Off-grid Solar PV: Is it an affordable or an appropriate solution for rural electrification in sub-Saharan African countries?

Glenn P. Jenkins*
Queen's University, Canada
and Eastern Mediterranean University, North Cyprus
jenkins@econ.queensu.ca

Saule Baurzhan
Eastern Mediterranean University, North Cyprus
saule.baurzhan@gmail.com

Development Discussion Paper: 2014-07

ABSTRACT

In this paper the feasibility of off-grid solar PV systems in Sub Sahara Africa (SSA) is analysed focusing on five major issues in the context of falling system costs: cost-effectiveness, affordability, financing, environmental impact, and poverty alleviation. Solar PV systems are found to be an extremely costly source of electricity for the rural poor in SSA. It is estimated that it will take at least 16.8 years for solar PV systems to become competitive with small diesel generators. The cost of reducing CO_2 emissions through solar PV electrification is far in excess of the estimated marginal economic cost of CO_2.

Revised paper published as: Baurzhan, S., & Jenkins, G. P. (2016). Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?. *Renewable and Sustainable Energy Reviews*, *60*, 1405-1418.

Keywords: Solar PV, rural electrification, sub-Saharan Africa, affordability, CO_2 emissions

JEL Classification: Q42, O55

* Corresponding author

Introduction

Solar photovoltaic (PV) electricity generation is not a new phenomenon in sub-Saharan Africa (SSA): solar PV technology has been used in development projects for rural electrification since the 1960s, yet the electrification rate of SSA is only 26 per cent (Legros et al. 2009). Solar PV has been perceived as one of the most appropriate solutions for rural electrification in the form of decentralized and off-grid power for SSA (Szabó et al. 2011; Szabó et al. 2013; UNEP 2012; Van der Plas and Hankins 1997). In this region grid connections are usually mainly in the major cities and their suburbs. Electric utilities have deficient generation capacity and lack sufficient infrastructure to expand electricity access (Eberhard, Foster, et al. 2008; Eberhard, Rosnes, et al. 2011; Eberhard and Shkaratan, 2012; IMF 2013; Mkhwanazi 2003; World Bank 2010). Universal access to electricity through grid extension is prohibitively expensive in SSA owing to the human geography of the region, in which a large percentage of the population lives in rural areas and in small settlements (Eberhard and Shkaratan, 2012; IMF 2013; World Bank 1996). It is estimated that 62.7 per cent of the population of SSA resides in rural areas (World Bank 2013), and 89 per cent of this rural population does not have access to electricity (Legros et. al. 2009). Some of these residents live within sight of the national grid, yet they cannot afford the initial cost of a connection (Eberhard, Foster, et al. 2008; Eberhard, Rosnes, et al. 2011; Lighting Africa 2011). Therefore, the majority of solar PV projects implemented in SSA have been off-grid systems targeted at urban poor and rural residents.

Recently solar PV system costs have been falling rapidly worldwide. These system costs have decreased mainly as a result of falling module prices, the biggest cost component of the PV system. The installed system costs have also decreased as a result of decreasing non-module costs. Because module costs have fallen at a much faster rate than non-module costs, they have decreased as a share of total system costs.

Global markets exist for the separate hardware parts of the PV systems, such as modules, inverters, and cables. As a consequence, the prices of these hardware parts do not differ much around the world, yet total solar PV system costs vary significantly worldwide, by continent, and by country. This can be attributed to different levels of maturity and competition in local PV markets, to dissimilar regulations and permission fees, and to the existence or absence of various incentives for the development of PV technology (Barbose et al. 2013; Bazilian et al. 2013; Chase 2013; Jäger-Waldau 2013; Salvatore 2013). Compared to other conventional power-generation technologies, solar PV markets are still in an early phase of development. They are expected to converge as the market matures (Barbose et al. 2013; IHS 2011).

The decreasing trend in solar PV system costs is expected to continue. Some argue, however, that current prices do not represent the true manufacturing costs, as there is currently a large over-supply of PV manufacturing capacity. Costs might even need to increase as the industry consolidates and tries to reach a profitable level (Barbose et al. 2013; Mints 2012). The list of companies that recently announced bankruptcy could be seen to support this view.

The aim of this paper is to examine the feasibility of off-grid solar PV technology in SSA in the context of the falling prices and costs of these solar PV systems. Only off-grid power systems will be considered here.

Lessons learned from donor-driven solar PV projects

Donor-driven solar PV projects have been implemented in many countries in Africa. The Energy Service Company (ESCO) project in Nyimba, Zambia, was initiated in 2000. ESCO was a part of a pilot project carried out by the Government of Zambia for the dissemination of solar PV technology in rural areas. It was supported by the Swedish International Development Authority (Sida) with the Stockholm Environment Institute (SEI) as advisers. ESCO owns and operates 100 (50 Wp) solar home systems (SHSs). ESCO charges the customers a service fee, but the fee does not include the capital cost of the system. Most of the rural households would otherwise be unable to use solar lighting, as they simply could not afford to pay the initial capital cost. Although customers' energy payments have increased, customers are satisfied with the service they receive. Rural households do not have to worry about the maintenance and breakdown of the system, as professional specialists from ESCO take care of the repairs, changes, and installation of PV system parts. This has been the key to the system's success. Surprisingly, the number of light hours did not increase significantly from the previous situation in which there was no SHS. However, the quality of light improved, leading to an increase in domestic work and studies at night, somewhat changing the lifestyle of the households. Children, even in households that did not have SHSs, were the group who benefited most, by having more opportunity to study at night (Gustavsson and Ellegard, 2004).

Another important example is the Global Environmental Facility (GEF) project in Zimbabwe, which had outcomes much below expectations. The GEF solar project was implemented in the period 1993–1997 with total funds amounting to US$7.5 million. It was sponsored by the United Nations Development Programme (UNDP) and the Government of Zimbabwe to disseminate solar PV technology in rural areas by installing 9,000 lighting systems of 45 Wp each. Zimbabwe qualified for GEF funding mainly because it was one of the first countries to sign and affirm the UN Framework Convention on Climate change (UNFCCC), agreeing to fulfil its global obligations, either on its own or as part of global actions. Unfortunately, the project attempted to simultaneously address too many ambitious and incompatible targets, such as the fulfilment of the UN Millennium Development Goals, mitigation of greenhouse gas (GHG) emissions, abatement of rural poverty, expansion and strengthening of the domestic solar PV industry, and employment creation. As a consequence, it achieved very few of them. For example, the amount of GHG emissions caused by kerosene and candle burning for lighting by rural households in Zimbabwe in comparison to other sectors, such as mining and industry, is insignificant. The installation of this project to mitigate GHG emissions caused by kerosene and candle burning for lighting was likened by Mulugetta, Nhete, and Jackson (2000) to 'using a sledgehammer to crack a nut'.

The biggest criticism of the GEF project is the absence of interest and a follow-up mechanism from the donors after the end of the project. Many similar donor-driven projects in developing countries failed to foresee the significance of post-project support, mistakenly supposing that solar PV systems are maintenance-free and can be maintained by untrained local people (Foley, 1995). The GEF project did succeed, however, in providing lighting for 9,000 households within the intended project deadline, although it fulfilled very few of its other goals. Unfortunately, many of the donor-driven rural electrification projects have been of this type: pushing a high-cost technology into rural and peri-urban areas of SSA as a condition for donor assistance, to the poorest of the poor who could not afford it (Wamukonya 2007).

Methods

The feasibility of off-grid solar PV systems in SSA is analysed focusing on five major issues: cost-effectiveness, affordability, financing, environmental impact, and poverty alleviation. First, a comparison is made between the cost-effectiveness of the solar PV systems versus small diesel generator sets. In order to make this comparison of the alternative technologies the levelized cost per kWh of energy (LCOE) is estimated using the formula:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + FOC_t + VOC_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad (1)$$

where I_t is the investment expenditures in year t, FOC_t is the fixed operating expenditures in year t, VOC_t is the variable operating expenditures in year t, E_t is the quantity of electricity produced in year t in kWh, r is the discount rate, and n is the economic operational lifetime of the system.

Second, the affordability of the solar PV systems is considered in comparison with the current budget allocation of households using kerosene lamps. Using the estimates of the LCOE for the solar PV systems, the annual cost of a solar PV system is estimated and compared with the annual household expenditure on kerosene lamps.

Third, issues related to the financing of the solar PV systems are examined from the households' point of view. Fourth, the environmental impact and costs of replacing kerosene lamps with solar PV systems are considered. A calculation is made of the CO_2 emissions avoided by solar PV systems, and the costs per tonne of CO_2 avoided are estimated. Fifth, the impact of solar PV rural electrification on poverty alleviation is examined.

A scenario analysis is carried to find out how long it will take for solar PV systems to become competitive with diesel generators for electricity generation. The number of years (N) needed for a solar PV system to have the same LCOE as a diesel generator set when the capital cost of a solar PV system is decreasing is calculated using the formula:

$$N = log_{(1-i)} \frac{LCOE_s}{LCOE_d} \quad (2)$$

where $LCOE_s$ and $LCOE_d$ are the LCOE of the solar PV system and diesel generation set, respectively, and i is the rate of decrease in the solar PV system capital cost. In this estimation a zero decrease in the cost of diesel generators is assumed.

Data on system costs of solar PV

Table 1 summarizes the most recent data available (2013 and later) on the capital and operating and maintenance (O&M) costs of solar PV systems in developed PV markets around the world. The data have been compiled from multiple current sources of cost information. The world average capital cost for small residential solar PV systems varies from US$3,000 to US$3,500 per kWp (Lazard 2013). The estimated annual O&M costs for these systems are estimated to be 1.5 per cent of the total initial investment cost of the PV system (Jäger-Waldau 2013).

Table 1. Capital and O&M costs of solar PV systems in developed PV markets (2013).

Region/Country	Typical system size (kWp)	System cost (US$/kWp)	O&M costs (US$/kW/yr)
USA	2–5	4,200–5,000	
Germany	2–5	1,928[a]–2,670[a]	52[a]
Italy	2–3	3,100	
Japan	3–5	5,900	
France	<3	4,800	
Australia	<5	3,100	
World		3,000–3,500	13–20, 1.5%[b]

Note: [a] Original cost data was in euros; the 2013 exchange rate of 1.48 US$/euro was used. [b] O&M is given as a percentage of the initial investment cost of solar PV system.
Source: Barbose et al. (2013); Chase (2013); Jäger-Waldau (2013); Kost et al. (2013); Lazard (2013); Salvatore (2013).

System capital costs exhibit significant economies of scale, making smaller systems more expensive than larger systems on a per-kW basis. The annual O&M costs of the various systems, however, do not differ much according to system size on a per-kW basis annually.

The latest cost data (2013) on solar PV systems was gathered for SSA and for the developing world (Table 2). In Africa solar PV system costs are generally above the global average (Moner-Girona et al. 2006). Solar PV system costs and prices are still high in developing countries, especially in SSA, because markets in these countries remain inefficient on the retail side and SHSs require expensive logistics (GTZ 2010). Although solar PV system costs are falling in SSA over time, they remain much higher than the world average, and unless political, financial, and economic situations stabilize in the region the situation is unlikely to change in the near future.

Szabó et al. (2013) used a value of €1,900 (US$2,819[1]) as the estimate of capital costs of PV systems per kWp in Africa. This value has been disregarded from the data sample, as it does not seem to match reality: it is smaller than the world average, and almost comparable to that of Germany (the lowest PV system cost country in Europe).

The capital costs of off-grid PV systems implemented in Africa fall within the range US$6,000–12,000 per kWp. In this study the mean value of US$8,000 per kWp is used. There are few recent estimates on the annual O&M costs for these systems. Therefore, for O&M costs, the world average estimate of 1.5 per cent of the total initial investment cost of the PV system is employed (Jäger-Waldau 2013). A standard size of solar PV system is chosen as 50 Wp, this being the size that would typically provide useful light at night for families of five–six persons in rural areas of

SSA[2]. The estimated up-front cost of such a system then, excluding the cost of financing and VAT, would be US$400. Assuming a value of 1.5 per cent of the total initial investment cost of solar PV systems as an annual O&M cost per kW, maintenance costs would translate into O&M costs of US$6 per year (US$4.5 at the low end, US$9 at the high end) for a 50 Wp system.

Table 2. Capital and O&M costs of solar PV systems in SSA and developing world (2013).

	Off-grid		
Country	Typical system size (Wp)	System cost ($/kWp)	O&M cost (% of the initial investment cost)
Kenya	25–30	12,000	
Malawi	40–65	12,500	
Zambia	20–100	6,000–10,000[c]	
Bangladesh	50	8,000	
Africa			2.5
Developing world	40	8,750	

Note: [a] O&M is given as a percentage of the initial investment cost of solar PV system. [b] Cost was given in $/kWh. [c] Authors' estimate based on system costs and sizes given in the source.
Source: Bertheau et al. (2014); Guevara-Stone (2013); KEREA (2014); Kornbluthn, Pon, and Erickson (2012); Samad et al. (2013); Szabó et al. (2013); WHO (2014).

Results

Cost-effectiveness issue

Using Equation (1), the LCOE for solar PV systems using a 10 per cent discount rate is estimated at US$0.83 per kWh[3]. This is a very high cost per unit of electricity generated compared to the conventional grid system tariff rates in Africa of between US$0.08 and US$0.16 per kWh (Eberhard et al. 2011). However, comparisons with conventional grid system tariffs may not be valid, as those do not usually reflect the true cost of power generation in many countries in SSA. The LCOE for small diesel generators would be a better benchmark for comparison.

The LCOE for a small diesel generator is estimated at US$0.42 per kWh[4]. This value is in the middle of the range of in-house electricity generation costs accrued by households and firms estimated by Foster and Steinbuks (2009) for countries in

Africa. Therefore, the cost per unit of electricity generated is much higher for solar PV energy than for diesel generators.

With the initial investment amount spent on a 100 Wp solar PV system, one could alternatively buy up to a 1.2 kWp (1,230 Wp) diesel generator that would increase electricity generation more than twenty-fold[5]. Although running costs of diesel generators are higher, households could use increased electricity generation for other activities such as water pumping, milling, irrigation, or in any income-generating activities, rather than just lighting, radio, or TV (Karakezi and Kithyoma, 2002). This makes diesel generators the most frequently used off-grid technology today in SSA, and they will remain the source of choice in the near future (GTZ 2010). The very important difference between solar PV (intermittent and high cost) and diesel generators (conventional and low cost) is that diesel power generators do not just generate electricity for household consumption. Because of the greater reliability of the source, the electricity generated by these generators can be used in income-generating activities. These have the potential to increase the economic well-being of at least some of the households much more than the solar PV systems could.

O&M and repair costs are the second or third largest cost factors of the total solar PV system costs. They comprise the costs of foreseeable repairs, maintenance, and exchange of components such as batteries, and the costs of the annual degradation of the solar modules (Jäger-Waldau 2013). Consumers are often unaware of the technical unreliability and reduced durability of the main parts of the PV system. The O&M costs are often underestimated, particularly for lower-quality systems (GTZ 2000). Failure to maintain the system appropriately causes the breakdown of components, leading to the benefits from the system either reducing or being completely eliminated. Financial schemes usually concentrate on the initial investment cost, and do not sufficiently consider the O&M costs. Consumers need to be capable of paying the credit, and at the same time of coping with O&M costs, which are the main reason why the rural poor simply cannot afford solar PV systems, even with most favourable credit schemes and subsidies (GTZ 2000).

Gustavsson and Ellegard (2004), in a survey conducted in Zambia, found that the clients of the PV ESCO project (who were paying O&M costs only) were paying more for energy services than their neighbours without the PV system. This shows that O&M costs on their own can be much higher for rural residents than the amount previously spent by them on energy services such as kerosene, dry cell batteries, car batteries, and candles.

There is a lack of standard after-sales service structures and a lack of private sector involvement. People are left on their own with their solar PV systems after purchasing them. Many of those who could afford a solar PV system preferred to switch over to the power company if grid connection became available in their vicinity (Bambawale, D'Agostino, and Sovacool 2011; Lemaire 2011; Mulugetta et al. 2000; Van der Plas and Hankins, 1997). Several essential questions were raised on this issue by Bambawale et al. (2011): Is solar PV an appropriate technology for the needs of the rural poor? Are people able to pay for technology they desire? Do village-level micro-grids offer a midway solution between grid connection and off-grid electrification? People prefer grid connection to an off-grid solar PV system because it allows them to use electricity for income-generating activities such as rice milling or refrigeration of fish they have caught.

Affordability issue

Except for a few recent grid-connected projects, the solar PV projects implemented in SSA have been off-grid systems. Households' access to electricity in SSA is very low. The situation is even worse in rural areas. Therefore, off-grid solar systems were targeted at rural residents.

In SSA, over three quarters of poor people live in rural areas (IFAD, 2010). More than half of the population lives below the international poverty line of $2 per day (PPP, purchasing power parity) in three quarters of the countries in SSA, and under $1.25 per day (PPP) in one third of SSA countries (World Bank 2013). Table 3 gives the poverty headcount ratio and the rural population data for a number of countries in SSA to illustrate the severity of the situation in the region.

Table 3. Rural population and percentage of the population living below the international poverty line.

Country	Poverty headcount ratio at $1.25 a day (PPP) (% of population, surveys 2000–2011)	Poverty headcount ratio at $2 a day (PPP) (% of population, surveys 2000–2011)	Rural population (% of total population, 2010)
Burundi	81.30	93.5	89.0
Ethiopia	39.00	77.6	82.4
Ghana	28.60	51.8	48.5
Kenya	43.40	67.2	77.8
Nigeria	64.70	57.5	50.2
Tanzania	67.90	87.9	73.6

Source: World Bank (2013).

The vast majority of the rural poor cannot afford the up-front cost of a solar PV system as they have low and/or irregular income that makes it difficult to save money and to pay the whole amount at once (GTZ 2000; Lighting Africa 2011). In Africa the average household of five members has a monthly budget of less than US$180 (US$60 in the lowest quintile, US$340 in the highest) (Eberhard et al. 2011). Table 4 gives the average monthly household incomes in selected countries in SSA.

Solar PV has been considered by some energy analysts as an unfeasible energy technology for SSA owing to its prohibitively high prices (Karakezi 2002; Karakezi and Kithyoma, 2002; Mulugetta et al. 2000; Wamukonya 2007). Even those who promote solar PV technology in SSA accept that the prices are high (Gustavsson and Ellegard 2004; Van der Plas and Hankins 1997). For most of the inhabitants of SSA solar PV continues to be a technology that is out of reach, and this is not expected to change in the short to medium term, in spite of falling PV prices and finance innovations (Deichmann et al. 2010; GTZ 2010; Lighting Africa 2010).

Table 4. Average monthly income.

	Ethiopia	Ghana	Kenya	Tanzania	Zambia
Monthly household income (US$)	115.7	115.9	153.6	90.0	150.9

Source: Lighting Africa (2011).

Using the estimates of the LCOE for the solar PV systems of $0.83/kwh, the annual cost of a solar PV system would be US$51 (US$4.2 per month), or 2.3 per cent of household income[6]. This can be compared with household expenditure on kerosene lamps, which are the most common alternative lighting source, followed by dry cell batteries and candles (Adkins, Oppelstrup, and Modi 2012; Apple et al. 2010; Bacon, Bhattacharya, and Kojima, 2010; Begg et al. 2000; Lam, Chen, et al. 2012a; Lam, Smith, et al. 2012b; Lighting Africa 2010, 2011, 2013; Mills 2000).

Expenditure on glass-covered kerosene lamps (taking into consideration the average purchase cost of the device, the monthly operating cost, the average lifetime of the product, and the number units of the device per household) is estimated to be US$40–98 per household per year in countries in SSA (Lighting Africa 2011). This represents an average annual expenditure of US$57 per household (US$4.75 per month), or 2.6 per cent of monthly household income[7]. Household expenditure on kerosene is roughly equal to the amount a household would have to pay to finance a PV system under annuity conditions.

Issues with financing

From the households' point of view, however, there are many important differences between these two alternatives. First, with solar PV, households are burdened with a long-term financial obligation involving the repayment of a sizeable debt, whereas with kerosene lighting they are free to buy energy sources in accordance with their needs and budget constraints (GTZ 1995). Second, the annualized cost of solar PV is calculated by spreading the cost of financing over the entire 20-year lifetime of the project, which does not match reality. Micro-finance institutions or commercial banks usually require both a short payback period, making the periodic payments much higher, and some type of collateral, which many rural customers cannot offer. Third, in most rural areas regular monthly household income is available in only a small number of households in which there are teachers, nurses, or civil servants. With an irregular income stream, it is very difficult to obtain and pay for a loan, which is the case with a solar PV system. Fourth, traditional energy expenditure is an average value, and it does not necessarily reflect the regular monthly expenditure on energy. For example, during times of economic crisis, expenditure on traditional energy sources can be cut or adjusted to suit income constraints. However, monthly repayments to financial institutions cannot usually be cut or adjusted. Fifth, the instalment of a solar PV system does not necessarily induce households to stop purchasing traditional energy sources. There is anecdotal evidence supporting this. Some households who can afford it continue to use kerosene lamps in order that the electricity from the solar PV system can be conserved for TV viewing (Martinot et al. 2002). Finally, even for households with regular income, an evaluation of solar PV should be based on households' income constraints, and not on hypothetical energy expenditure. The quantity in which PV electricity is consumed depends on the marginal utilities per unit of cost derived from both consumption goods. Only when marginal utility of the PV electricity is higher than that of traditional energy applications per unit of cost would consumers be willing to pay higher amounts for it (GTZ 1995).

Today, there are a few working micro-finance institutions in the world offering SHS credit for ESCO-type service schemes. Moreover, those loans that are available are mainly designed for income-generating activities such as farming and crop cultivation. Financial institutions generally require a ‘productive use of credit’ from loan applicants, which SHSs do not usually satisfy (GTZ 2000). The solar PV systems discussed here are systems that, because of their size and the intermittent nature of the solar resource, generate electricity to provide some lighting and to power communication devices. Such systems create very little, if any, additional cash flow for rural households. Therefore, users should finance solar PV systems from their current income and savings, paying not only the initial investment cost, but also the O&M costs occurring throughout the lifetime of the system. The financing cost of solar PV systems is too high for most rural households, so solar will be automatically excluded from lighting options (Hankins 2013).

Environmental issues

Solar PV technology is often promoted in SSA for health and global environmental reasons. Burning kerosene indoors for lighting emits fine particles, carbon monoxide, nitric oxides, and sulphur dioxide, which increase the risk of respiratory illnesses and lung cancer (Apple et al. 2010; Lam et al. 2012b). The elimination of kerosene and candles for lighting could reduce GHG emissions, thus improving the health of the local people who are using them, and would also have a positive effect on the environment. However, the amount of GHG emissions caused by kerosene and candle burning for lighting by rural households remains relatively small, particularly when compared to the GHG emissions from household cooking. The cost of reducing CO_2 emissions through solar PV rural electrification is in the range 150–626US$/t$CO_2$[8], which is extremely high compared to the current price of CO_2 emission permits being traded anywhere in the world today. It is also high as compared to current estimates of the marginal economic cost of CO_2 emissions (Greenstone, Kopits, and Wolterton 2011).

There are many ways to reduce carbon emissions that have costs per tonne far lower than these values (Creyts et al. 2007). The UK Department for International Development made an initial evaluation of Clean Development Mechanism (CDM)-type projects in developing countries and found that improved cooking stoves (ICSs) had a much higher impact than solar PV in terms of reducing GHG emissions, because cooking makes up a greater proportion of household energy use. The cost of reducing GHG emissions through ICSs is between −190 and −40US$/t$CO_2$. They also found that solar PV systems have no effect on the environment: they score 0 out of 100. Therefore, the introduction of ICSs has far better outcomes than solar PV lighting systems in terms of reducing GHG emissions; hence, solar lighting systems are the least preferred option on the basis of emissions reduction and cost (Begg et al. 2000). This should be noted by decision makers when considering solar PV projects in developing countries for carbon emission-reduction mechanisms such as CDM defined by the Kyoto Protocol.

The problem of priorities and poverty alleviation

Households that can barely afford to buy a PV system might find themselves drawn into long-term debt through purchasing a solar PV system which would add little to their living standards. The problem here is the issue of priorities: the sum spent on a solar PV system could be spent on something else that would increase the economic well-being of households much more than lighting would. There are many other issues that are more fundamental in the lives of households in SSA, such as malnutrition, health, and the education of their children. Over 600 million people in SSA still rely on solid fuels – traditional biomass and charcoal – as their primary cooking fuel. There is strong evidence of a link between smoke from solid fuel use and three important diseases: childhood pneumonia, chronic obstructive pulmonary disease (COPD), and lung cancer. Large amounts of smoke are released from the incomplete combustion of solid fuels as a result of using indoor open fires and inefficient stoves in households. The biggest groups affected by these diseases are children and women, as they are more exposed to the smoke. Such exposure increases the risk of contracting pneumonia 2.3 times for children up to the age of 5, of developing COPD 3.2 times for women, and of contracting lung cancer 1.9 times for women. Almost 30 per cent of the deaths in SSA are attributable to solid fuel use (Legros et al. 2009).

These problems would not be solved, but would be relieved by the introduction and promotion of ICSs. According to the World Bank (1996), relatively simple and inexpensive ICSs can reduce the amount of fuel needed for cooking by 30 per cent, reducing the amount of smoke and causing less damage to the domestic environment and householders' health. Only 34 million out of 777 million people use ICSs in SSA (Legros et al. 2009). The amount spent on solar PV systems could be spent on these ICSs, which would improve the well-being of households much more than lighting provided at high cost.

One of the important drivers of attempts to disseminate solar PV in SSA has been the belief that solar PV technology will alleviate poverty (Wamukonya 2007). However, there is no strong evidence of rural development benefits occurring as a result of renewable energy. There are certainly social benefits from lighting, TV, radio, and the powering of telecommunication devices by solar PV systems, and even some economic benefits from reduced kerosene and candle use (Martinot et al. 2002). For instance, as previously mentioned, the ESCO project in Zambia has improved household welfare, but mainly as a result of electric light: an improvement in the quality of the light is the main benefit accrued, especially in terms of opportunities to study more at night (Gustavsson and Ellegard, 2004). However, productive economic development has not followed rural electrification projects if these were not supported by the necessary economic infrastructure and skills. Economic benefits from rural renewable energy are more likely to occur in areas where economic development is already taking place. Moreover, only those who can afford solar PV systems and the necessary infrastructure to convert energy into useful services and productive activities can derive the most benefit from the availability of the energy (GTZ 1995; Martinot et al. 2002; Weaving 1995; World Bank 1996).

GTZ, based on its experience with the dissemination of small-scale PV systems in developing countries, noted that there is little evidence that these systems have an impact on poverty alleviation. GTZ concluded that rural households buy SHSs for improved services such as longer TV viewing and better lighting quality, not because these SHSs actually reduce their energy costs (GTZ 2000). Begg et al. (2000) conducted a multi-attribute decision analysis of different CDM projects in developing countries. SHSs scored 0 out of 100 in poverty alleviation, whereas ICSs, for example, scored 90. This shows that the emphasis on high technology does not necessarily lead to direct poverty alleviation.

At a household level, the acquisition of a solar PV system is a lower priority for rural households than other basic needs and commodities. Solar PV systems become an option only after these other needs have been satisfied (GTZ 2000; Lighting Africa 2011). For the poorest of the rural population, lighting is not always a priority.

Solar PV technology has been suggested as a pre-grid electrification option for use before residents in rural areas receive an electricity connection through a power utility (Van der Plas and Hankins, 1997). It is certainly the case that unless households' demand for electricity increases, power utilities will not extend power grids to them. Yet using solar PV in the meantime until a grid connection is provided in their vicinity is the most costly way of dealing with the current situation prevailing in SSA.

In summary, despite the notable cost decreases in solar PV systems, this continues to be an expensive method of rural electrification. Therefore, encouraging rural households in SSA to purchase solar PV to supply household electricity is not a sound policy for the promotion of their economic development.

Scenario analysis: reductions in the cost of solar PV technology over time

Solar PV system costs have fallen and continue to decrease. Expectations of continuing cost reductions prevail. A scenario analysis was undertaken to find out how long it will take for solar PV systems to become competitive with the diesel generators for electricity generation. The expected average annual percentage decrease in system costs (*i*) is calculated as 4 per cent[9]. It is assumed that there will be no change in the capital costs of diesel generators over time.

Substituting this percentage change in system costs into Eqn. (2), it is calculated that it will take 16.8 years for solar PV systems to become competitive with diesel generators, *ceteris paribus*. As is well known from the theory of economic cost–benefit analysis, when the investment cost of a project decreases over calendar time, it is often better to postpone such an investment. With the current costs and falling prices of solar PV systems it is not advisable for rural communities in SSA to invest in this technology until about 2030.

Discussion

Providing electricity access to rural inhabitants of SSA is of great significance and is a major challenge. Access to a reliable, cheap, and abundant energy source is one of the key drivers of economic development and the well-being of citizens.

Countries in SSA might succeed in increasing the rural electrification rate if they were to first develop well-planned rural electrification programmes. With no targets determined, there would be few, if any, achievements in the rural electrification field. Well-defined rural electrification goals and properly understood aims would lead to much better outcomes than blindly following any renewable dissemination project – in this case solar PV – and hoping that it would solve the rural electrification problem.

Countries with rural electrification programmes, with budgets devoted to these programmes, and with governments committed to increasing rural electrification have succeeded more than those with no rural electrification programmes or targets (Eberhard et al. 2011; Eberhard and Shkaratan, 2012). For example, Laos was able to increase its electrification rate from 16 per cent in 1995 to 63 per cent in 2009. Laos is one of the least developed countries in South Asia, and like many countries in SSA it lacks adequate power-generation capacity and infrastructure. Extending grid connections to rural areas is difficult and costly owing to the low population density and rugged terrain, yet the country has found ways to overcome these problems. The Government of Laos is committed to expanding domestic electrification, and it seems it has succeeded in meeting its aims. This has been achieved mainly through rural electrification projects undertaken in conjunction with multilateral donor organizations (Bambawale et al. 2011). In contrast, some countries in SSA do not even have a national energy policy (Mulugetta et al. 2000); let alone an explicit rural electrification policy (Onyeji, Bazilian, and Nussbaumer 2012).

Rural electrification agencies exist in only half of the Africa Infrastructure Country Diagnostic (AICD) sample countries, and in only two thirds of these countries are there dedicated funds available for rural electrification (Eberhard et al. 2011; Eberhard and Shkaratan 2012). Among the AICD sample countries, those with rural electrification policies have achieved almost four times the annual increase in rural connections than countries with no rural electrification policies. In the same way, countries with rural electrification agencies and funds dedicated to them have reached more than three times the annual increase in rural connections than countries with no rural electrification agencies and funds dedicated to them (Eberhard et al. 2011). Although it would be wrong to suppose that a policy framework would on its own be sufficient, it could be a good starting point. As noted by Eberhard et al., “in an African context, it is legitimate to ask how far it is possible to make progress with rural electrification when the urban electrification process is still far from complete” (2011, 129).

Instead of promoting solar PV, or any other renewable technology, as a means of obtaining donor aid or finance, governments and power utilities in SSA should select technologies on the basis of demand-driven judgements, which could bring much higher benefits to the society as a whole, rather than of technology-push incentives of donors. Prerequisites for donor aid and support programmes differ, yet the most popular one is the environmental concern of the donors.

Mitigation of GHG emissions by developing countries is one of the main preconditions set by many bilateral and multinational institutions when considering aid-receiving countries as eligible for development aid (Deichmann et al. 2010). These prerequisites on their own need a great deal of careful consideration and discussion. Governments and power utilities in SSA could follow an energy policy that targets the priorities of the country.

Diversified renewable energy policies would be more beneficial than simply following a single solar PV technology dissemination target. Renewable energy technology should be chosen based on cost-efficiency concerns, rather than considering only the availability of renewable resources. Of course, in a country where water resources are abundant, hydro-power solutions should be considered first. Likewise, where geothermal resources are available, geothermal power plants should be considered first. Yet all such decisions should be based on cost-effectiveness.

In such capital-scarce countries, economic efficiency should be promoted ahead of the political agendas of donors.

Conclusions and policy implications

Despite substantial worldwide cost decreases in recent years, off-grid solar PV systems remain an expensive power option for SSA. Although solar PV system costs have fallen in SSA over time, they remain much higher than the world average, and unless political, financial, and economic situations stabilize in the region, the situation cannot be expected to change in the near future. Most of the rural poor, at whom off-grid solar PV systems have been targeted, cannot afford to buy even the smallest system at the most favourable rates. More than half of the population continues to live below the international poverty line of $2 per day (PPP) in three quarters of the countries in SSA.

Solar PV systems power a limited number of services such as lighting, radios, and TV, which do not generate any income for rural households. The environmental effect of off-grid solar PV technology is insignificant, and the costs of reducing GHG emissions are extremely high. The costs and prices of solar PV systems have been falling. Many renewable energy supporters promote solar PV technology, as they claim that this technology has reached ‘grid-parity’, and that the LCOE of the solar PV energy has decreased. Energy planners should be cautious in their interpretations because although the values of such energy benchmark tools have been improved over time, they may still be high compared with conventional power-generating options.

As is well known in economic benefit–cost analyses, if the costs of the project continue to fall and the benefits stay constant, it is better to postpone such investments. Therefore, as the prices and costs of solar PV systems are decreasing, it is recommended that investments in such technology be postponed until it becomes competitive with conventional power-generation technologies. Accordingly, in SSA solar PV might be the technology of the future, rather than the present. Subsidizing poor people to buy or use a technology that is forecasted to be obsolete and much cheaper to purchase in the future is usually not a recommended strategy for economic development.

Although there can be no doubt about the impact of electricity access on the economic growth and well-being of any society, a systematic policy and plan for the expansion of electricity services at the margins by national or local electricity grids seems at the present time to be a more promising strategy for eventually achieving a higher degree of rural electrification. Promoting costly renewable technologies such as solar PV to increase electricity access in rural areas of SSA is not an effective anti-poverty policy to follow. Unless the technology is subsidized from abroad, it is the relatively poor consumers of Africa who will pay the high cost of these renewable energy technologies. The only clear beneficiaries are the commercial interests in developed countries that are supplying these technologies.

Notes

1. The exchange rate of 1.48 US$/euro was used.

2. The average number of persons per household was found to be five in a study done in five countries in SSA (Lighting Africa 2011).

3. The amount of energy generated by solar PV systems is calculated as an average of energy generated by solar PV systems in different countries of SSA using values provided by European Commission. It is assumed that a solar PV system has an operating life of 20 years. Annual degradation is assumed to be 0.6 per cent. Performance ratios (PR) of off-grid PV systems were found to be in range of 10–60 per cent in a study carried by IEA-PVPS Task 2 (Jahn et al. 2000). The authors are using a value of 60 per cent as a PR estimate. Discount rate is assumed to be 10 per cent (Bertheau et al. 2014).

4. A capital cost of US$650 per kWp is assumed for household diesel generators, taken as an average of the costs given for different countries in studies by Deichmann et al. (2010), Lazard (2013),

and Pauschert (2009). For the calculation of the amount of power generated by diesel generators, the same assumptions were made as those of Deichmann et al. (2010). Diesel price is taken as US$1.3 per litre as an average value calculated for SSA countries based on the data given by GIZ (2013); heat rate is taken as 10,000 Btu/kWh; fixed O&M costs are taken as US$15/kW/yr (Lazard 2013).

5. See note 4 for assumptions.

6. The average monthly household income is assumed as US$180 (Eberhard et al. 2011).

7. A study by the World Bank found that it was 2.1 per cent for Kenya and 1.5 per cent for Uganda (Bacon et al. 2010).

8. The cost of mitigating CO_2 through a solar PV system is 622 US$/t$CO_2$ if households were using simple wick kerosene lamps as the main lighting source, 626 US$/t$CO_2$ for small hurricane kerosene lamps, 440 US$/t$CO_2$ for large hurricane kerosene lamps, and 150 US$/t$CO_2$ for pressure lamps.

9. Based on the system cost projections given by Chase (2013).

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