring their causes, and ultimately proposing solutions that serve to improve the energy access and thus the living conditions of the refugee population.

### 3. Methodology

#### 3.1. Zone of study

Field analysis of the photovoltaic installations at the health institutions was conducted during the visits of the multidisciplinary team in 2015 and 2016. These health institutions can be divided into two large groups: first, the large installations such as regional hospitals and the school of nursing, and second, the smaller community medical centres. The large installations studied include the four regional hospitals corresponding to four of the five wilayas (El Aiun, Awserd, Smara, Dakhla; Boujador does not have its own regional hospital yet) and at the School of Nursing 'Ahmed Abdel-Fatah' in Smara. On the other side, seven community medical centres were inspected covering different conditions regarding operation and maintenance characteristics: five at El Aiun (dairas of Boukra, Hagunia, Doura and Amgala), one at Awserd (daira of Zug) and one at Dakhla (daira of Gleibat el Fula).

#### 3.2. Methodology

For the field analysis inspection of the photovoltaic installations, the 'Universal technical standard for solar home systems' developed by Egido, Lorenzo and Narvarte in 1998 has been followed [18,19]. This standard was developed after a comprehensive comparison of specifications used in rural electrification programs and a worldwide experts critical review. It covers all aspects related to a solar home system, from system design and associated components, to installation, safety, user friendliness and maintenance issues. Next, the main aspects that have been considered for the field analysis inspection conducted at the Saharawi refugee camps are presented, including those related to PV system design verification, PV generator, batteries, charge controller, loads, wiring and inverters.

##### a) Design verification

To start a PV system installation inspection, the first step is to review the initial PV design, verifying that it was correct and adequate according to the local climate conditions and the expected loads, avoiding overloading. All the specifications of the components that compose the PV system must be verified to ensure that they comply with the system design. In this study, an additional method of verification was introduced, simulating the PV design production vs. the current loads of the system using the online free solar photovoltaic software PVGIS (Photovoltaic Geographical Information System) [20]. This tool allows to calculate the estimation of solar electricity generation of stand-alone or grid-connected systems in Europe, Africa and Asia, giving the annual output power. By comparison with the energy consumption of the loads connected to the system, we can confirm whether the PV design is adequate or not, determining potential causes.

##### b) PV generator

The main aspects to inspect related to the PV generator start with the orientation of the system (it should be south-oriented in the northern hemisphere) and the tilt angle of the PV modules, which should be as maximum the latitude plus 10°. The next step is to verify whether the access to the PV modules for cleaning and connection boxes inspection is easy or not, allowing for regular access. Then it is required to inspect if the PV modules are correctly fixed to

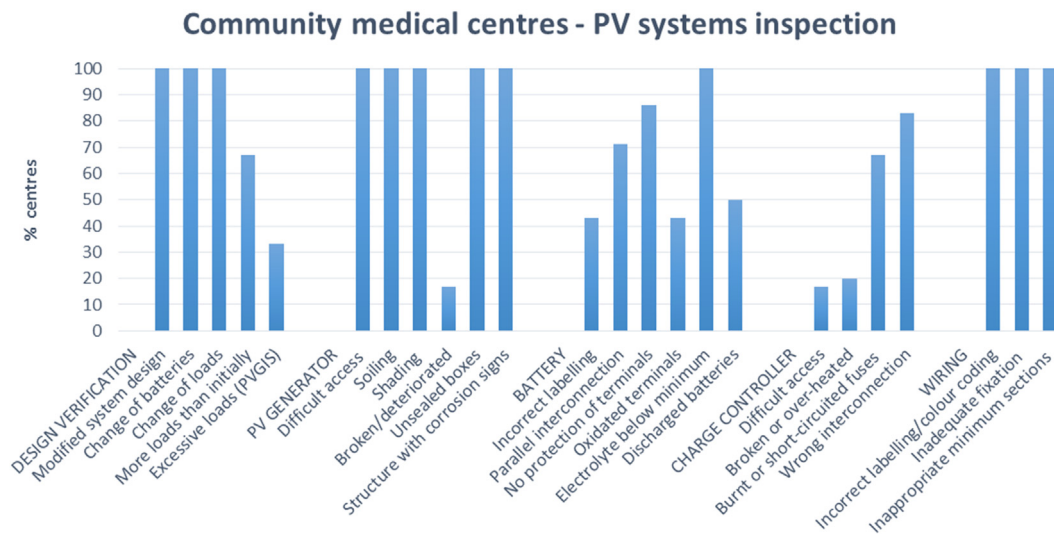


Fig. 3. Main issues regarding poor operation and maintenance of PV systems in community medical centres in the refugee camps of Tindouf, including aspects related to design verification, PV generator, batteries, charge controller, loads, wiring and inverters.

the structure, if their surface is clean, if they are without shading, and if they are not broken or deteriorated. As the refugee camps are located in the desert, it is critical to assess the specific environmental factors, in this case, apart from exposure to high temperatures over the year, dust from desert sand on the modules surface. Soiling from dust on the PV cells has been identified as one of the main causes of power loss in PV plants, especially in harsh environments [21–25], so the assessment of the dust over the modules in the refugee camps will be compulsory. Finally, the state of wiring must be revised, checking the wiring itself, the connection boxes that must be sealed, and identifying any corrosion signs that could compromise the safety and performance of the system.

#### c) Balance of Systems (BOS)

BOS components include the battery, the charge controller, the loads, the wiring and the inverters. Regarding the battery, the aspects to be inspected are: identification of type and capacity (is it adequately labelled?), no parallel interconnection of batteries, existence of measures to avoid short-circuit terminals, no oxidation of terminals, appropriate location in a well ventilated space with restricted access, no presence of liquid leakage and/or other broken elements, state of wiring (no corrosion), electrolyte levels and density (level above minimum, density above 1.1 g/cc and below 1.28 g/cc), and state of charge (no fully discharge, with open-circuit voltage above 11.4 V).

Aspects related to the charge controller and its inspection are: appropriate location in a covered place (protected from sun and rain), easy access to fuses and terminals, no signs of being broken or over-heated, alarm signs off, adequate voltage levels according to its specifications, fuses in adequate conditions (not burnt nor short-circuited), and adequate interconnections with PV modules, batteries and loads.

Main issues related to loads to be inspected include the type of loads, their nominal power, and appropriate interconnection. Then, depending on the type of load, other aspects might be revised, for example in the case of lamps, it is required to review if they are functioning and if their general state is ok (no blackened or broken).

Wiring must be correctly labelled and colour coded, with protections, and adequately fixed to the support structures and walls. Other important requisite is the minimum section of the cables: from PV to charge regulator must be at least of 2.5 mm<sup>2</sup>, and from the charge regulator to the battery the minimum is 4 mm<sup>2</sup>. Finally, they must not allow for excessive voltage drop and associated plugs and switches must be correctly functioning.

Finally, for the case of presence of AC loads requiring inverters, the

inspection covers standard aspects of correct operation: appropriate general condition (not broken, no over-heating signs), alarm signs off, fuses in adequate conditions (not burnt or short-circuited), and adequate interconnections.

## 4. Field analysis results

Results from the photovoltaic installations analyses, including both the community medical centres and regional hospitals, are presented below.

### 4.1. Community medical centres

After a comprehensive inspection of the PV installations, it is important to note that there is not a pattern per wilaya neither daira, i.e. there are not significant differences between wilayas, and all results are uniform within medical centres in all refugee camps, which means that the same issues have been found all around.

In general, the average size of the PV systems installed at the community medical centres is 325 W<sub>p</sub>, usually composed by 5 PV modules of 65 W<sub>p</sub> each, a group of batteries and a charge controller, plus the loads that are mainly fluorescent lights and a small fridge to store medicines. From the RASD Ministry of Health reports [26], the average system age is 10 years (ranging from 9 to 12) by 2015, with the exception of the batteries that have been changed at least once over the 10-year period, with a final average of batteries on only 3 years.

#### 4.1.1. Design verification

On the positive side, one of the main aspects is that the initial PV system designs were adequate according to the climate conditions and expected consumption from the loads [19] initially calculated. Another positive fact is the high quality of the components that have been used for the PV system.

But although the PV systems were originally designed accordingly to the climate conditions and the expected loads, these designs have been modified and not respected during their current 10-years of life. 100% of the revised systems have been changed (Fig. 3), with change of batteries and/or loads being the main components that have been replaced. In general, the connected loads have been increased (67% of the installations) without considering the real capacity of the PV system. In fact, in more than 33% of the cases the loads are excessive according to the initial design after a simulation of the power generated by the PV installation using PVGIS and the current connected loads. This has

affected dramatically the average lifetime of the batteries, which have achieved lower lifetimes, from the standard average of 7–9 years down to 2–3 years. All the inspected PV installations had changed their batteries at least once over their 10-year lifetime.

This overloading of the system is common in all solar electrification programs, especially when the needs of the final users have not been adequately assessed or they have changed after a period of time and no training was provided so the user does not know how to do it correctly. Another example in a refugee camp is the connection of two mobile phones instead of one to the solar lanterns deployed in Burkina Faso to the point of not using the solar lantern for its initial purpose that was lighting [5].

#### 4.1.2. PV generator

Regarding the PV generator, the orientation and tilt angles are correct, the PV modules are correctly fixed to the structure, and the PV modules are in general in good condition (only 17% broken).

But there are other issues that have been found that are critical for the good operation and maintenance of the PV systems, such as the absence of easy access for PV module cleaning and connection boxes inspection (100% cases). In some cases, the easiest access to the PV installation had to be done by parking the car next to the rooftop and then jumping directly onto the rooftop (Fig. 4a). Another issue is the shading of PV modules by their own support structure and/or other

external elements (100% of the systems). In Fig. 4b an example of shading of the PV module by its own structure is shown, where it can be also observed the corrosion of the structure (100% cases) and the soiling on the PV module surface (100% cases). Fig. 4b also shows the serious soiling on the surface of PV modules, mainly from dust from the desert sand, which will have a high impact on the total power production, decreasing it dramatically. Another examples of shading on the PV modules are shown in Fig. 4c, where the shading is produced by a fence installed by the director of the community medical centre to protect the modules from children using them as a slide to play (Zug, Awserd); and in Fig. 4d, with a shade over the modules produced by the only tree found in the vicinity Gleibat el Fula (Dakhla). Finally, the last issue found is related to the connection boxes that were unsealed (100%), often with sand inside.

#### 4.1.3. BOS

Regarding the batteries, the main positive findings are the appropriate location in a well-protected place and the lack of liquid breakages. On the contrary, some of the identified issues that should be solved as soon as possible are: incorrect/inexistent labelling of type and capacity (43% of cases), oxidated terminals (43%); and lack of measures to avoid accidental short-circuit between terminals (86%). But the most serious issues are the parallel interconnection of batteries (71%), the electrolyte levels below the minimum that reduce the lifetime of the

### COMMUNITY MEDICAL CENTRES – PV GENERATOR ISSUES



(a)



(b)



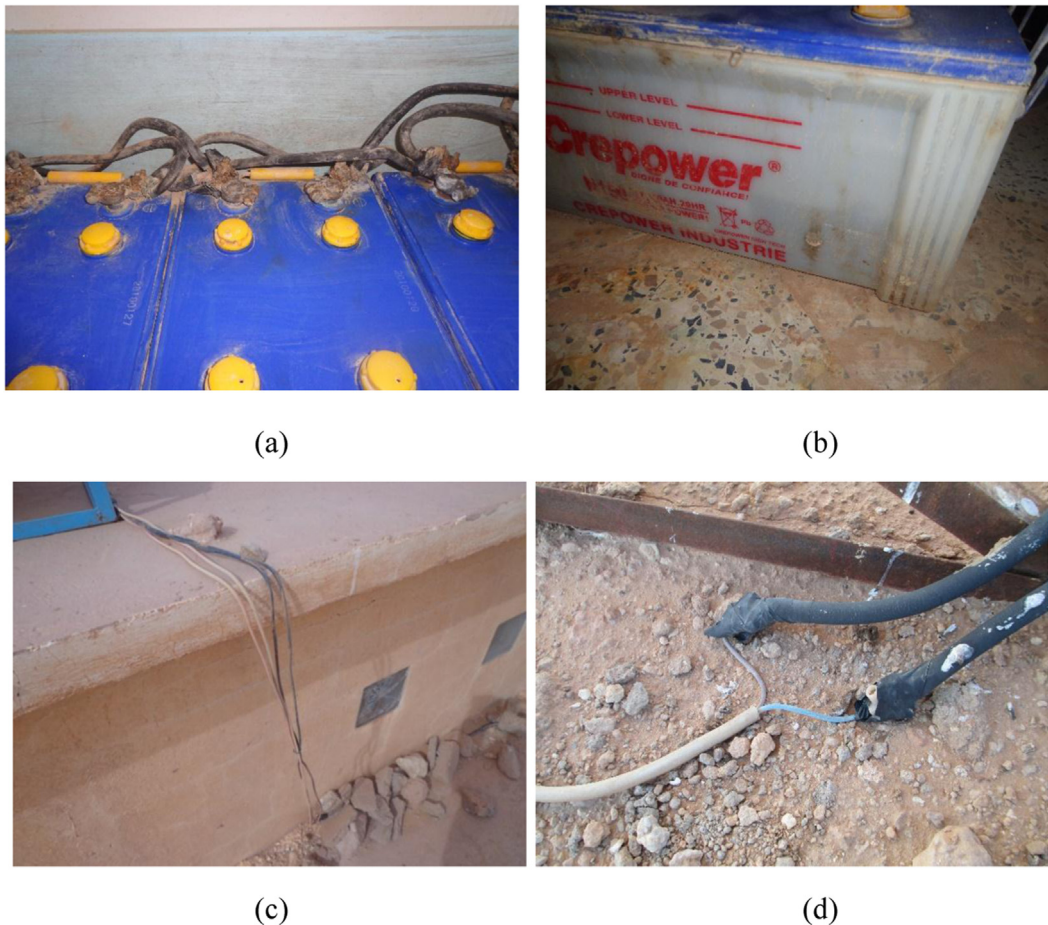
(c)



(d)

**Fig. 4.** Examples of issues related to the poor maintenance of the PV generator in community medical centres: a) absence of easy access to the PV generator for cleaning or inspection in Boukra (El Aiun), where the access had to be conducted by parking the car near the PV generator rooftop and then jumping directly; b) shading of the PV module in its edges by its own structure in Hagunia (El Aiun) and corrosion of the structure plus serious soiling on the surface of the PV; c) shading in the PV module produced by an external component, in this case a fence over the modules for protecting them from children using the modules as a slide in a park (Zug, Awserd); and d) shading produced by a tree in Gleibat el Fula (Dakhla).

## COMMUNITY MEDICAL CENTRES – BOS ISSUES



**Fig. 5.** Examples of issues related to the poor maintenance of the BOS in the community medical centres: a) oxidated terminals of batteries in Boukra (El Aiun); b) batteries electrolyte levels below the minimum in Hagunia (El Aiun); c) incorrect fixation of the wiring from the support structure to the walls, without protection in Zug (Awserd); and d) lack of use of wiring of appropriate sections in Boukra (El Aiun).

batteries (100%); and the fully discharge batteries (50%). Fig. 5a and b show several examples of these issues.

The charge controllers were always in adequate places, covered, and usually with easy access to fuses and terminals (only 17% presented a difficult access). Most of them were also in good conditions, not being broken nor over-heated (only 20%). Main issues to be solved were related to the state of fuses, which were absent, burnt or short-circuited (67%). The other important problem was the wrong interconnection of the charge controllers, as 83% were not adequately connected: direct interconnections between the PV modules and the batteries were detected, ignoring completely the charge controller function.

Overall, all the loads were correct in type and performance, including both state of the loads (for example, in lamps, no signs of blackening) and interconnection. The only issue was already reported in the first section related to design verification: some cases with excessive loads according to the PV installation capacity.

The interconnection and wiring presents several problems in all PV installations, from lack of correct labelling and colour coding (100% of cases), to inappropriate fixation to support structures and walls (100%) and lack of use of minimum sections of cable for the interconnections (100%). Fig. 5c and d show various examples found during the inspections.

### 4.2. Hospitals and school of nursing

Four regional hospitals and the School of Nursing were inspected. In

this case, the PV characteristics of each installation are very different between the hospitals (as opposed to the community medical centres that were very similar). For example, regarding size, the PV systems range from the 960 Wp of the hospital of Awserd to the 2200 Wp of El Aiun, the 4620 Wp of Dakhla or the 11880 Wp of Smara. The School of Nursing installation was 1566 Wp. This means that the PV systems are very different, including several types of PV modules, charge controllers, batteries, inverters and/or loads. It is usually due to various programs from agencies that try to renovate and improve the hospitals installations, often without coordination between them. As a consequence, the PV systems are also very different in lifetime: while Dakhla and Smara hospitals have installations with 3–8 years age, Awserd hospital installation is 12 years old and the School of Nursing is 18–20 years old. From El Aiun hospital there was no available data regarding the system age. But as presented below, despite the different PV system core characteristics, the installations show similar results/problems regarding the operation and maintenance issues of the different components (Fig. 6). All these large installations have an additional diesel group.

#### 4.2.1. Design verification

The initial designs of the PV systems have been always changed, not only by including more loads but also modifying the PV generator configuration, usually trying to increase the total nominal power of the system. But this latter modification has not been done properly, and it is common to find modules of different characteristics connected in series

## REGIONAL HOSPITALS AND SCHOOL OF NURSING

### a) El Aiun



### b) Awserd



### c) Smara

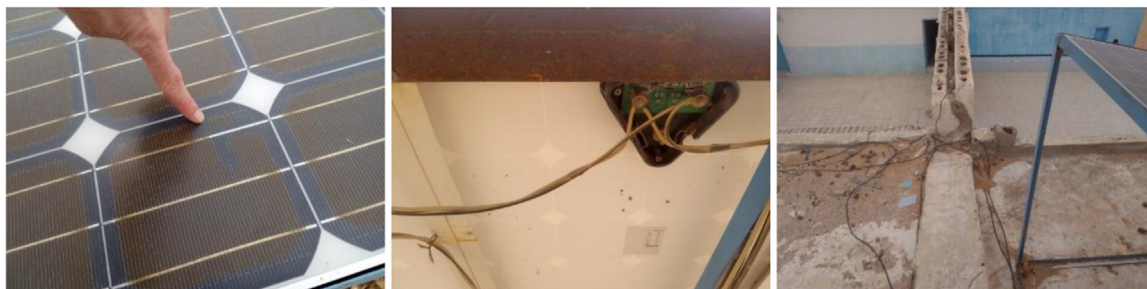


Fig. 6. Regional hospitals and School of Nursing PV installations showing similar problems regarding operation and maintenance: a) El Aiun, overall view of the installation and detail of some issues, such as sand within the connection boxes and shading by misalignment of the PV structures; b) Awserd, problems with the PV generator showing burnt cells in the modules and poor wiring; c) Smara, burnt cells and broken glasses in the PV modules, poor wiring; d) Dakhla, overall view with a fixed antenna in the middle that provides shading over the PV modules, poor wiring and not appropriate location for the batteries; and e) School of Nursing, showing different types of PV modules with burnt cells, poor wiring.

**d) Dakhla**



**e) School of Nursing**



**Fig. 6.** (continued)

and parallel in the same array, leading to performance losses and malfunctioning of the PV generator (causing hot spots).

Regarding loads, it has been observed that they are always excessive, and although some of them are supposed to be connected directly to the diesel group, the inspection showed 12 Vdc cables connected directly from the loads to the batteries, without passing through the charge controller.

**4.2.2. PV generator**

Main issues related to the PV generator are similar to those found in the smaller community centres inspection: lack of easy access to the PV modules, soiling on modules, unsealed connection boxes (often with sand inside), shading by the structure or other external elements (trees, antennas, etc.). The main difference with respect to the smaller medical centres is the conditions of the PV modules: while in the centres they were usually in good condition, the modules at the larger installations

(hospitals and school) were in poor conditions, including burnt cells and/or broken parts (glass). All the installations showed burnt cells within the modules. This is due to the wrong interconnection of modules of different characteristics (mismatch), which lead to hot spots that finally damage the modules and reduce their electrical performance, along with their average lifetime, down to 7 years when the normal values are 20 years.

#### 4.2.3. BOS

Regarding the batteries, their condition has been usually much better than in the case of community medical centres. They are usually in an appropriate location (except for Dakhla hospital), correctly labelled, adequately interconnected in series, and not fully discharged.

Charge controllers and loads are in general in good conditions, and the main issue regarding the charge controllers is their interconnection: there are often direct connections between the DC loads and the batteries, omitting the intermediate charge controller functions. In some occasions they are also connected to nominal powers that are superior to their specifications (El Aiun, Dakhla).

As for the case of the smaller medical centres, the wiring presents serious deficiencies, which are more significant in these larger installations due to the increased number of interconnections and lengths of cables: lack of minimum section of cables, inappropriate fixation to support structures and inadequate protection including exposed interconnection of wires to outdoors conditions (sun, wind and sand).

Finally, inverters have been found to be working properly and the main problematic issues have been the absence of fuses and protections in some cases, malfunctioning in one of the installations (Awserd), and the connection of superior power than the specifications of the inverter, wasting energy production (El Aiun).

## 5. Conclusions

After a careful and comprehensive inspection of the PV installations at the health institutions of the Saharawi refugee camps, including both large installations (four regional hospitals and a school of nursing) and smaller systems (seven community medical centres), main conclusions related to the identification of technical and social problems associated with the adequate PV systems operation are that although the PV components used in the installations are usually of very high quality, the maintenance is practically inexistent.

*There is a lack of training on operation and maintenance of the PV systems once the installation and set-up is complete, which is even more dramatic when added to the special conditions of the Saharawi refugee camps, where there is also a lack of cooperation between the different agencies that work in the field.* This means that despite the best of the intentions and important efforts made, the agencies usually focus on a particular installation (especially the smaller agencies), which they fund, going to the field, completing the installation and then leaving, usually with no time for training of the personnel that will be in charge of the day-to-day. If the agency is lucky and the funding continues, they might keep the collaboration with the local personnel, but it is difficult to find numerous examples of a long-term collaboration. This is in agreement with other works regarding solar programs in refugee camps, usually lacking funding for sufficient time [7,8]. In general, we have found that the same PV installation corresponding to a particular health centre has been funded several times by different organisations, without coordination between them. *It would be necessary to improve the coordination of the efforts made by different organisations so the cooperation can be maintained over time, especially for the cases of refugee camps that persist in time (the 'protracted refugee situations').*

In more detail, *the lack of training of the local personnel for operating and maintaining the PV systems have led to several problematic issue that reduce rapidly the lifetime of the systems:* from the absence of access to the PV generator for cleaning and inspection, to the general soiling found or the high percentage of modules presenting hot spots (for example all

the large installations presented damaged modules with burnt cells), which have reduced the PV modules lifetime from 20 years to only 7 in average.

On the other hand, initial PV systems designs have been modified over time without considering the sizing of the PV installation, usually due to the lack of training on PV systems. The modifications have largely corresponded to an increased number of loads connected to the systems that are in general excessive according to the system characteristics, i.e. the loads have increased but the PV generator and BOS (Balance of System) have not been re-sized. This has been especially critical in the larger installations such as the regional hospitals. The main consequence has been the reduction of the lifetime of batteries, from 8 to 10 years to only 2 years in some cases. This is in agreement with other works, where the loads were modified over time, resulting excessive and not using the systems for its initial purposes [5].

Wiring and interconnection have also presented many problems, especially caused by the modifications in the systems that have been done without a careful defined project. In some cases, inverters have been changed by new ones with smaller nominal powers than the previous ones. In other, direct connections between batteries and loads bypassing the charge regulators have been detected. Other interconnection issues have been related to the PV modules: in the cases where the PV generator has been changed with the objective of increasing the total system power, the inspection has shown that PV modules with different characteristics have been connected in series and parallel within the same array, thus reducing the overall system performance and causing the generation of hot spots. The other important issue has been the parallel interconnection of batteries, which is totally inadvisable as it reduces their lifetime. Finally, wiring has been generally done without respecting the minimum standard sections and without the appropriate protections neither fixations.

*To solve this situation, it would be necessary to organise a strong training program on PV systems, including both general concepts (especially sizing and interconnection) and operation and maintenance. This should be also done when a new installation or update is planned by any agency, at the same time of the field work.* This would not only increase the current lifetime of the systems but also improve the living conditions of the Saharawi refugee population that continues relying on PV systems for the electricity supply in the health centres.

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