Energy for Sustainable Development 23 (2014) 228–236

Contents lists available at ScienceDirect

Energy for Sustainable Development

# Community Charging Stations in rural sub-Saharan Africa: Commercial success, positive externalities, and growing supply chains

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ARTICLE INFO

*Article history:*
Received 19 April 2014
Revised 28 July 2014
Accepted 18 September 2014
Available online xxxx

*Keywords:*
Sierra Leone
Development
Solar power
Energy kiosks
Community Charging Stations

ABSTRACT

Over the past two decades there has been a proliferation of energy kiosks across Africa and other parts of the developing world. Typically drawing on solar power, these enterprises provide services such as mobile phone and lantern recharging to (largely) rural communities with limited or no other access to electricity. This article develops a broad analytical framework for evaluating the outcomes of energy kiosks, taking into consideration long-term commercial viability, positive community impacts, the dissemination of improved lighting products, and the provision of credit. Using three energy kiosks as case studies, this article applies the developed framework to critically evaluate a NGO's energy kiosk programme in Sierra Leone, West Africa.
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## Introduction

Extending grid-electrification into rural areas has proved to be a 'wicked problem' in much of sub-Saharan Africa (IEA, 2012). Given the region's continued rapid urbanisation and increasing constraints on state spending, governments have been largely forced to focus on the challenges of maintaining and expanding urban grid-based service and, as a result, the still more difficult problem of rural electrification has remained effectively unaddressed (Acker and Kammen, 1996; Bhattacharyya, 2013; Khennas, 2012). Given this situation, it has been argued that for rural electrification to be achieved, energy planners need to look to new approaches outside the traditional model of expanding conventional grids. At the same time, the improving affordability of photovoltaic technologies and other renewable energy options has presented a critical new range of options for bringing electricity to remote (and not so remote) communities (Deichmann et al., 2011; Karekezi, 2002). Moreover, and particularly in the context of rising concerns over anthropogenic climate change, modular renewable energy technologies have gained increasing appeal as 'leap-frog' technologies, holding the promise of bypassing conventional grid based approaches (Collier and Venables, 2012; Murphy, 2001; Shaaban and Petinrin, 2014) and putting Africa on a 'green' energy pathway (Bosetti et al., 2009; Winkler, 2005). Nonetheless, a key question remaining to be addressed is how the dissemination of renewable energy sources can be realised given the realities of Africa's current political and economic trends.

In the context of this challenge, photovoltaic technology is increasingly suggested as the most promising source of potential solutions. Solar power is seen as a good fit for Africa due to the continent's natural endowment of strong sunlight well distributed throughout the year, the inherently modular nature of photovoltaic hardware, and therefore also its associated potential for 'leapfrogging' in a manner akin to the rapid uptake of mobile phones across the continent (Collier and Venables, 2012). Despite these congruencies, as well as an almost fifty year history of attempts to disseminate solar energy in the region (Lorenzo, 1997), its uptake in Africa has been minimal at best, and only South Africa and Kenya have successfully established viable domestic commercial markets in solar technology (Bawakyillenuo, 2009; Hajat et al., 2009). Assessing such failure, observers have primarily argued that solar power dissemination efforts have most often employed flawed technical approaches, inadequately addressed questions of commercial viability and/or been based on a poor understandings of local socio-cultural realities (Gómez García and Montero Bartolomé, 2010; Nygaard, 2009).

Amongst the various solutions to the dissemination issue that have been explored, a particularly important approach has been the creation of solar powered charging stations: small village kiosks electrified with

*Abbreviations:* CCS, Community Charging Stations; PCS, Privatised Charging Station; EFO, Energy For Opportunity; SHS, Solar Home Systems.

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http://dx.doi.org/10.1016/j.esd.2014.09.005
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photovoltaic modules which act as centres for recharging mobile phones, lanterns and other small electrical items. They offer an operating model that is based on relatively sound economic principles but that is also flexible enough to be adapted to different local contexts. Nonetheless, although such decentralised systems have been trialled for the past three decades, it has only been in the last few years, with increasing global attention to the relationships between poverty reduction and climate change mitigation, that the approach has gained widespread prominence (Schäfer et al., 2011). Therefore, as Schäfer et al. note, "due to the current international relevance of the topic, a window of opportunity seems open that may allow for the enhancing of discussion about adequate methods and instruments for integrating different types of knowledge in this field" (2011, p. 325). They emphasize, however, that in order to move forward, such a discussion must be underpinned by rigorous research that systematically evaluates the lessons learned from the wide variety of field trials in order to draw transferable conclusions (2011, p. 325). As such, there is a need to establish a "charging station research community," that examines the variety of technologies currently in use in very different geographic and cultural contexts across sub-Saharan Africa (Schäfer et al., 2011).

This paper presents an initial step in responding to the appeal made by Schäfer et al. by presenting the experiences of a non-governmental organisation (NGO) Energy For Opportunity (EFO) which has installed over 30 solar-powered charging stations in rural communities across Sierra Leone, West Africa and has many more planned in future. Focusing on three of EFO's charging stations employing different technological designs and located in dissimilar geographical contexts, the paper provides a rich understanding of the impacts of EFO's approach and lessons learned to date.

## Charging Stations in Africa—an evaluation rubric

Whilst there are numerous different approaches to developing and operating solar powered charging stations, a survey of the literature that has emerged on the topic thus far indicates four major criteria for success: 1) commercial viability; 2) positive community impacts; 3) dissemination of improved lighting; and 4) the provision of credit.

1) *Commercial viability* is conceptually straightforward but frequently complex to achieve in practice. As noted earlier, many solar power projects in Africa have failed due to the lack of financial mechanisms to facilitate their long-term maintenance (Nygaard, 2009). Thus, it is important for charging stations to be based on sound business principles to ensure that they raise enough revenue—not just to cover day-to-day operational expenses, but also to finance the replacement of key parts of the system (e.g., batteries, controllers) should they breakdown. In short, the charging station needs to be able to operate completely independent of any external funding.
2) *Positive community impacts* is a more amorphous category. 'Positive impacts' could simply be construed as the provision of the charging station in itself; however, a charging station that demonstrates a greater degree of 'community ownership' and facilitates broader positive developmental impacts in the community can be judged as having greater success. As LeMaire (2011) notes, this could include improved education outcomes, increased business opportunities, and the raising of community revenue.
3) *Dissemination of improved lighting* is directly linked to the charging station's potential to replace kerosene lamps and other 'inefficient' lighting technologies with higher quality lighting sources (Adkins et al., 2010). Key amongst these are LED lanterns (high lumen, low energy lamps) and Solar Home Systems (SHS)—small residential kits that usually include a small solar module, controller, battery and lights, as well as a plug for recharging mobile phones in some cases. The charging station's ability to provide a 'self-sustaining model' for the dissemination of such technologies therefore can be taken as a key measure of its success (Chaurey et al., 2012; Pode, 2013). Whilst this measure may evidently overlap with the previous category of 'community benefits' it is primarily focused on residence-level improvements in quality of life and is often quite an overt focus of charging station projects.
4) *Provision of credit* links directly to improved lighting. LED lamps currently cost around $US15, whilst SHSs are upward of US$100—prices generally beyond the immediate disposable income of many rural households in Africa. Nonetheless, due to reduced household costs for kerosene and battery purchases these lighting options are actually more cost-effective than traditional lighting sources in the long-term. The challenge, therefore, is to develop funding mechanisms so that households can overcome the purchase cost barrier to 'transition' over to these improved lighting products. Given that such mechanisms frequently entail purchasing on credit, a One-Stop-Shop model in which the same entity that disseminates improved lighting products also provides options for credit is of great advantage because it consolidates operations under a single organisation (Pode, 2013).

Drawing upon these four criteria we have developed an evaluation rubric, seen in Table 1, which can be used to assess the impacts of a charging station. Importantly, the rubric is not concerned solely with a station's commercial dimensions, but rather more broadly with its ability to spread positive impacts throughout the community in which it is situated. Each of the rubric criteria has four levels that, taken together, can provide a qualitative evaluation of the charging station's progress. In addition, we wish to emphasize that this rubric is not presented as a perfected finished product, but rather as a first step towards more standardised and transferrable charging station evaluation and a means of focusing broader debates on disseminating improved lighting products throughout West Africa on certain key matters of concern.

It is evident that a charging station which fulfils all of the above criteria has the potential to be a very powerful transformative force at the village level. Figs. 1 and 2 below provide a conceptualisation of what this transformation might look like. First, the pre-charging station village (Fig. 1) uses low lumen lighting (i.e., kerosene, battery operated torches) that presents significant household hazards. Second, money paid to recharge mobile phones at generator-powered telecentres and to refill lamps with kerosene or torches with batteries represent a significant leakage of hard-won household income.[1] Third, profits from these sales largely flow out of the village, and even the country, as generator fuel, kerosene, and batteries are usually imported commodities with attendant issues of foreign exchange expenditures at the national level and vulnerability to supply disruption for all users. In contrast, the post-charging station village (Fig. 2) is able to trap most of this revenue: as operational costs for the kiosks are minimal, previously leaked funds can be redirected to community projects. Furthermore, if the dissemination of 'improved lighting' products is achieved, the charging station will also assist in improving overall household lighting in the village whilst simultaneously reducing a number of considerable domestic health and safety hazards.

In sub-Saharan Africa one of the major barriers to realising the transformation from Fig. 1 to Fig. 2 has been the large initial capital costs of solar power installations (unlike generator systems which have relatively lower initial capital cost but much higher operating costs). Other issues include a lack of available photovoltaic equipment and a lack of skilled installers in country. All three issues are slowly being addressed by the growing international market as the price of photovoltaic systems has dropped dramatically whilst photovoltaic installers are becoming increasingly common across Africa, but nevertheless the ability to realise the installation of these systems tends to be beyond the financial and logistical capabilities of most rural villages.

[1] Pode (2013) estimates that rural households spend around 10–15% of their income on lighting needs.

**Table 1**
Evaluation rubric for charging stations in West Africa.

| Theme | Failure | Struggling | Functional | Successful |
|---|---|---|---|---|
| 1. Commercial viability | Charging station has ceased to function due to insufficient revenue or poor commercial management | Charging station operates, but is heavily reliant on donor or other external funding to maintain its operations (i.e., it is operating at a loss) | The charging station produces enough revenue to fund its operations and finance maintenance costs | The charging station produces enough revenue to not only cover running costs, but also produces a profit which can be used for business expansion or other ventures |
| 2. Positive community impacts | It is a small operation that has had a negligible impact of the wider community | The charging station has helped to positively impact a small proportion of community members | The charging station has helped to positively impact a large proportion of community members | The charging station has produced meaningful positive changes for its community at large |
| 3. Dissemination of improved lighting | The charging station does not disseminate improved lighting products | The charging station has disseminated improved lighting to a small proportion of the community | The charging station has disseminated improved lighting to a large proportion (more than 5%) of the community | The charging station has facilitated large-scale transformation of lighting use in the community |
| 4. Provision of credit | The charging station has no mechanisms in place to provide credit to community members | The charging station has a system of credit dissemination; however, it is rarely used or poorly administrated | The charging station has a system of credit dissemination; however, it has some issues in regards to its management and defaulting payments | The charging station has a system of credit dissemination that operates effectively and is widely used |

## Sierra Leone and Energy For Opportunity (EFO)

Sierra Leone has an extremely low rate of electricity access with only 10% of the population connected to mains electricity and a rural access (or connection) rate of only 1% (MEWR, 2009b). The vast majority of these grid connections are concentrated in the capital city of Freetown and other major urban centres like Makeni, Bo, and Kenema. This situation, in combination with the general unreliability of grid-based electricity supply, has led to heavy reliance on personal generators for electricity generation in urban centres, with little solar power or other forms of generation in the overall energy mix. However, generators and their running costs remain far beyond the means of much of the rural population and outside the larger settlements average ownership rates are also as low as 1% (MEWR, 2009b). Moreover, whilst Sierra Leone has experienced substantial economic improvement over the past decade and has succeeded in rebuilding much of its infrastructure since the country's civil war (1991–2001), the severe energy deficit has meant that electrification projects have largely been focused on providing power to urban centres and plans for improved rural electrification remain largely aspirational (MEWR, 2009a).

Interestingly, there are a couple of energy transitions occurring in Sierra Leone independently of government or NGO interventions. The first transition, more pertinent to this research, has been the change in rural lighting consumption. As in much of rural sub-Saharan Africa, kerosene has long been the dominant rural lighting fuel in Sierra Leone (Davidson, 1985). In the past few years, however, dry-cell battery powered torches (known locally as “Chinese Lights”) have become an increasingly common rural lighting source.[2] A survey conducted in 2013 by EFO of 585 households across nine villages revealed that 93% of households used battery powered torches as their main source of light whilst only 3% primarily used kerosene lamps. Other lighting sources utilised include grid power, personal generators, candles, fire, and solar-powered lanterns. This transition is particularly interesting, as most of the literature on rural energy in Africa continues to describe kerosene as the main source of lighting fuel (Adkins et al., 2010; Kaygusuz, 2011; Leach, 1988; Lighting Africa, 2010; Mills and Jacobson, 2011). The second transition relates to cooking fuels. Prior to the 1990s, firewood was the dominant source of cooking energy in both rural and urban settings (Davidson, 1985; Kamara, 1986). However, over the past decade there has been a dramatic rise in the production (by rural communities) and consumption (in urban centres) of charcoal (Munro and van der Horst, 2012).

[2] Johnson and Bryden (2012) have observed this phenomenon occurring elsewhere in West Africa.

Energy For Opportunity (EFO) was founded in Sierra Leone in 2009 with the goal of promoting the dissemination of renewable energy across the West African region. So far, however, most of EFO's work has been in Sierra Leone where it has conducted over 50 solar power installations in schools, health clinics, NGO offices, government buildings, and other sites, as well as over 30 charging station installations in community kiosks or public buildings (the focus of this paper). Broadly speaking, EFO's charging station model is centred on the building of a solar-powered kiosk adjacent to a central communal structure such as a market, public hall, or wharf. This kiosk acts as a hub for the charging of mobile phones and the rental and sale of solar powered rechargeable LED lanterns and Solar Home Systems (SHS). The LED lanterns and SHS, which rival battery powered lights and kerosene in affordability, provide a much higher lumen output and avoid the adverse health effects of other off-grid options. Though the CCS is initially funded through non-profit finance, its operating model is based on purely for-profit principles. All services, including charging and lantern rental, occur on a for-profit basis with all revenue put back into operations. Ongoing support for the CCS, such as maintenance and resupply of lighting products, is also all handled through for-profit principles. Excess profit, which is managed by the community, is then used to fund future community projects such as solar installations on health clinics and schools (Willans et al., 2011).

Since the beginning of 2013, there have been a couple of important iterations in EFO's approach to its charging stations. First, it has experimented with the provision of solar powered water filtration systems and commercial water sales at nine of its charging station sites. Second, it has experimented with Privatised Charging Stations (PCS)—i.e., charging stations that are managed and operated by private individuals. These have been located in larger urban centres, where overall ‘community’ institutions for charging station management are less apparent. The objective of the PCS, however, is not only to spread the reach of charging stations to larger urban centres, but also to help facilitate the supply of LED lanterns and other household lighting products to community-administered stations. This PCS approach is discussed in more depth with the Kabala case-study below.

## Case studies: charging stations

This section examines charging stations in three population centres in the north of Sierra Leone: Kamabai, Bendugu and Kabala. The town of Kamabai is located in the Bombali District of Sierra Leone and is the headquarter town of the rural Biriwa Chiefdom. It is located approximately 30 km from Makeni, the district capital, and 160 km from Sierra Leone's capital city Freetown. Kamabai has a population of 4000 people

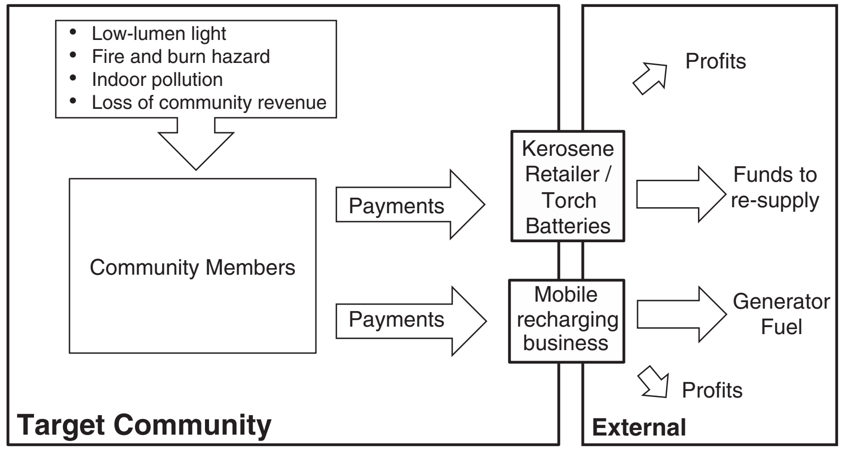


**Fig. 1.** Lighting and mobile phone charging economy for a village without a Community Charging Station.

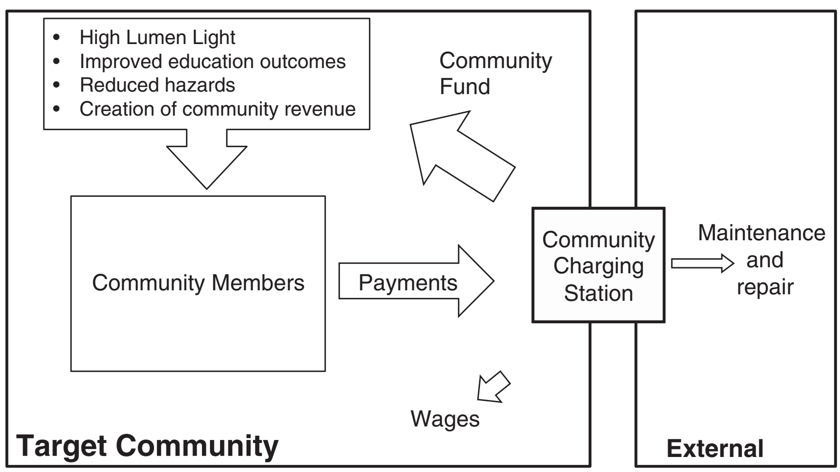


**Fig. 2.** Lighting and mobile phone charging economy for a village with a Community Charging Station.

and approximately 335 households. One of the few rural secondary schools in the Bombali District is located in Kamabai, and therefore the town acts as a satellite centre for many surrounding small villages. Bendugu is the most isolated community of the three surveyed here. It is located near the border of Guinea in the Koinadugu District and acts as the headquarter town of the Mongo Chiefdom. It is located approximately 50 km from Kabala, the district capital, and around 280 km from Freetown. The town has a population of around 3500 people and approximately 315 households. Finally, Kabala is the district capital of the Koinadugu District in the north of Sierra Leone. It is an ethnically diverse town with a population of around 16,000 people. The town has a relatively vibrant commercial centre and acts as an important agricultural centre for Sierra Leone as a whole. None of the three sites has a grid electricity service.[3]

The data and analysis presented in this section are derived from research conducted in June 2013 which included household surveys conducted at Kamabai ($n = 60$) and Bendugu ($n = 60$); interviews with charging station operators at the three sites; financial and administration records kept at the three charging stations; and interviews with EFO staff and the working experience of one of the authors (SW) who has been involved in EFO's charging station programme since its inception. Whilst the interviews and financial records have been used to evaluate the efficacy of the charging stations along the lines of the earlier developed rubric, the household surveys were part of a larger project and have been mainly used to provide broader background information on energy use and mobile phone ownership in target communities.

### *Kamabai*

The Kamabai solar powered Community Charging Station (CCS) was installed in March 2010, and is EFO's oldest and arguably most successful CCS installation. It has two 175 W photovoltaic modules, one 300 W inverter and two 200 AH batteries installed at a total cost (including labour) of around US$5000. The CCS kiosk is located adjacent to the village's market (for which it also supplies lighting), town hall and communal water tap. This strategic location has allowed the CCS to secure the dominant market share (78%) of mobile phone recharging business in Kamabai (the remaining 22% recharge their phones at private telecentres powered by diesel generators). This is an important market, as 98% of households in Kamabai reportedly own a mobile phone and pay to have their phones recharged an average of 2.2 times per week. Currently the Kamabai CCS recharges an average of 36 mobile phones daily at a fee of Le800 [~$US0.20] per charge, more than enough to ensure financial sustainability. Indeed, the CCS has been a profitable venture since it was first established in March 2010, with long-term trends—taking into account the vagaries of Sierra Leone's rainy season—indicating a gradual growth in sales, and hence also profits (see

[3] These numbers were approximated using data extrapolated from the 2004 Sierra Leone census (Sesay et al., 2006) (Statistics Sierra Leone, 2004) and an earlier survey of the villages (Munro and Kebbay, 2012).

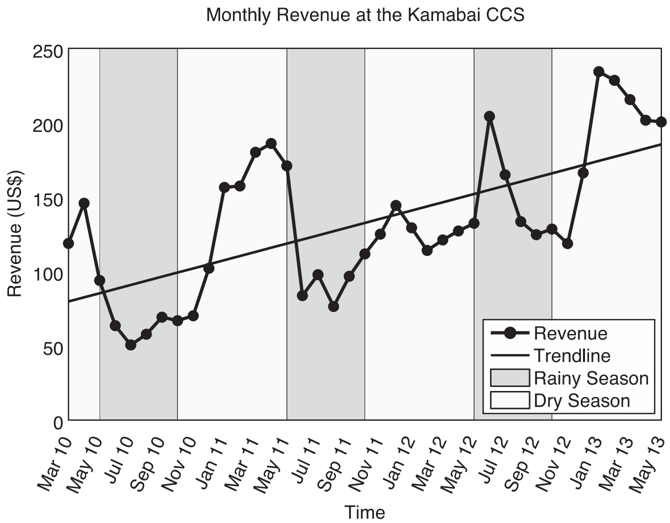


**Fig. 3.** Monthly revenue at the Kamabai CCS from 2010 to 2013, calculated using the blended rate of Le4300/US$.

Fig. 3). Given its current revenue stream, the Kamabai CCS will generate profit sufficient to cover the eventual replacement of batteries (around every 3–4 years) and modules (around every 25 years).[4]

Whilst a portion of the revenues have been required for operational costs of the CCS such as wages for kiosk operators and equipment maintenance, the healthy surplus has helped finance solar power installations at the village's secondary school and health clinic, as well as the construction of a water purification system and a series of street lights. These additional projects have also proven to be successful in their own right. According to interviews with officials at the community health clinic, its solar power system has resulted in a thriving maternity ward, improved patient care, and a more productive work environment. The solar water purification system has also been a relative success, regularly selling purified water (known locally as *Solawata*) to a number of Kamabai households, and also helping to improve the village's overall water supply infrastructure (public taps, water storage containers, etc.). It is the Secondary School installation, however, that has arguably had the greatest success. Since the installation of solar power, student test scores for the university entrance exam (the WASSCE) have substantially increased (see Fig. 4). According to the school's principal this has been a direct result of students, both from Kamabai and from many surrounding villages, now having access to light for evening study (even creating competition amongst students for the desks directly surrounding light fixtures).

Given the commercial success of the CCS and the additional projects it has helped to fund it is unsurprising that it is viewed in an overwhelmingly positive light by members of the community. From the household survey conducted, 91% of households viewed the CCS as having a positive impact on the community, 9% of respondents stated that they had a neutral position towards the CCS, and no respondent reported having a negative perception of the installation.

Although the Kamabai CCS has undoubtedly been a commercial success as well as a community-oriented project, there have been some notable limitations and constraints to its operations. The most obvious, as illustrated by Fig. 3, is that each wet season there is a significant drop in revenue at the CCS. This is not because there has been a lack of demand for mobile phone recharging during the rains, but rather due to the solar panels low rate of electricity production in the heavily clouded conditions common at this time of year. Furthermore, CCS kiosk operators also reported that the batteries occasionally ran out during the dry season as demand for charging outpaced electricity production. In the short term this insufficient power hinders the growth and community impact of the CCS and in the long-term such repeated battery depletion can shorten the life of the system. This suggests that the future growth of the CCS may well be hindered unless more investment in the solar array and battery bank is made in the near future. Indeed, the Kamabai CCS has already needed to replace failing batteries and, according to the principal of the secondary school, the school's battery bank is becoming decreasingly reliable.

More of a concern, however, has been the Kamabai CCS's limited success in disseminating improved lighting products. In early 2010, EFO gifted the Kamabai CCS its initial inventory of 23 LED lanterns and 5 solar home systems for rental and sale. Whilst revenue was raised through lantern sales and village level financing, organising the payment and delivery for additional stock has remained a perennial problem. Put simply, the kiosk cannot buy new products because there are major issues in sourcing the products from Freetown where the supplies are mainly located. Although EFO has attempted to partner with various distributers such attempts have often resulted in failure as companies are either unreliable—delivering incorrect products—or are prohibitively expensive, and EFO lacks the resources to locate, deliver, and finance the technologies itself. As a result, SHS and LED lanterns have represented only a small fraction (1.7%) of household lighting sources in Kamabai, and by far the majority of residents still use battery powered torches (96.7%) for their lighting needs. This is unfortunate, as early LED lantern and SHS sales indicated that there is great interest in Kamabai and other sites with CCSs in purchasing these improved lighting products. Overall, improved systems of credit could result in the enhanced dissemination of solar products.

*Bendugu*

The Bendugu Community Charging Station was installed in February 2012. Smaller than the Kamabai CCS, it includes one 90 W panel and four smaller 15 W panels with a 180 AHr battery and operates entirely as a DC system without an inverter. The total cost of the Bendugu system, including labour, was around US$500. Since its inception the CCS has been a profitable venture and like the Kamabai CCS, a gradual growth in sales is evidently occurring over time (see Fig. 5).

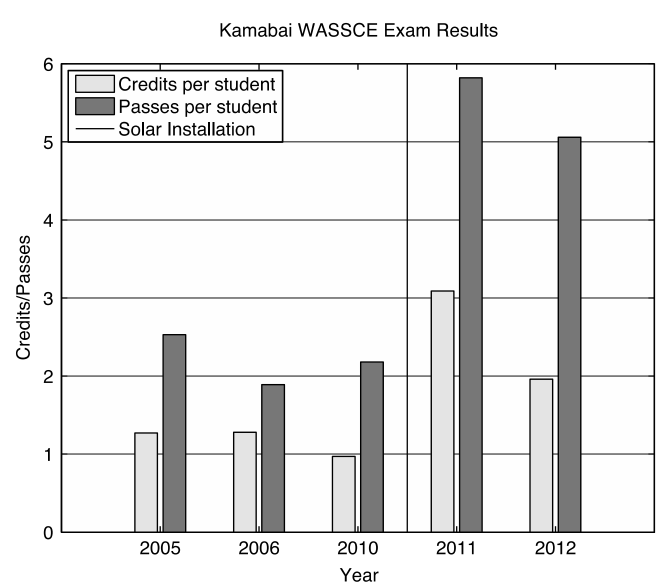


**Fig. 4.** Kamabai Secondary School's West Africa Secondary School Certification Examination (WASSCE) results.

[4] If the revenue continued to be US$150 a month; then in a 25 year period the CCS would have around US$45,000 in revenue, while the costs of batteries during this period (every three years) and module (every 25 years) would be around US$12,000. Overall, however, this a conservative estimate because a) the CCS monthly revenue stream is apparently increasing each month; and b) the relative cost of photovoltaic equipment has been decreasing.

Furthermore, the lack of a sales dip during the rainy season suggests that the system has not been stretched to its full charging capacity, leaving room for growth (the massive growth in sales during early 2013 is likely due to the many students coming to the town during the country's major school examination period). The commercial success of the Bendugu CCS is particularly interesting because Bendugu does not have mobile phone network coverage. Nevertheless the survey of the village revealed that household mobile phone ownership was still very high (85%), indicating that in this settlement availability of mobile phone reception is not a major factor influencing phone ownership rates.[5] According to the CCS operators, Bendugu residents regularly use their mobile phones to listen to music (purchased from across the border in Guinea, or during trips to Kabala) resulting in high demand for phone recharges. Indeed, Bendugu residents on average recharge their mobile phones around 2.3 times a week, marginally higher than their Kamabai counterparts. Thus, at the time of this research, the CCS was selling around 20 mobile phone charges each day at Le 1000 [~$US0.23] per charge, making the operation a profitable venture. Like the CCS in Kamabia, the Bendugu installation was funded through a donor grant.

One factor limiting the Bendugu CCS's profits has been competition from a rival charging station operated by another non-profit organisation and known as the ABC centre. It charges roughly sixteen phones daily for Le 1,000 [~$US0.23] per charge and channels all profits into a community fund for the village. Indeed, in this and most other respects, this charging station and the EFO kiosk are remarkably similar and indeed their primary difference is that the rival charging station is inconveniently located at the edge of town, about a 10-min walk from the school, hospital, and town hall, whilst the EFO kiosk is located in the centre of town. Likely as a result of its 'superior' location, the EFO CCS has secured the larger portion of the phone recharging market; 63% of the survey respondents reported using the EFO CCS as their primary source for phone charging, whilst only 35% report using the ABC centre as their primary source.[6] There are also private generator-powered charging stations in Bendugu; however, these currently have only a negligible market share and it appears that villagers in general prefer the community-oriented charging stations. Indeed, in the household survey, an overwhelming majority of residents (93%) viewed the EFO CCS as having a positive impact on the community (only 3% reported having a negative view). This in part can perhaps be explained by the CCS having already installed a community streetlight using its revenues, and its plans to fund a solar power installation at the local Secondary School. Overall, the fact that the Bendugu CCS is still profitable despite the town's relatively small population, competition from other charging stations, and the lack of phone network, demonstrates the commercial strength of EFO's CCS model.

Similar to Kamabai, whilst the Bendugu CCS has been a success in terms of commercial viability and positive community impacts, it has been less successful in disseminating improved lighting products and providing credit. The recent household survey indicated that 87% of households were still using battery operated torches for lighting, 7% were using candles, and only 5% were using LED lanterns or SHS. This is a slightly better outcome than in Kamabai, especially considering that the Bendugu CCS has been operating for a shorter time period, but still falls well short of the goal of a village-wide improvement in lighting. Like Kamabai, the high level of early demand evidences considerable interest in the improved lighting products, but uptake has ultimately been limited by two key constraints. The first issue is the physical location of Bendugu, in the remote northern part of the Koinadugu district, which makes inventory supply very difficult to manage. The second issue has been payment default by customers. The CCS was initially stocked with ten SHS. Whilst each systems costs Le 450,000 [~US$105], customers were able to purchase a system with a Le 200,000 [~US$46.50] deposit based on a commitment to additional payment instalments to be made over a three to twelve month period. The kiosk sold all ten systems almost immediately, and although nine of the customers completed their payment schedule, the tenth defaulted. This one default offset most of the kiosk's SHS sales profit, constraining its ability to restock more inventory. A related difficulty is that the CCS has also experienced some theft, and the CSS has had to reimburse customers for the cost of two mobile phones and a battery that were stolen. Although the theft and the default payment did not compromise overall profitability, the revenue drains did further constrain the CCS's ability to restock its supply of lighting systems. Thus, like the Kamabai CCS, whilst the Bendugu kiosk is a commercially successful community phone charging station, its success in disseminating improved lighting products is still very much a work in progress.

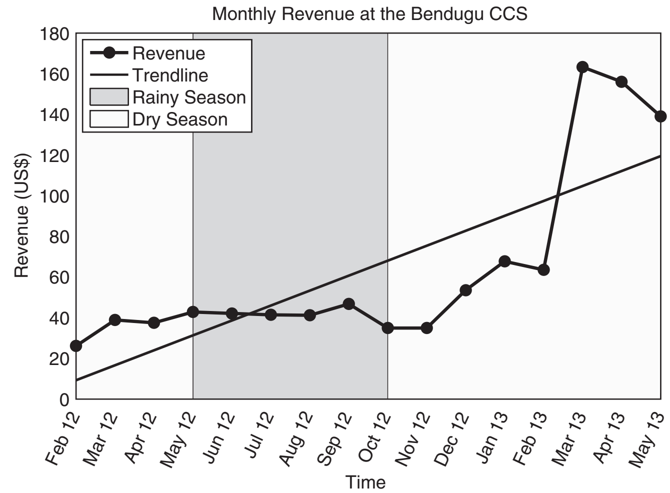


**Fig. 5.** Monthly revenue at the Bendugu CCS from 2012 to 2013, calculated using the blended rate of Le4300/US$.

*Kabala*

The Kabala solar powered charging station, installed in February 2013, differs from the Kamabai and Bendugu stations (and most of the other charging stations installed by EFO) in that it is a Privatised Charging Station (PCS) rather than a Community Charging Station (CCS). The reasons for operating the Kabala kiosk as a PCS are twofold. The first is that PCSs are established in large towns, such as district capitals (like Kabala), which are too large to have effective community organisations to oversee the charging station's operations. This means that profits from the PCS are realised by its private operators, rather than the community as a whole. The second reason, and perhaps more pertinent, is that the PCSs are intended as a strategic innovation by EFO to help facilitate the resupply of improved lighting products to CCSs around the country without excessive donor seed funding.

Like all EFO charging stations, the PCS is a solar-powered kiosk that charges mobile phones and rents and sells solar powered LED lanterns and SHS. For the privilege of operating the PCS, its operators pay EFO a predetermined fee each month and keep the remaining profit for themselves. This monthly fee depends on the location of the PCS and the season. If the attendants wish to stop operating the PCS, EFO either engages new operators or moves the PCS to a new location. This model allows EFO to disseminate solar technologies into towns where the CCS model could not function and provides EFO with a small but reliable income for further project development. In the short term PCS funding is

[5] This same phenomena was also observed in the nearby village of Bafodia, where a survey ($n = 60$) revealed that 80% of households owned mobile phones, despite there being no mobile phone reception in the area.

[6] Important to note, the remaining 2% reported charging their mobile phones using SHSs.

useful for covering overhead expenses and in the long-term could make EFO independent of external donor funding.

In terms of facilitating improved lighting trade networks, the PCS enters an exclusive deal in which EFO is the sole lantern supplier to the PCS, and the PCS is the sole lantern distributor to the surrounding CCSs. This model has been designed specifically to overcome the previous lantern supply chain issues, as noted in the above Kamabai and Bendugu examples, through the establishment of a reliable distribution network between EFO, the PCSs, and the CCSs: EFO purchases lanterns from an international distributor and then sells them to the PCSs, which then sell them to the CCSs, which in turn sell them to the general public (see Fig. 6). At each step along the commodity chain, there is a small increase in the price margin to cover operational costs and generate a small profit. In this distribution network EFO is only responsible for transporting lanterns to the PCSs, as opposed to all of the CCSs, which translates into significantly fewer shipments taking place over a simpler road network. The CCSs, no longer dependent on EFO, can buy any desired quantity of product from their local PCS. The PCS is given an initial inventory of LED lanterns and SHS on credit and revenue from their sales is used to purchase replacement goods and reimburse EFO. The location of the PCS in a central town also enables the easy installation of new CCSs nearby and, as the PCS network grows, it will allow EFO to quickly scale up the network of CCSs around Sierra Leone. Furthermore, in the event EFO were to cease operations the PCSs could locate an alternate lantern supplier and continue selling to the CCSs, ensuring the long-term sustainability of the project. Indeed, the actual process through which an operator would locate another supplier is an important aspect of the PCS attendant training that occurs during system installation. Finally, the PCS can also sell lanterns to private enterprises and individuals, providing a second revenue stream for when the CCSs are not buying frequently. The Kabala charging station is EFO's first PCS installation; however, four more have been installed recently to help facilitate improved lighting supplies to other parts of the country. Thus in this model LED lanterns and SHS can be supplied to the CCSs affordably and efficiently, preventing stagnation in the dissemination of solar products.

The PCS in Kabala has one 200 W photovoltaic module, a 300 W inverter and a 100 AHr battery. Its total installation cost was around $2000, and EFO will recuperate the funds it invested in the PCS installation within two years via the rental payments. The Kabala PCS is operated by two brothers: the elder, at the time of the research, was roughly 27 years old and the younger still in secondary school. The elder brother operates the PCS whilst the younger is at school and then works a second job at the local rice mill when the younger returns from school and takes over operations. Although the elder brother has a second job, the PCS is his primary source of income. The Kabala PCS sells around 30–35 phone charges each day, and realises a substantial profit each month, enough to support the two brothers' living expenses and the younger brother's education. Currently the Kabala PCS buys LED lanterns from EFO and sells them to CCSs in the Koinadugu Distinct, which then sell them to the general public for Le 102,000 [~$US24]. At the time of the research (July 2013), the PCS had already sold 15 lanterns, more than any CCS, and has used the revenue to construct a community streetlight immediately outside the kiosk. Thus the Kabala PCS, like the Kamabai and Bendugu CCSs, is a commercially successful venture directly beneficial to its host community. All 15 lanterns were sold without financing to avoid the risk of credit default. Although this strategy is appropriate for a PCS as it is located in a large town with a decent sized demographic of relatively wealthy residents, most of the CCS target communities cannot afford to buy solar products without financing.

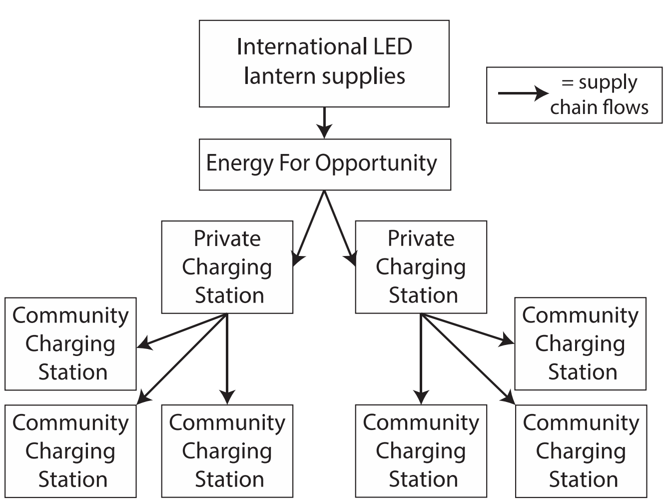


**Fig. 6.** Diagram of the supply chain network for LED Lanterns and SHS.

At the time of research, the PCS had yet to fully realise its role as distributor of improved lighting products to CCSs in the area. This appeared to be due to two main reasons. One of the main constraints had been that many of the CCSs near the Kabala PCS are currently in debt to EFO (and its donor GIZ) for CCS upgrades that occurred in November 2012.[7] Whilst almost every CCS will have settled these debts by December 2013, prior to this time the CCSs had limited revenue available to purchase improved lighting products from the PCS. A second challenge relates to the physical transportation of the LED lanterns from the PCS to the CCS—a particularly acute issue in the Koinadugu District, where the Kabala PCS is located. Koinadugu is Sierra Leone's largest and most sparsely populated district, and therefore most communities are located great distances from each other on poorly maintained roads. EFO, however, is currently negotiating with a donor for the supply of motorbikes for its PCSs, which should help to alleviate this issue in the near future.

## Discussion

Returning to the four evaluation criteria developed in the rubric in section two—1) commercial viability; 2) positive community impacts; 3) dissemination of improved lighting; and 4) the provision of credit—EFO's charging stations can be credited with mixed success, with potential for major improvements in future if its PCS initiative is fully realised. Table 2 summarizes the particular successes and challenges of each charging station within the context of the four criteria.

All three charging stations have proven profitable and hence commercially sustainable ventures, producing adequate revenue from inception and recording continued gradual sales growth over a long period of time. Key to this success has been the massive proliferation of mobile phones in Sierra Leone, as mobile phone recharge sales easily provide the lion's share of revenue for the charging stations. This indicates that whilst EFO's charging station model is currently commercially viable, it probably would not have been a workable approach 10 to 15 years ago before the massive growth in mobile phone usage, and perhaps also explains why similar initiatives of the 1970s and 1980s struggled to succeed. In terms of positive community impacts, the EFO charging stations have also had great success. The Kamabai CCS is a case-in-point, using its revenue to help fund numerous projects within the community that have helped to promote improved educational, health and other developmental outcomes. The Kabala PCS has provided more limited community benefits, but in its short time of operation has nonetheless installed a streetlight and sold a number of SHS, contributing in a limited way to improving lighting in the small urban centre. It has also provided some direct benefits to its operators, in particular funding the education of the younger operator. Thus overall, if adjudicated by the first two criteria, EFO's charging station model could be seen as a solid success.

[7] The upgrade converted the CCSs from DC systems to AC systems, extending the lifetime of mobile phone chargers and enabling the system to charge new kinds of electronics.

**Table 2**
Rubric evaluation of the three charging station.

| Theme | Ranking: Failure | Struggling | Functioning | Successful |
|---|---|---|---|---|
| 1. Commercial viability | | | | • **Kamabai**<br>• Bendugu<br>• *Kabala* |
| 2. Positive community impacts | | | • *Kabala* | • **Kamabai**<br>• Bendugu |
| 3. Dissemination of improved lighting | | • **Kamabai** | • Bendugu<br>• *Kabala* | |
| 4. Provision of credit | | | • **Kamabai**<br>• Bendugu<br>• *Kabala* | |

In terms of achieving improved village level lighting and the provision of credit, the success of EFO's charging stations has been more circumscribed. There evidently has been great interest in LED lanterns and SHS at the village level, as indicated by early sales at Bendugu and Kamabai and by the current sales being realised at the Kabala PCS, but such sales are limited by the difficulty of supplying inventory to the CCSs. This challenge is being addressed with the Privatised Charging Station model, which will become the primary source of inventory for the CCSs beginning in January 2014. Moreover, as more CCSs are established, the economy of scale for 'improved lighting' sales will be increased, potentially strengthening the supply chains and leading to easier product dissemination. This is perhaps a testament to the importance of an NGO, such as EFO, in taking a long-term approach to the implementation of CCSs. At the time of this publication, EFO had been involved in installing CCSs in Sierra Leone for three years and had many more planned for future. The focus of the work has not been on just setting up CCSs in villages, but also on overcoming the institutional, economic and logistical barriers in terms of CCSs realising their full potential. The future plans of EFO are ambitious, creating not only CCS installations but also the establishment of a full-fledged 'improved lighting' trading network at the national level in Sierra Leone that will be transitioned into a completely private sector venture. If successful, it will represent quite a revolutionary approach to development in which a developmental NGO has succeeded in 'working' itself out of a job. It is, however, too early to evaluate if these efforts will prove successful.

Regarding the provision of credit for improved lighting products, there appears to be much more room for improvement in CCS operations. Part of the problem is an overall lack of knowledge and experience at the village level, amongst both CCS attendants and villagers, of credit financing and capital management. EFO has made efforts to improve these skills at the CCSs but it is starting from a low base (Willans et al., 2011). It is expected, however, that over time CCS operators will develop better knowledge of the new market and payment systems through experience, leading to gradual improvements. Part of the problem so far has arisen from defaulting payments for SHS. Although defaults have not been common, the low profit margins that CCSs realise on their LED lanterns and SHS sales has meant that even a single customer default seriously constrains a CCS's cash flow. Occasional cases of theft present similar challenges. Whilst the regular cash flow from recharging mobile phones has acted as insurance against defaulting payments and theft (ensuring a basic flow of revenue for restocking), given that the mobile phone charging has been so profitable there is a risk that the CCS operators might give up on the more risky area of improved lighting sales altogether. It is important to note, however, that despite the slowing of 'improved lighting' sales, they are still occurring at CCSs and in the vast majority of cases the credit systems are still working. Thus because village sales have been occurring at a relatively slow pace, village-wide improvement in lighting is likely to be a long-term process.

## Conclusion

This paper has provided an overview of Energy For Opportunity's solar power charging station programme in Sierra Leone, focusing on the experience of three of its installations. As has been illustrated, the charging stations have proven to be profitable village-level ventures, largely thanks to the high demand for mobile phone recharging. Although the distribution of improved lighting has been somewhat limited, nevertheless there is evidence that there is great local demand for these products and that the credit systems implemented, whilst not without their issues, have been functioning reasonably well. Overall, the research indicates that charging stations represent a viable model for disseminating improved lighting in rural sub-Saharan Africa; however, important to this success has been the constant presence of a local NGO (i.e., EFO) that has been able to make strategic adjustments to its approach to ensure that the overall model is economically sustainable in the longer term.

## Acknowledgements

We wish to thank Energy For Opportunity for sharing its experiences establishing Community Charging Stations in Sierra Leone and for providing partial funding of this research. In particular we gratefully acknowledge the field assistance of Chernor Jalloh, Albert Thoronka, Alusine Thorpe, Mohamed Kebbay, Mambu Alie, and Maggie Sauce. Additional funding and assistance was provided by the Princeton University International Internship Program, through the Charlotte Forbes Escaravage International Initiatives Fund. Earlier versions of this article benefited from the comments of one anonymous referee.

## References

Acker RH, Kammen DM. The quiet (energy) revolution: analysing the dissemination of photovoltaic power systems in Kenya. Energy Policy 1996;24(1):81–111.
Adkins E, Eapen S, Kaluwile F, Nair G, Modi V. Off-grid energy services for the poor: introducing LED lighting in the Millennium Villages Project in Malawi. Energy Policy 2010;38(2):1087–97.
Africa Lighting. Solar lighting for the base of the pyramid—overview of an emerging market. The World Bank: Washington D.C.; 2010.
Bawakyillenuo S. Policy and institutional failures: photovoltaic solar household system (PV/SHS) dissemination in Ghana. Energy Environ 2009;20(6):927–47.
Bhattacharyya SC. Electrification experiences from Sub-Saharan Africa. In: Bhattacharyya SC, editor. Rural electrification through decentralised off-grid systems in developing countries. Springer; 2013. p. 131–56.
Bosetti V, Carraro C, Tavoni M. Climate change mitigation strategies in fast-growing countries: the benefits of early action. Energy Econ 2009;31:S144–51.
Chaurey A, Krithika P, Palit D, Rakesh S, Sovacool BK. New partnerships and business models for facilitating energy access. Energy Policy 2012;47(1):48–55.
Collier P, Venables AJ. Greening Africa? Technologies, endowments and the latecomer effect. Energy Econ 2012;34(Supplement 1):S75–84.
Davidson OR. Energy use patterns. International Development Research Centre (IDRC): Sierra Leone; 1985.
Deichmann U, Meisner C, Murray S, Wheeler D. The economics of renewable energy expansion in rural Sub-Saharan Africa. Energy Policy 2011;39(1):215–27.
Gómez García V, Montero Bartolomé M. Rural electrification systems based on renewable energy: the social dimensions of an innovative technology. Technol Soc 2010;32(4):303–11.
Hajat A, Banks D, Aiken R, Shackleton CM. Efficacy of solar power units for small-scale businesses in a remote rural area, South Africa. Renew Energy 2009;34(12):2722–7.
IEA. World energy outlook 2012. Paris: International Energy Agency; 2012.
Johnson NG, Bryden KM. Energy supply and use in a rural West African village. Energy 2012;43(1):283–92.
Kamara J. Firewood energy in Sierra Leone—production, marketing, and household use patterns. Hamburg: Verlag Weltarchiv; 1986.
Karekezi S. Renewables in Africa—meeting the energy needs of the poor. Energy Policy 2002;30(11):1059–69.
Kaygusuz K. Energy services and energy poverty for sustainable rural development. Renew Sustain Energy Rev 2011;15(2):936–47.
Khennas S. Understanding the political economy and key drivers of energy access in addressing national energy access priorities and policies: African perspective. Energy Policy 2012;47(1):21–6.
Leach G. Residential energy in the third world. Annu Rev Energy 1988;13(1):47–65.

Lemaire X. Off-grid electrification with solar home systems: the experience of a fee-for-service concession in South Africa. Energy Sustain Dev 2011;15(3):277–83.
Lorenzo E. Photovoltaic rural electrification. Prog Photovolt Res Appl 1997;5:3–27.
MEWR. National Energy Policy and Strategic Plan: energy for poverty alleviation and socio-economic development, part i: national energy policy. Freetown: Ministry of Energy and Water Resources, Government of Sierra Leone; 2009a.
MEWR. Sierra Leone National Energy Policy. Freetown: Ministry of Energy and Water Resources; 2009b.
Mills E, Jacobson A. From carbon to light: a new framework for estimating greenhouse gas emissions reductions from replacing fuel-based lighting with LED systems. Energy Efficiency 2011;4(4):523–46.
Munro PG, Kebbay M. Study of water access and health issues in Sierra Leone's Bombali, Kambia, and Koinadugu districts. Freetown: EFO/DfID; 2012.
Munro PG, van der Horst GA. The domestic trade in timber and fuelwood products in Sierra Leone: current dynamics and issues. Freetown: FAO/EU; 2012.
Murphy JT. Making the energy transition in rural East Africa: is leapfrogging an alternative? Technol Forecast Soc Chang 2001;68(2):173–93.
Nygaard I. The compatibility of rural electrification and promotion of low-carbon technologies in developing countries-the case of solar PV for Sub-Saharan Africa. Eur Rev Energy Mark 2009;3(2):125–58.
Pode R. Financing LED solar home systems in developing countries. Renew Sustain Energy Rev 2013;25:596–629.
Schäfer M, Kebir N, Neumann K. Research needs for meeting the challenge of decentralized energy supply in developing countries. Energy Sustain Dev 2011;15(3):324–9.
Sesay IM, Karama AA, Ngobeh JJ. 2004 population and housing census: analytical report on population distribution, migration and urbanisation in Sierra Leone. Freetown: UNFPA, SSL, EU; 2006.
Shaaban M, Petinrin JO. Renewable energy potentials in Nigeria: meeting rural energy needs. Renew Sustain Energy Rev 2014;29(1):72–84.
Statistics Sierra Leone. Final results: 2004 population and housing census. Freetown: GoSL, EU, UNFPA; 2004.
Willans S, Christiansen A, Munro PG. Emerging forms of entrepreneurship: for-profit and not-for-profit partnerships for the dissemination of solar power into rural sub-Saharan Africa. Paper presented at the The 56th Annual ICSB World Conference, Stockholm: Sweden; 2011.
Winkler H. Renewable energy policy in South Africa: policy options for renewable electricity. Energy Policy 2005;33(1):27–38.