Energy for Sustainable Development 40 (2017) 68–76

Contents lists available at ScienceDirect

Energy for Sustainable Development

Practical constraints for photovoltaic appliances in rural areas of developing countries

Lessons learnt from monitoring of stand-alone systems in remote health posts of North Gondar Zone, Ethiopia

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ARTICLE INFO

Article history:
Received 20 April 2017
Revised 2 July 2017
Accepted 2 July 2017

Keywords:
Photovoltaic stand-alone systems
Rural electrification in developing countries
Maintenance
Gender
User training
Remote health centers

ABSTRACT

Photovoltaic stand-alone systems are largely regarded as a viable option for decentralized rural electrification in developing countries. However, literature review reveals lack of documented experiences with installed PV systems such as Solar home systems as well as general problems with system maintenance and battery up keeping. This paper presents results from monitoring 31 stand-alone PV systems in remote health posts of North Gondar Zone in Ethiopia from installation until system failure; several systematic factors were found to have contributed to failure: lack of clear responsibility for the systems due to regular job rotation among health workers and lack of upfront, gender sensitive training, lack of equipment for maintenance work, very slow and unreliable chain of information in case of system failure and costly double tracking of energy supply. Nonfunctioning PV systems were found to threaten the technology"s reputation by word of mouth. The results gained in this research provide important lessons for future programs of rural electrification by means of PV systems: they stress the importance of awareness building amongst funding agencies as well as the imperative of intense and sensitive training for users, especially women, and advocate for considering living conditions of users in system design.

Introduction

Lack of access to electricity is frequently indicated to dampen or even hinder economic development in rural areas of developing countries. Existing literature on electrification stresses the hopes for benefits on socio-economic effects. Three areas of impact are assessed: educational benefits because of increases in study time, improvements in income because of increased non-agricultural activities, and decrease in respiratory diseases because of decreases in usage of open fire, candles and kerosene.

To this background, the United Nations set their aim of universal access to electricity by 2030 via their initiative Decade of Sustainable Energy for All (2014–2024) (The Secretary-General's advisory group on energy and climate change (AGECC), 2010). More than 1.3 billion people in developing countries lack access to electricity today; Out of these, 590 million live in Africa where the rural electrification rate is only 14% (International Energy Agency, 2012: 226). The investment requirements for electrification on the continent are therefore enormous: International Energy Agency (2011: 483) quantified them to 390 billion US Dollars if universal access to electricity should be achieved by 2030.

Given these requirements, photovoltaic stand-alone systems[1] are largely held as a viable option for decentralized rural electrification in developing countries. Ecological sustainability of renewable energy sources such as PV, paired with the general abundance of solar energy in the regions in question, have frequently been cited as prerequisites almost demanding the adoption of this specific technology in remote areas of the Global South, especially as "few connected households consume an amount of electricity and require peak loads that cannot be provided by off-grid technologies." (Peters and Sievert, 2015).

Additionally, low running costs of PV systems are perceived as beneficial for poor and marginalized sections of the rural population, diminishing their dependence on increasingly costly and unsustainable fossil fuels – this is regardless of the actual devices powered by electricity generated by photovoltaic panels. Furthermore, health risk reductions are identified in regard to lighting when candles and kerosene lamps are replaced by CFLs (Compact Fluorescent Lamps) resp. LEDs Light Emitting Diode; whether they are powered from PV generated electricity or grid connected). These lamps significantly "reduce" both the quantity of fume inhaled by household members and the associated fire hazards.

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[1] PV generators (panels) not connected to a public electricity grid and thus relying on suitable storage media such as batteries.

http://dx.doi.org/10.1016/j.esd.2017.07.001
0973-0826/

While this last causality remains largely uncontested and valid, doubts have increasingly arisen with regards to the general suitability of the PV technology in the said rural context. So while Vervaart and Nieuwenhout (2001), for instance, give a figure of 1 million solar home systems which had been built until early 1999, they state: "Very little information is available about the actual use of solar home systems[2] in practice. There are some scattered monitoring activities." They see ownership as an important factor in the attitude of people toward their PV systems and their maintenance: "A sense of ownership is a strong incentive for maintaining the system. For this reason, projects where the government provides the systems at no charge usually show much higher failure rates than commercial schemes."

Similarly, Nygaard (2009) cites Togola (2001), Afrane-Okese and Mapako (2003) and Martinot et al. (2002) as finding that "donor supported PV projects have in a number of cases only been operational for a few years due to economic, technical and organizational reasons".

Villavicencio (2002) has analyzed the viability of solar home systems[3] using indicators such as affordability, efficiency, freedom from risk of obsolescence, flexibility and technological capability. Based on this analysis he contests that PV systems are a universal energy strategy for rural households in developing countries, because, as he argues, solar home systems are expensive, inefficient, have a high risk of obsolescence and are far more difficult to maintain than expected.

It turns out that maintenance requirements center around battery quality: "It is not always realized that batteries are usually by far the most expensive part of a solar home system over the lifetime of the system. Lifetime of batteries vary considerably from project to project, from less than 1 year to more than 4 years." (Nieuwenhout et al., 2001).

Vervaart and Nieuwenhout (2001), too, stress this point when finding: "The total costs of the different components, over a life cycle of 20 years, present a different picture than for the initial costs. […].. the cost of batteries increases from 13 percent to 46 percent, substantially greater than the life-cycle cost of the modules. […] To reduce the 20-year cost of solar home systems, it is therefore of utmost importance to increase the lifetime of the batteries used."

One crucial factor for battery life expectance is system maintenance: Erkkila (1990), examining the case of solar refrigerators, comes to the conclusion that "contrary to the unfortunate common perception, solar refrigerators are not miracle machines which can be forgotten once installed and have no need of maintenance and repair thereafter. Indeed, experience has shown that […] solar refrigerator projects, without ….well – established support system for maintenance have minimal chance of succeeding."

Foley (1995) agrees that "perhaps the greatest weakness of PV programs to date has been the serious underestimate of the need for adequate repair and maintenance systems" Hence, he identifies user awareness as the second key issue for the avoidance of system failures in the long run: He claims that "People need to be made aware […], what systems can provide, and, equally important, what they cannot. They need to be told of the need for maintenance and how to carry it out. They need to know about the management of loads on the systems – for example, restricting the use of lights and appliances during cloudy periods". The technicians involved in the installation, maintenance and repair of PV systems need to be trained if they are to do their jobs properly. But Foley warns: "Simply providing training courses for technicians will not meet this need. Unless these technicians are employed and appropriately compensated for their knowledge, they will not consolidate their skills, and the training will be wasted."

[2] A small, photovoltaic (PV) system that consists of one or more solar modules, a battery and several 12 Vdc appliances.

[3] Small PV systems of a few W_p (Watt peak) capacity only, deployed mostly to private households, primarily for energy use in lighting, radio, TV or refrigerator.

It is evident from these findings that electrification by means of PV solar technology has to be regarded as a yearlong process rather than the mere installation of the required devices at the beginning. Therefore Nieuwenhout et al. (2001) come to the conclusion that "For a considerable number of these [hundreds of solar home systems (SHS) projects which have been conducted in the past few years], descriptions of the organizational set-up exist, but only very few studies describe in some detail how SHSs are actually used by households. Some early successes might have given the impression that everything is running well and there is no need to spend time and money at this stage on further research. But relatively high failure rates, even in some recent projects, prove that there is still scope for improvement. … Those studies that were available usually deal with the first 1–2 year of the project, while information over longer periods of time is more relevant to conclusions regarding lifetime of equipment and sustainability in general. Negative experiences are seldom narrated. Monitoring needs to be continued after the installation stage of the project."

Need for further research in this respect is clear. Accordingly, keeping track of systems' performance after installation until system failure therefore was one of the main purposes of the investigations presented in this paper which studies PV systems in remote rural health posts in Northern Ethiopia. Not surprisingly, the issues of maintenance, user awareness and training with regards to system operation turned out to be of crucial concern in this instance again.

Finally, against the background of public efforts to effectuate the broadest possible rural electrification, related policies turn out to be of major influence on outcome and sustainability of PV projects and they therefore have to be explicitly addressed in project design and implementation. Martinot et al. (2000: 14) reports that some participants in his investigation "cited unrealistic political promises or planning about rural grid extension as a serious barrier to solar home system market expansion, …". And he states: "Of course, all else being equal, households would prefer to be connected to a grid than obtain energy services from a solar PV system. Still, in most countries, 100 percent grid extension is too costly and unrealistic." Thus, in monitoring the long term functioning of PV systems in remote rural health posts in Northern Ethiopia, several supply systems (PV, public electricity grid, kerosene, diesel generators) existing in parallel were found to pose questions on reliability and sustainability as well as donor driven development.

Material and methods

General description

In 2010, several remote rural health stations in Amhara Province of Northern Ethiopia were equipped with stand-alone PV systems for lighting and solar refrigerators.

This partial rural electrification program was implemented in close cooperation of the Amhara National Regional State Bureau of Health (ANRS BoH) and the Provincial Government of Lower Austria (PGLA) as funding partner.

The two partners agreed on a recurring monitoring of the installed systems to keep track of their further functioning; regular visits aim at updating information on the current state of the systems and at thereby providing a data base for decisions on further measures required to maintain the functionality of the PV systems. So far, two monitoring visits to the project area have taken place in 2011 and 2013 respectively.

While monitoring is ongoing, results up to date stress the importance of training on PV maintenance for the concerned health workers, – most of them female -, their empowerment and the clear definition of responsibilities within the organizational framework of ANRS BoH. The monitoring has thus proven to be a reliable key for engaging both donor and local agency in a sound collaboration to the end of supporting and improving electrification of rural health care by means of Photovoltaic.

Location and climate

The Project area is located in North Gondar zone, a region north of the provincial capital Barhir Dar and a local center, the historical city of Gondar. The latter one is situated at a height of 2133 m and the whole zone is generally characterized by mountainous terrain except for the low laying districts nearing the Sudanese border to the West (around the city of Metenma) and Eritrea to the North (border city Humera).

The local climate features average temperatures ranging from 13 to 26 °C and a distinct rainy season between June and August. During these months daily hours of sunshine drop to 3.7–4.5, while for most of the rest of the year this figure is higher than 8 h per day. Average daily solar irradiation falls within a range from 2100 to 2800 W/m^2.

31 remote rural health stations were equipped with stand alone PV systems in 15 of the 23 *woredas* (districts) of North Gondar Zone, 6 of them providing electricity supply for both refrigerator and lighting while all further systems provide lighting only.

Technical specification

Systems exclusively used for lighting consist of one 80 W peak (Wp) photovoltaic panel, two car batteries of 90 Ampere-hour (Ah), a charge controller and up to 10 CFLs running on direct current (DC) (Figs. 1 and 2).

In health stations equipped with both lighting and refrigerator a second system is installed independently. This includes a panel of 240 W_p and two batteries of 250 Ah each.

PV panels are generally installed on the station's roof; wiring via window openings is led to the charge controllers inside the buildings. Given Ethiopia's geographical location near the equator (the regional capital Gondar is situated at 12°36′6.30″N) and the consequently prevailing vertical incidence of solar irradiance, all panels were mounted in almost horizontal position (optimal inclination angle 17°) which in turn imbeds self-purification due to gravity in case of rainfall (see Fig. 3).

CLF lamps are mounted to suspended ceilings while batteries are stored in boxes on the floor.

Organizational framework

Fig. 4 displays the organizational structure of ANRS BoH in the national context as well as its substructures at regional, zonal, district

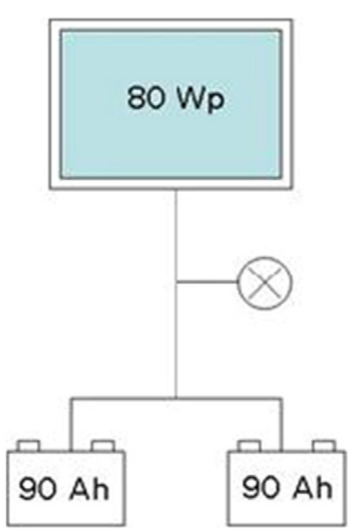

Fig. 1. Scheme of the technical system for lighting only.

(*woreda*) and village (*kebele*) level: the regional Bureau of Health is headed by ANRS office in the regional capital Bahir Dar, while the Zonal Health Department in Gondar coordinates all activities in the project area's *woredas*. These are headed by the respective *woreda* health office which is in charge of all health centers in the district. Accordingly each health center and its health center manager is responsible, not just for the center itself, but also for several health posts located in the nearby villages.

The investigated photovoltaic systems were deployed both in health centers and in health posts. The latter ones generally consist of single rectangular brick buildings (as opposed to the local vernacular dwellings, frequently of circular shape and generally built from wood, clay and straw). They serve as meeting place and storage room for health extension workers. These health extension workers are mostly women from the local community who have undergone one year of training in preventive health care. Thus, it is their main task to inform the villagers about health risks and basic hygienic measures to avoid them. They chiefly perform this task by visiting families and especially women in their own huts and compounds. Only in cases of difficult deliveries are pregnant women transferred to the health post itself where very basic tools and medication are available and the sanitary situation is supposedly better than in the family's huts.

Health centers, on the contrary, consist of several buildings fenced off from the rest of the nearby settlement. They are the working place to several health workers who have accomplished three years of medical training prior to their placement. They are mainly engaged in treating sick persons coming to the center from the surrounding hamlets and villages. Occasionally they also run vaccination campaigns and public awareness building in health matters.

Interestingly, the chief technician in charge of all 31 PV systems is a member of the Regional Bureau of Health in Bahir Dar, thus the whole organizational structure of ANRS BoH was involved in the project period; While the systems' design was decided upon in Bahir Dar, a field technician of the Zonal Health Department in Gondar was responsible for supervising the installation process which was contracted to a Ethiopian PV supplier based in Addis Ababa.

The PV systems where installed in both health posts and health centers. As most of them are located in areas without access to paved roads the technical devices, including refrigerators, had to be transported to the sites mostly by donkey. During these installation processes basic training was provided to the local health workers and health extension workers by members of the contracted installation team.

The national Ethiopian government has prioritized an ambitious program for amplification of rural health care. ANRS BoH is implementing this program for the Amhara province. Within this program it is a declared goal of ANRS BoH to upgrade remote health posts to full-fledged health centers. In the course of this development, PV systems which have originally been installed in health posts may find themselves being placed in health centers instead. However, no differentiation was made in the design of the system design for either of these two.

System usage

The organizational setting of ANRS strongly influences the way the PV systems are used: In health posts the electricity produced during daytime is mainly needed to provide light during nocturnal deliveries. While formerly health extension workers used to jam a torch light between cheek and shoulder in order to have some illumination in such instances they now have both their hands at their disposal in the process.

By contrast, in health centers PV produced electricity is more regularly used for lighting wards and rooms as at least one health worker is on duty each night for emergency calls and patients eventually stay overnight.

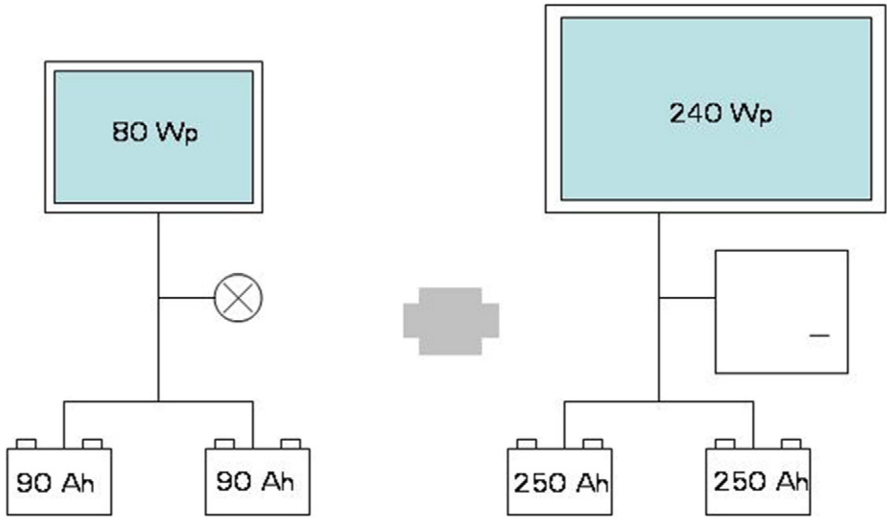

Fig. 2. Scheme of the technical system for lighting and refrigerator.

Methodology of investigation

On behalf of PGLA, two monitoring site visits have taken place in 2011 and 2013 respectively. In close cooperation with ANRS BoH these visits included: focus group meetings with representatives of Provincial Bureau of Health in Bahir Dar and Zonal Health Department in Gondar, visits to selected health stations including semi-standardized, qualitative interviews with health workers, health extension workers and health center managers as well as rough technical inspection of the PV systems and photo documentation.

Technical inspections consisted of visual checks of the installed equipment, wiring and connections for obvious failures and risks such as fire hazards due to covered batteries and potential maintenance problems.

Interviews in health centers and health posts inquired whether health workers had received on-site training, if they were satisfied with their knowledge about the newly installed PV systems and felt safe in matters of usage and maintenance, how they used the lights and refrigerator, if they were satisfied with these services and who was in charge of maintaining them.

While during the 2011 site visit all systems - except for one refrigerator and five lighting systems which had not yet been installed - were found working properly, none of them was still working two years later. In all cases failure of the installed lead acid batteries accounted for system break down. Furthermore several cases of problems with

Fig. 3. PV panel installed on a health station's roof.

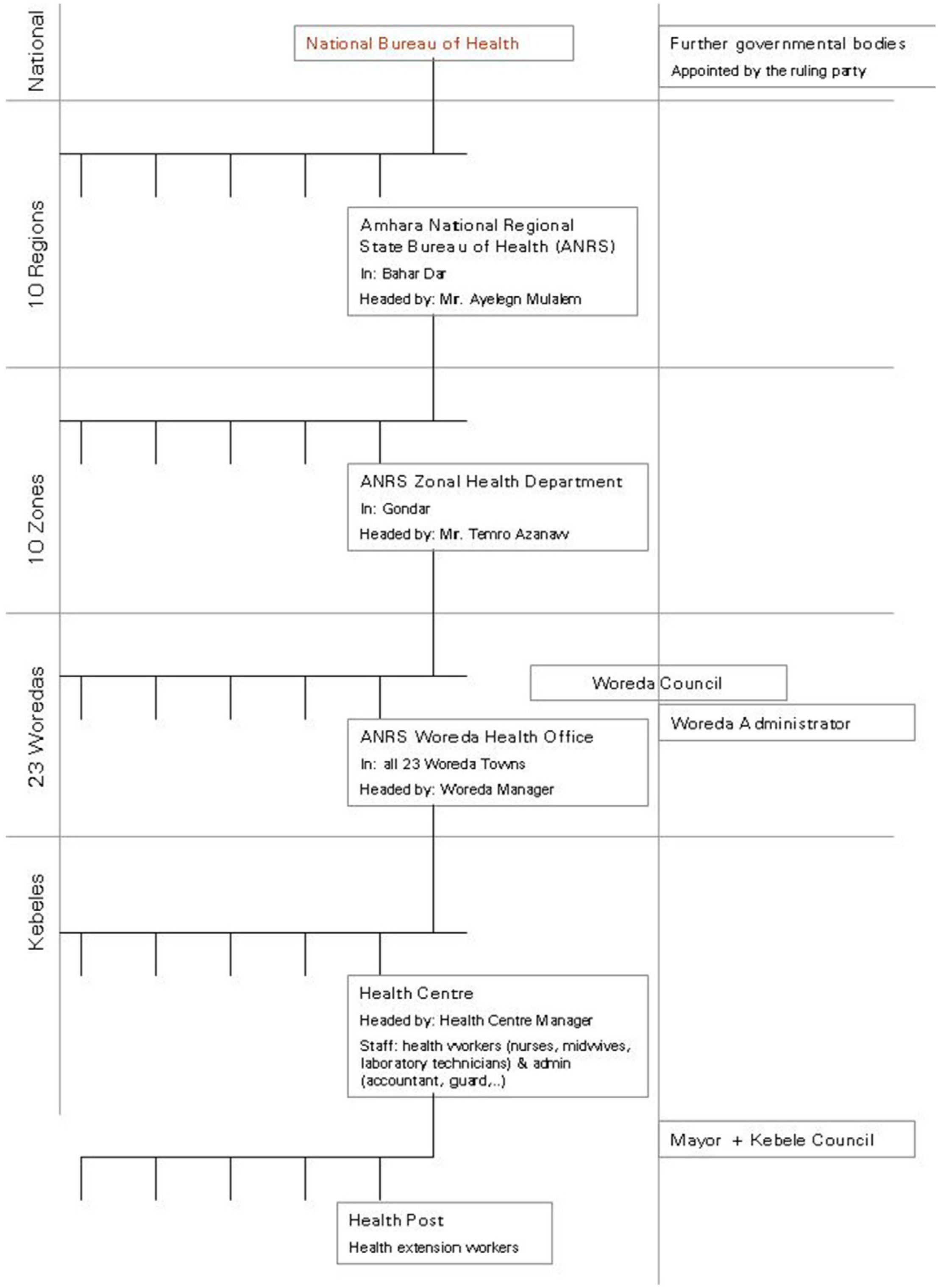

Fig. 4. Organogram of ANRS BoH.

charge controller were reported and all refrigerators displayed broken hinges (see Fig. 5; these broken hinges prevent the fridges' lids from shutting, thus leaving a slot via which warm air is able to enter). Most batteries were reported to have stopped working in 2012. Their lifespan in average thus had been about 2 years while batteries are often assumed to have lifetimes of 3 to 5 years.[4]

[4] Tschernigg & Becker (2011: 71).

Results

While harsh climatic conditions in the target region may well account for some premature battery failures, such explanation seems to miss out on further reasons which tend to be more systematic in nature.

Several observations during the monitoring site visits help to explain the developments and are therefore described in detail hereafter. This description is qualitative in nature as the scope of the PV program itself

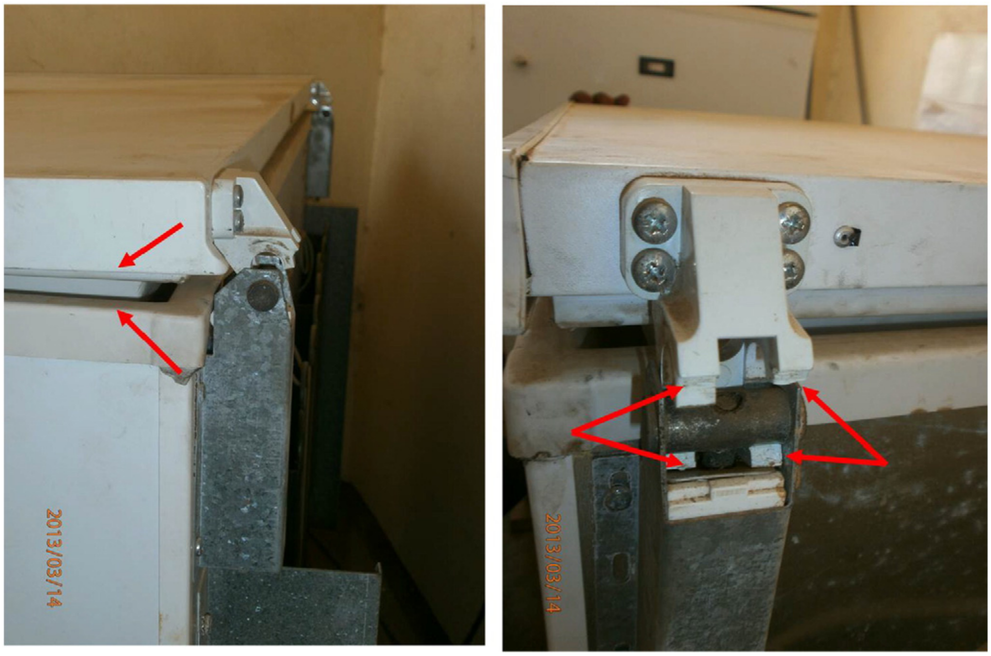

Fig. 5. Broken hinges of refrigerators.

and the monitoring of its implementation was limited and not quantitative in nature.

Personnel in charge

Already during the first visit it could be observed that clearly attributed responsibility for the PV systems was not in place on local scale. While both in the Zonal Health Department in Gondar and the Provincial Bureau of Health in Bahir Dar one focal technician was appointed as being in charge of the systems, adequate counterparts were missing in the health stations proper. Even health center managers indicated that they had not been informed about the PV systems prior to their installation. Consequently, they perceived these devices as just one more of their duties - but one which they did not know very much about. Health workers and health extension workers didn't feel particularly responsible either.

As a result, by the time of the first monitoring visit in 2011 - when most PV system had been installed for approximately one year - hardly any maintenance had taken place and health stations' staff indicated that they didn't know how to perform it.

Job rotation

The aforementioned difficulties were further aggravated by the frequent and intentional job rotation of health workers within ANRS BoH. On regular basis, health workers and even health extension workers are deployed to a new station every third year. As only 31 out of approximately 500 health stations of ANRS BoH in North Gondar Zone were equipped with PV systems under the PGLA funded project scheme each PV trained health worker shifting from a PV equipped station to another one meant a loss of information. After her or his departure there was essentially one informed person less in the station (except for the unlikely event that she or he was replaced by one of the few other PV trained health workers). It is thus to be expected that within a comparably short period of time most of the trained personnel would have been shifted to other premises, leaving the stations in question without those who - at least in theory - received PV system training. At the same time these persons were shifted to health centers and post without PV where their specific knowledge was of little use for them and ANRS BoH. Without frequent usage of this know how it has to be expected that it - and the effort originally invested in training - will be lost. During the 2013 monitoring, none of the health workers and health extension workers who had been deployed in the 31 stations of the PGLA project was encountered still working there.

Standardized chain of information in case of system failure

Several questions of the interviews during the first monitoring focused on the foreseen information chain in case of failure of a PV system and whether the health workers were aware of it. It became obvious that this information chain exactly reflects the hierarchical structure of ANRS BoH; Health workers knew that in case of system failure they had to inform the center manager of their respective center – which in the case of remote health posts could mean several hours of walk. It is plausible that a simple PV failure alone would not justify such a trip. Rather, the information would be passed on to the next health center and the *woreda* health office once other tasks prompt a health worker to get there. Only then could the information be passed further on to the Zonal Health Department in Gondar.

The department would then deploy a technician. Sometimes, however, the technician would not have the necessary spare parts or replacement batteries. The technician would then have to contact the Regional health Bureau in Bahir Dar, where three ANRS technicians were stationed. Even at the regional office, spare batteries were not available and the technicians lacked authority to purchase them without involving higher level managers. Thus, it could take several weeks to resolve a minor problem, during which time the health station personnel had to rely on other power sources.

Equipment for maintenance work

Apart from missing spare parts, proper maintenance was also hindered by the fact that due to considerations of possible theft and vandalism all PV panels were installed on the buildings' roofs. Cleaning panels in order to prevent performance losses therefore requires climbing up to these roofs (see Fig. 3). However, the ladders necessary for this purpose are either not available at all in the health stations or they are of inferior quality endangering a user's safety.

Occasional checks during the monitoring visits did not find significant dirt accumulation on the panels, however, only few checks could be performed due to the lack of ladders.

On-site training

The original call for tender for the installation of the PV systems had included the requirement to provide on-site training for health workers. The Ethiopian PV supplier contracted to provide the systems had offered this service free of charge and promised to render it within the processes of system installation. However, as this installation in many cases took place without prior announcement to the center managers and the health (extension) workers in place it seems that frequently only a couple of people from the staff happened to be present at the time of installation. As the work of health workers and health extension workers especially includes a considerable percentage of field work in preventive health care they are often absent from the health station.

Thus, the initial training by the PV supplier did not reach many of the health workers. Most health (extension) workers reported during the first monitoring visit that they had not undergone any training.

The chief technician himself had conceived a three-level training scheme, as shown in Fig. 6, which in addition to the initial on-site training, included in-depth training for health workers and specialized maintenance training of ANRS BoH technicians for repair works. Both were developed in cooperation with the PV supplier and by the time of the first monitoring one training for ten health workers, comprising four days of schooling, had already taken place in Bahir Dar. Later on, however, the chief technician was hired by UNICEF for neighboring South Sudan and left ANRS BoH, so no further training took place.

It has to be assumed that lack of instruction and training contributed to system failures. The system design presumed that a maximum of 9 CFLs would be used no longer than 4 h daily. In reality, this temporal restriction is difficult to follow. This is especially true for systems placed in health centers where staff is present 24/7 and thus there is need for illumination all night long. However, no reliable information could be gathered as to whether batteries in health centers generally failed earlier than those in health posts. In the absence of sufficient training few health workers were aware of the temporal restriction at all (let alone the difficulty of implementing it as the system would not automatically switch of in case of danger of deep discharge). Consequently, frequent deep discharging is assumed to have substantially contributed to battery failure. This in turn resulted in overall system failure even though other components such as the PV panels themselves are still operable.

Any kind of training needs to take into account that health workers' focus is in health issues, not PV. They primarily want to use electricity produced by the system but not deal with them more intensive than necessary. Training thus needs to enable them to do so.

Gender

A further aspect which was found to be of importance with regard to the functioning of the monitored PV systems is gender. The PV systems monitored are predominantly used by female health workers and midwifes to the benefit of likewise predominantly female patients all of whom come from poor rural communities.

As Razavi (1998: ii) states: “An understanding of the causal processes leading to poverty has important policy implications: it raises questions about whether it can be assumed, as is often done, that the kinds of policies that can strengthen the position of poor men will have much the same impact on poor women.”

There are what Cecelski (2000: V) describes as different “‘ways of thinking’ in the energy sector and on poverty and gender. Poverty and gender thinking prioritizes people, while energy thinking often prioritizes other objectives such as efficiency or environment.” She therefore sees a need to focus on “building up a body of evidence and experience (conceptual, methodological, and case studies) linking attention to gender in energy policy and projects to equitable, efficient and sustainable outcomes in energy and development;” and to “encourage and support a dialog and interaction between ‘ways of thinking’ in energy, poverty and gender, as well as create capacity to work in this interdisciplinary area.”

In the case of the PV systems investigated in this article, this mainly applies for the conceptualization of the afore mentioned training and user awareness building activities which urgently need to be designed to fit the needs of female users and beneficiaries.

Taking into account the distinct societal roles of women in rural Ethiopian communities, it becomes apparent that training on the correct usage and maintenance of the PV systems ought to be gender sensitive for this user group; if in such kind of training setting, a male technician is to explain matters concerning his field of expertise to a female audience it has to be doubted whether women will ask for further clarifications even if they have difficulties to understand what he is telling them about a technology which is generally alien to them.

The ability to convey a reasonable understanding of such technical matters may of course be attributed to a particular trainer's capability (and the fact whether he/she has been trained in didactical terms). It therefore needs to be checked if technicians are most suitable to teach

Level	Training for	Implemented by	Status
advanced	3 – 5 ANRS BoH technicians, in Bahir Dar	ANRS BoH chief technician, Manual from contracted PV supplier	planned, on hold
intermediate	Health (extension) worker; duration: 4 days, in Bahir Dar	ANRS BoH chief technician, assisted by contracted PV supplier	Implemented once in January 2011 for 10 Health workers; further training scheduled for workers from 21 stations, on hold
basic	Health (extension) worker; during installation process, on site	PV supplier	unclear whether all health worker received training

Fig. 6. 3 level training scheme.

these technical matters to non-technicians (which also applies for male health workers).

Energy supply double tracked

Already during the 2011 monitoring, several of the health stations visited displayed AC devices such as lamps and electrical water heaters. These had been installed even though none of the health stations had access to the public AC electricity grid at that time and therefore the devices could not be used. ANRS BoH staff indicated that this equipment was planned to be used once the public grid reached the remote village.

The national Ethiopian government is indeed running an ambitious rural electrification scheme which increased the overall national grid coverage from 13% in 2002 to 55% in 2011 (nevertheless the rate of connections at household level is a lot lower than this). The Ethiopian landscape, population spread and rural population density cause grid extension in some regions to be rather inefficient and expensive in terms of per capita connection costs (Afanador et al., 2016:4).

During the monitoring activities, construction work for electrification could be observed along several gravel roads in the hinterland. By 2013, at least one of the investigated health centers had already been connected to the grid. However, it is ANRS BoH's experience that, for the first 2 to 3 years after connection, the grid is not stable. Therefore, PV systems are intended to remain in newly grid connected health stations until grid stabilization has taken place. Only afterwards should PV systems be shifted to stations still unconnected. Doubts exist as to whether a full grid coverage will be possible at all (Martinot et al., 2002), let alone at the intended speed. AC devices might deteriorate due to environmental influences while lying idle until grid connection is effectuated.

In several investigated health stations, kerosene powered refrigerators can be found, even in those which are equipped with solar fridges. During both monitoring visits the vast majority of these fridges was not operating due to lack of kerosene. While kerosene is generally available from rural suppliers health stations generally lack funds to purchase it. In non-functioning kerosene refrigerators, damaged vaccinations were abundant. If no fridge is available in a station, health stations' staff have to hurriedly transport vaccinations from local *woreda* health offices to their stations and immediately use it in order to keep them cool.

In 2013, at least two stations had been equipped with additional diesel generators of 7 kWh capacity each. ANRS BoH personnel indicated that due to funding from different donors and budgets it is not possible to alternatively opt for battery replacement instead of generator at local level.

This is to demonstrate that a veritable double tracking of energy supply from different energy sources exists in several health stations. This can be understood as a pragmatic way of minimizing risks (out of 2 or 3 possible energy supplies at least 1 might be working at any given time). However, costs are higher than for just a single but reliably functioning supply choice.

Resulting damage of reputation for photovoltaic

In 2013, interviewed health workers complained about the PV systems which they perceived as being unreliable. Many had not received training and, knowing little about the technology, had expected PV powered devices to work like grid-connected devices. They were dissatisfied with the performance of the devices.

Interviews with manager of installation firms from the Ethiopian PV industry revealed that therein lays a considerable threat to the technology's overall reputation and the progress which could be made in implementing it on national scale. If widely uninformed users experience PV as non-reliable they will not be interested and inclined to try to use it again. They will tell others about their experiences and a negative reputation will build up and counteract efforts to shift energy supply toward renewable resources.

Conclusions

While efforts are under way to secure funding for battery replacement in this specific project some more general lessons may be learnt from it for future programs of rural electrification by means of PV systems; The results gained here fit well with broader findings portrayed in the introduction. It is therefore assumed that these findings are relevant beyond this PV program proper.

- First of all donors and funding agencies – whether overseas NGOs, partner countries or national administrations – should be made aware that PV is not a maintenance free technology and that they should devote more resources to the maintenance of PV systems, including battery replacement; At least it requires regular battery replacement which users cannot afford in many instances in rural Africa. Funds should therefore be attributed for as long a period as possible in order to safeguard recurring battery replacement and thus system functioning.
- Institutionalized arrangements should be found for recycling of expired batteries.
- Still more attention has to be paid to provide basic training for end users. In particular, users need to be trained to avoid deep discharge of batteries. To this end, trainings have to be gender sensitive if predominately women are using the technology.
- Problems can further be minimized by considering more in detail lifestyle and specific living conditions of users in system design. In the case discussed here, for instance, it is fairly understandable that midwifes engaged in a complicated and long nocturnal delivery will not consider switching off the battery powered lighting after the indicated number of hours even if this would prolong the life of the battery.

Acknowledgements

This monitoring was funded by the Provincial Government of Lower Austria (PGLA).

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