

Report

Accelerating access to electricity in Africa with off-grid solar

The impact of solar household solutions

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PRACTICAL ACTION
Technology challenging poverty



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Cover photo: A Malawian teenager reads outside her house using a micro-solar light purchased from her school and supplied by SolarAid.
Photo by Jerry Barnett.

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Introduction

The solar energy sector in Africa is relatively young when compared to grid-based electrification,¹ but it is growing rapidly. Falling costs, combined with improvements in the energy efficiency of end-use technologies, including lights, and innovations in payment systems are helping the expansion of solar. Over the last five years (2009-2014), an estimated 17.4 million pico-solar lights were sold in Africa, and sales of quality-certified products alone reached 3.4 million in 2014. Following this growth, there is increasing evidence that solar household systems are contributing towards several development goals, including income poverty reduction, better education and improved health.

One of the strengths of solar PV is the opportunity it provides to target different income levels by varying generation capacity. Systems vary in scale, and cost, from small portable solar lights to large home systems able to power several high-powered appliances. Over 99 different solar devices have been quality certified

by Lighting Africa.² This variety enables access to modern energy services for households of different income levels.

This paper summarises the evidence that is currently available on the impact of solar household systems on poverty reduction and the environment in Africa. It is one of three papers about solar household systems in Africa, prepared as background papers for the Energy Africa campaign, which was launched in October 2015.³

To understand the impacts of many different solar household systems it is useful to categorise them. Categorisation can be based on the technical specifications of the systems and on the services they provide, or both of these factors. Kearney (2014) identifies three categories (solar portable lights (SPLs), solar household systems (SHSs) and large SHSs) while GOGA has six product categories (see Table 1). This report considers the full range of solar devices, using terms such as ‘solar household solutions’ or ‘solar off-grid options’, except where it specifically refers to solar lanterns or larger solar home systems (SHS).’

Table 1: Categorisations of solar household systems

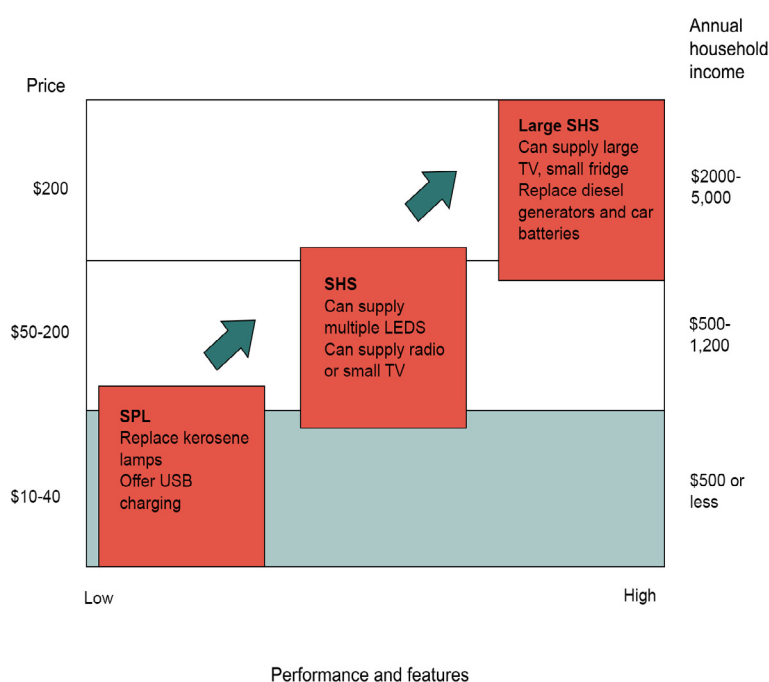
Tier 0		Tier 1		Tier 2		Tier 3	Tier 4	Tier 5
Kerosene lamps/ candles		Task lighting & phone charging		General lighting & TV/ fan		Tier 2 & medium power appliances	Tier 3 & high-power appliances	Tier 4 & very high-power appliances
> 3 W		< 10 W		> 50 W		> 200 W	> 800 W	> 2 kW
GOGA	PC1	PC2	PC3	PC4	PC5	PC6		
	Single light source only	Single light source only	Single light source with power outlet	Multi-light source with power outlet	Multi-light source with power outlet	Street or public lighting	Other lighting products	
	< 100 lm	> 100 lm	<100 lm	> 100 lm				
Kearney		SPL		SHS		Large SHS		
Single light sources with or without mobile phone-charging outlet				Multi-light source with power outlet; can power radios and televisions		Multi-light source points and devices such as televisions and refrigerators		

1 Solar lights have been sold in Africa since the late 1970s (IEA, 2013).

2 <https://www.lightingglobal.org/qa/statistics/>

3 The other two papers provide an assessment of the market for solar household systems and the policies that would enable the market to grow rapidly. For more information about the Energy Africa campaign visit <https://www.gov.uk/government/news/energy-africa-campaign>

Figure 1: The solar product energy ladder



Source: Kearney (2012)

Table 1 positions these categories in relation to the tiers of the SE4All Global Tracking Framework (2015), showing how solar household systems contribute to broader energy access objectives.

The great majority of solar household systems sold to date have been at the small-scale end of the range, i.e. SPLs or pico-solar systems (GOGLA Product Categories 1 to 4). The great majority of users, therefore, have gained Tier 1 access to electricity in the SE4All framework. The impacts discussed in this section are mainly the impacts from this first, basic level of access to electricity.

There is some evidence that buyers of pico-solar systems will upgrade to solar products with more functionality or capacity when they are able to do so. For example, they may move up from a solar light to a mid-level system with a higher wattage, longer battery life and mobile phone charging outlet. The 'energy ladder' for solar products, illustrated in Figure 1, is discussed further in the next section.

Methodology

Evidence of the impact of solar household systems has been obtained from a review of the available literature and unpublished research data held by SolarAid. It focuses

predominantly on the evidence from Africa, but draws from relevant studies conducted in other regions.

The literature reviewed was identified from SolarAid's specialist collection, the literature covered by Practical Action's previous study on *Utilising Electricity Access for Poverty Reduction* (2014), Sun-Connect's new resources list on impact,⁴ and online searches. GOGLA members were also invited to share any published and unpublished papers or data on the impact of solar lights and home systems. The evidence from the literature was synthesised and written up under key headings identified in the study's terms of reference.

The published evidence of the impact of solar household systems is limited. The study, therefore, relied heavily on SolarAid's primary unpublished research data. This research, conducted over the last three years in Kenya, Malawi, Tanzania, Uganda and Zambia, is based on interviews with randomly selected purchasers of pico-solar systems from SunnyMoney, SolarAid's social enterprise. Over 9,600 solar light purchasers were interviewed by phone at the time of purchase and then 6-9 months afterwards and over 10,600 surveys were conducted in-person with members of the rural public.

4 <http://www.sun-connect-news.org/downloads/impact/>

The evidence review also drew from the work of GOGLA's Impact Metrics Group, which is chaired by Kat Harrison, SolarAid's then Director of Research and Impact, now Associate Director of Impact at Acumen. The working group released the first draft of a harmonised impact reporting framework for the off-grid sector in June 2015, update January 2016.⁵ This framework is based on two years of work to identify priority impact metrics, develop appropriate formulae for calculating metrics, and source data to propose default coefficient values. The framework will provide a comprehensive and consistent way of calculating and communicating the impact of the sector, and has been adopted by the Global Impact Investing Network's IRIS metrics.⁶

While this review of the evidence draws from credible reports and studies, there are some limitations in the evidence base. Many studies are geographically specific and may not be representative of the region. A number are based on a small sample size (e.g. Practical Action Consulting, 2015; Furukawa, 2013; Collings, 2011; Obeng & Evers, 2010), or may have biases through their sampling method (e.g. Brossman, 2013). The Powering Education (2014) study examines the use of lights given free to students in an apparently uncontrolled way. Analytical method and assumptions are not clear in some cases (e.g. UNEP, 2013; UNFCCC, 2012; Lighting Africa, 2010). Some studies relied on self-reported information, which may have been biased by other factors (e.g. fear of tax assessment).

The SolarAid primary research is not free of some of these limitations. It focuses on five countries (Kenya, Malawi, Tanzania, Uganda and Zambia), using different sample sizes in each country and depending on the question. The information is self-reported, and was collected through interviews conducted by phone - for the solar light user interviews. Solar light purchasers who do not have access to a mobile phone, possibly the poorest, may have been omitted. The interviews were conducted in local languages, to ensure accurate information was collected, but some emphasis or understanding may have been lost in the translation to English.

Household finances

Poor households tend to spend a higher proportion of their income on energy, often for vastly inferior levels of energy services (Alstone et al., 2015). The price they pay per unit of energy is also higher than that paid by

higher income households. An Energy Sector Management Assistance Programme (ESMAP) (2015) report suggested that electricity offers 10 times more affordable lighting than fuel-based lighting in terms of cost per lumen-hour (looking at cost, quality, and time). According to The Economist (2015) poor households are buying lighting at the equivalent of \$100 per kilowatt hour, more than a hundred times the amount people in rich countries pay. Mills and Jacobson (2011) estimated that the world's off-grid households spend approximately \$40 billion per year on lighting, around 20% of all global lighting expenditures, but receive only 0.1% of the lighting service consumed by the electrified world in total. In aggregate, we estimate that African low-income households are spending around \$6.5 billion a year on inefficient lighting.⁷

Empirical evidence that solar household systems are or are not acquired by households living in extreme poverty is limited. In Kenya, Jacobson (2006) found that most solar systems are owned by the rural middle class, those in the top one-third by wealth. In Uganda, Harsdorff et al. (2009) found that market-based approaches to disseminate solar systems seem to favour wealthier and better-educated households. The study concluded that international support is essential, sometimes even a pre-condition, for companies entering the rural solar market. However, these studies covered a small number of households and were published before the market in east Africa began to expand rapidly.

In Bangladesh, where the evidence is strongest, the likelihood of a household having a SHS increases with income (Komatsu et al., 2011), but the majority of SHS users are below the regional poverty line (Brossman, 2013). The World Bank (2008) found in Lao PDR that off-grid components promoted social equity in electrification coverage, reaching remote communities that would otherwise not have access to electricity for a decade or more.

SolarAid's research (2012-15) with pico-solar light customers suggests that an average family purchasing a basic pico-solar light has a monthly household income of around \$ 111, varying across the countries of research.⁸ Assuming an average household size of 6, they estimate that 77% of their customers live below the \$ 1.25 per person per day poverty line.⁹ While testing small-scale trials for payment by instalment (pay-as-you-go) for solar products, SolarAid saw customers with lower incomes being able to access the solar lights, because families had access to the lights at minimal risk and cost.

5 <http://global-off-grid-lighting-association.org/wp-content/uploads/2016/01/GOGLA-Standardised-Impact-Metrics-for-the-Off-Grid-Energy-Sector1.pdf>

6 More information about IRIS metrics is available at <https://iris.thegiin.org/> assessments estimate an average of \$ 71 a year spent per household on kerosene.

7 This estimate is based on an average of \$ 50 a year per household (Scott, 2015) and 130 million off-grid households. UNEP's off-grid lighting country assessments estimate an average of \$ 71 a year spent per household on kerosene.

8 Monthly household income varied between countries: \$ 191 in Zambia, \$ 126 in Tanzania, \$ 119 in Kenya, \$ 107 in Uganda, and \$ 43 in Malawi.

9 61% in Zambia, 54% in Kenya, 70% in Tanzania, 90% in Uganda, 99% in Malawi.

The ability of solar lights and smaller SHS to reach the lowest income households is in direct contrast to the failure of electricity grids to do so. Grid-based electrification can occur in a regressive manner because the criteria used to select which communities to extend the grid to first (e.g. distance from the grid, population size, ability of households to afford connection costs and service costs) favour higher-income communities. When communities are electrified, low-income households frequently cannot afford the connection charges. The grid connection charges in Africa range from \$2 to \$400, and often exceed households' average monthly income (Scott, 2015). As a result, the World Bank (2008) found that even in villages which had been connected for 15–20 years, it was not uncommon for 20–25% of households to remain unconnected. When households are connected, the tariffs for electricity can remain too high for households living on very low incomes (Africa Progress Panel, 2015).

For these reasons, solar lights and smaller solar systems are often more affordable options for low-income households than grid connections, even in urban areas. Moreover, they are available in the short term and not dependent on government infrastructure plans.

Change in spending on lighting

One of the principal impacts of solar household systems is the financial saving to users from reduced expenditure on lighting. Most studies estimate rather than measure these savings. Empirical evidence of financial savings is provided in a small number of studies.

Rural families across Africa are spending 10% of household income for 4 hours of light at night using kerosene, torches or candles.

The Powering Education study (Hassan & Lucchino, 2014), which gave solar lights free to families of school children, saw a reduction in expenditure on fuel equivalent to around 10–15% of the average weekly income. A study in Rwanda (Grimm et al., 2014) found that 'treatment households' which were given free pico-solar lights paid one-fifth as much per hour of lighting as 'control households.' The result was even more pronounced when comparing lumen hours,¹⁰ showing quality not just

quantity of light: control households paid 7 times more per lumen. Treatment households' expenditure on kerosene declined almost 70%.

SolarAid primary research (2012–15) across Kenya, Malawi, Tanzania, Uganda and Zambia, found that before solar light ownership, families were spending \$ 1.20 a week on lighting, equivalent to 9% of household income for 4 hours of light at night. The most commonly used source of light was kerosene, with 69% of households regularly using kerosene lighting in Kenya, Uganda and Tanzania, and fewer in Zambia and Malawi. Torches/ flashlights and candles are the other two main sources of lighting for those living off-grid. The Power, People, Planet report of the Africa Progress Panel (2015) noted that in Ethiopia, households spend \$ 2 a month for 3 hours of lighting each night, on average.

After purchasing a solar light, SolarAid (2012–15) found that 71% of families reduced their lighting spending, primarily on kerosene. Of those households which were using kerosene for lighting before purchasing a solar lantern, 69% eliminated kerosene use altogether.¹¹ After solar light ownership, families saved \$ 60 a year, spending on average just 2% of their household income on lighting.¹² These savings differed depending on the lighting source that was previously used (for example, kerosene lamps account for a higher weekly spend for families compared to torches). The savings were most pronounced in Kenya where households went from buying an estimated 9 litres of kerosene a month for lighting to 1 litre a month after adopting solar lighting. The pico-solar lights offer a replacement ratio of 1:1 – one solar light replaces the use of one kerosene lamp (SolarAid, 2012–15; Lighting Africa, 2010; UNEP, 2012; UNFCCC, 2012).

Families with a solar light save over \$60 a year, spending 2% of their household income on lighting.

Solar lanterns are conservatively estimated to have a lifespan of 3 years, suggesting that they could save families on average \$170, after the cost of the solar light is taken into account. The IFC and World Bank's joint initiative, Lighting Africa, reported that replacing kerosene lamps with solar lights offers returns on investment of 15–45 times the cost of the solar light (2010).

10 A lumen is the measure of total amount of visible light (to the human eye) from a light source. The higher the lumen rating the 'brighter' the lighting source.

11 91% eliminated all use of kerosene after solar light purchase in Zambia, 75% eliminated use in Malawi, 72% in Uganda, 70% in Kenya, 64% in Tanzania.

12 In Malawi, families spent 12% of their income on lighting prior to solar light ownership and 5% after, in Kenya expenditure went from 10% to 1%, in Tanzania and Uganda from 7% to 1%, and in Zambia from 6% to 2%.

Replacing kerosene lamps with solar lights offers returns on investment of 15-45 times the cost of the solar light.

Because the savings appear to be quite large for even small solar systems, there is not a massive increase in relative savings for households using larger systems. In fact, there is some evidence that larger systems reduce the replacement rate of traditional lighting less than portable solar lights, because large systems frequently power a fixed light, which cannot be moved from room to room, necessitating the continued use of kerosene. A study in Bangladesh (Brossmann, 2013) found that for households which purchase a SHS (i.e. a larger system) the decrease in energy-related expenditures was the most important outcome for households. The study showed that energy-related expenditures declined by 74%. An evaluation conducted on a GIZ solar electrification project in Uganda found that households with SHSs spent less than half per lumen hour than non-users (Harsdorff & Bamanyaki, 2009).

There is some evidence to show that when lower-income households access larger systems, maintenance could become a problem, for example, if funds are not available for replacing batteries (study in the Philippines, Hong & Abe, 2012). There is an increase in companies offering solar as a service, i.e. systems that are not owned by the household, but the energy is paid for monthly. There is little evidence of the effectiveness of this model, though it appears to be a sensible solution to the challenges of maintaining bigger systems and spreading out costs for families.

Halving costs of inefficient lighting sources would save \$50 billion for people living on less than \$2.50 per day.

Solar light manufacturer, d.light (2015) argued that delivering energy access to the energy impoverished could save \$ 38 billion in energy expenditures. The Africa Progress Panel reports (2015) that halving the costs of inefficient lighting sources would save \$ 50 billion for people living below \$ 2.50 per day. It estimated that the monetary saving from cost reductions would be sufficient to reduce poverty by 16-26 million people

‘[The solar light] is cheap. It just uses the sun. It’s been a year and I’ve saved. Life has become cheaper.’ Nixon Ketere in Kenya

Cost savings of inefficient lighting sources would be sufficient to reduce poverty by 16 - 26 million people.

Use of savings

There is some evidence on how the savings in lighting expenditure are used by families using pico-solar systems. SolarAid research (2012-15) found that households predominantly reported spending their savings on food (46% of respondents), education costs (i.e. fees, uniforms, books) (30%), farming inputs such as fertiliser, seeds, and equipment (8%), and investment in other types of small-scale businesses (7%). In Malawi, expenditure on toiletries, in particular soap, being specifically important (26%).¹³ Interestingly, 64% of the time, it is a male member of the household who makes the decisions on spending of savings.

There are other co-benefits experienced too. Kudo et al.’s (2015) research in Bangladesh found that solar products increased the likelihood that a household succeeded in obtaining a loan as their expenditure on energy was reduced. The GIZ study by Harsdorff et al. (2009) in Uganda found that 50% of households with SHS hold savings accounts whereas only 10% of non-users do.

Quality of lighting

The benefit of pico-solar lights and solar home systems goes beyond the financial savings. In particular, it creates opportunities through extra lighting hours and better lighting quality for income-generating activities and productive work-hours in the home.

Brightness available

Brightness is measured in lumens, with a standard kerosene lamp providing 20 lumens, a single-wick lamp providing 10 lumens (Mills, 2003), a candle providing 10 lumens (Lighting Global, 2010) and a pico-solar light providing 20 to 100 lumens, depending on the product and setting used.

Grimm et al.’s study in Rwanda (2014) found that the reduction in lighting costs due to use of pico-solar translated into a large increase in the amount of lumen hours consumed per day: two times as high as in control households. Bright lighting allows activities that may not

¹³ Top expenditure items differed across countries; families in Kenya most commonly reported spending savings on education costs, food was most important in Malawi, Tanzania, Uganda and Zambia.

‘The [solar] lamp is bright enough and can be used for security at night and therefore we can stay up late with little fear.’ Badru Sserwada in Uganda

be conducted under dim light, adds to security, and can reduce eye strain and illness.

Light hours available

Once households have a pico-solar light, their light hours increase to 5.1 each day, on average (SolarAid, 2012-15). A small GVEP study in Rwanda (2012) also noted a treatment group given pico-solar lights consumed 15% more lighting hours afterwards.

Before purchasing a solar light, pico-solar light users across Kenya, Malawi, Tanzania, Uganda, and Zambia had an average of 4.1 hours of light each night with traditional lighting methods (SolarAid, 2012-15). Lighting Africa (2010) and UNEP (2013) also estimated that off-grid households light their homes for 4 hours per day using traditional methods. Pico-solar systems thus increase the number of hours that lights are used by about 1 hour a day, which is roughly equivalent to 50 days in a year.

Reliability

Once bought, a solar light can provide reliable, cost-free lighting. In Bangladesh, 92% of SHS users reported that their systems had enabled them to use lights whenever they wanted to, and to watch TV programmes without interruptions by power failures (Urmee & Harries, 2011). 22% of microenterprise SHS users interviewed for a GIZ evaluation (Harsdorff et al., 2009) specifically said that they see the product as a reliable source of light. SolarAid (2012-15) found that 13% of pico-solar customers use their solar light as a back-up for electricity, as even when homes are connected to the grid the supply can be unreliable or insufficient. For homes using kerosene, access to the fuel in some countries can be cut off at periods due to foreign exchange or import issues.

Solar lights provide families with brighter, more reliable light.

While there are many poor quality solar household systems on the market in Africa, those that are quality tested by Lighting Global have warranties that give some level of protection and support to customers in case of fault. While the logistics of upholding warranties and replacing faulty lights are not always simple, quality assurance tests reduce the risk of fault in the first place.

A further indication of reliability, 93% of over 2,930 pico-solar light customers interviewed across Kenya,

Malawi, Tanzania, Uganda and Zambia rated themselves as satisfied (4/5) or very satisfied (5/5) with their solar light (SolarAid, 2012-15). 86% of SHS users in Bangladesh were generally satisfied with their system (Harsdorff et al., 2009).

Income generation

A UNEP (2014) ‘Light and Livelihoods’ survey in 17 sub-Saharan African countries found that many businesses lacking grid electricity employed fuel-based lighting. Lack of electricity in the workplace ranged from 92% of businesses in Mali and Niger, to 12% in South Africa (Tortora & Rheault, 2012). Lack of energy after dark can inhibit people’s opportunities for earning income by cutting the productive day short due to insufficient or unreliable light. Access to electricity can increase income generation by improving the productivity of labour and capital, and helping to create new business opportunities.

Use of solar for income-generating activities

Solar lighting can improve income generation by increasing the time available for productive work. 11% of pico-solar light users interviewed by SolarAid (2012-15) reported using their solar light for business use. Of these 98% said it had positively affected their hours of business, and 76% said it had positively affected how their customers interacted with their business. A study in Kenya (Hassan & Lucchino, 2014) also found significant evidence that mothers, and especially fathers, increased their time at work after being given a solar light – fathers increased their time spent working for pay each day by 13%.

Average incomes of solar-electrified enterprises were 82% higher than non-electrified enterprises.

In a number of cases, the availability of solar lighting after sunset has been shown to increase the likelihood that enterprises will generate additional income by extending their working hours. Obeng and Evers’ (2010) study in Ghana found that the average income of solar-electrified enterprises was 82% higher than non-electrified enterprises. However, the causality of this relationship is difficult to untangle.

‘My shop remains open and we are able to sell things in the night.’ Pharoah Mweemba in Zambia

The GIZ evaluation in Uganda (Harsdorff et al., 2009) found that micro-enterprises with solar systems experienced higher profits of \$ 4.40 a month due to their ability to attract new clients. The solar system users attracted more customers per day. 76% of the micro-enterprises with solar systems reported growth in sales, while 64% of non-users reported growth in sales. The evaluation noted that users benefitted from higher savings rates and increased use of financial instruments and financial literacy. Practical Action Consulting's report (2015) on households using pico-solar lights found an increase in incomes for families in India. However, there was no change reported in Kenya.

Having access to reliable light at night provides opportunities for task-shifting, meaning that there are more productive hours in the day and more opportunity to do different tasks at different times. 80% of women from households with SHS in Uganda did domestic work in the evenings after sunset (for 2.2 hours, on average), whereas 66% of those without SHS did (for 1.9 hours). 27% of women specifically said they used the SHS to complete their household chores after sunset (Harsdorff et al., 2009).

Conversely, the study by Obeng & Evers (2010) in Ghana found that the working hours of enterprises using solar systems were limited by a faulty battery problem and power fluctuation due to insufficient sunlight during rainy seasons. As a result, micro-enterprises combined solar and kerosene lamps to extend their working hours throughout the year.

Solar products that enable energy services beyond lighting create new income generating opportunities. Mobile-phone charging businesses are particularly common. Families often use their solar systems to charge neighbours' and friends' phones. Families across East Africa reported spending around \$ 0.26 per week on mobile phone charging, with a member of the household spending an hour, on average, travelling to charge it each time (SolarAid, 2012-15). A study by GVEP (2011) found that a phone charging business in Tanzania could earn revenues of \$100 a month. The size of a solar system required to service that level of business costs around \$480 (excluding installation), meaning that the business could pay for itself in five months.

Solar-powered pumps also offer an option for small-scale irrigation systems. Irrigation systems could, in many cases, greatly enhance agricultural productivity. Land that has irrigated systems is, in general, more than twice as productive as non-irrigated land, yet only 4% of agricultural land is thought to be under irrigation in sub-Saharan Africa (World Bank, 2008). Given their high capital costs, they are typically out of the reach of

'[The kerosene lantern] was polluting the air, my kids were having eye infections and they were coughing a lot. It was costing me a lot for their treatment.' Dickson Murumbi in Kenya

individual smallholder farmers (Burney, Naylor, & Postel, 2013). Solar-powered irrigation also has the disadvantage of allowing pumping only during daylight hours and requires an installed capacity that may only be used for 30-40% of the year (Nederstigt & Bom, 2014).

A recent review of renewable energy options for smallholder irrigation (Nederstigt & Bom, 2014), which found only one successful example of solar pumping for small scale irrigation, in Benin,¹⁴ concluded that fossil fuels were still an attractive, low-risk option for small-scale farmers. The World Bank recently reported, however, that with declining costs, small solar irrigation pumps are now more cost-effective than diesel-powered pumps in India (Jain, 2015).

Health

Household air pollution

By reducing the use of kerosene lanterns, solar energy can help reduce air pollution in the home. While household air pollution resulting from cook stoves has been extensively studied in the literature, particulate concentrations from fuel-based lighting have received less attention (Apple et al., 2010). Some kerosene-using devices emit substantial amounts of fine particulates, carbon monoxide (CO), nitric oxides (NOx), and sulphur dioxide (SO₂) (Lam et al., 2012). Studies on kerosene used for cooking or lighting provide some evidence that their emissions may impair lung function and increase infectious illness (including tuberculosis), asthma, and the risk of cancer.

Solar energy can help to reduce risk of fires, burns, and pollution in the household.

The World Health Organisation's (WHO) Guidelines for Indoor Air Quality (2014) state that existing evidence shows that household use of kerosene can lead to particulate matter levels that exceed the guidelines – substantially so in developing country homes using simple unvented combustion technologies like kerosene lamps.

14 This was the Benin SELF project, which involved high capacity systems managed by groups of farmers. For more information see Nuomon, T. (2008) Irrigation Schemes Using Solar Energy: Case Study in Togblo, District of Athieme, Province of Mono, Benin.

However, epidemiological evidence on the morbidity and mortality associated with kerosene lighting is currently inconclusive. The WHO does attribute 4.3 million deaths globally to household air pollution, predominantly caused by cooking. The Economist (2015) writes that household air pollution caused an estimated 600,000 preventable deaths a year in Africa alone. The WHO Guidelines recommend that the household use of kerosene be discouraged while further research into its health impacts is conducted.

Existing evidence shows that household use of kerosene can lead to particulate matter levels that exceed WHO guidelines.

The WHO's *Fuel for Life* report (2006) stated that indoor air pollution was equivalent to smoking two packs of cigarettes a day. This was widely misinterpreted and was used as a statement for the equivalent of using a kerosene lamp. Working with Dr Nicholas Lam,¹⁵ SolarAid conducted work (2014) to calculate an accurate equivalent for kerosene lamp contribution to indoor air pollution. It was, unsurprisingly, estimated to be significantly lower, but serious nonetheless, at 170 cigarettes a year.

While it is acknowledged that the use of kerosene lamps contributes to household air pollution, much of the evidence on health relies on reported effects from users. SolarAid research (2012-15) found that 40% of solar light users using kerosene lamps for household lighting reported experiencing health problems that they associated with its use. Respiratory health issues (chest problems, flu-like symptoms and coughing) were reported by 44%; 30% mentioned eye irritation and eye strain occurring from the smoke and dim light; 26% talked about general illness, and 8% talked about headaches. There were different levels of reported health issues, which is likely due to a combination of awareness and type of kerosene lamp used, as the single wick lamps give off more particulate matter than hurricane or pressurised lamps.¹⁶ It is also possible that the health effects of cooking were attributed by users to kerosene lighting.

A study in India (Chakrabarti & Chakrabarti, 2002) found that 21% of families reported suffering from eye problems from the use of kerosene, a finding that is corroborated by a UNICEF (2015) report which stated that compromised visual health was a common result of

'One of my kids got burnt as a result of the tadooba [kerosene lamp] that had been put near the net and fell spreading the fire to the bed where the boy was sleeping.' Bosco Yaliyo in Uganda

'I am now healthier than before because the money used to buy [kerosene] has been diverted to food.' Gilbert Mwalwanda in Malawi

poor lighting from fuel based lanterns, citing studies by Harvey et al., 2009 and Mills, 2012.

A number of studies have shown that houses with solar systems have less experience of the health issues associated with kerosene lighting. Harsdorff et al.'s (2009) study in Uganda found that only 5% of people in households with a SHS experienced respiratory tract infections compared to 19% of people in households without. Again, this finding may be in part due to other behaviours including cooking methods.

Research in rural Rwanda found that 45% of households given pico-solar lights said the air quality in their home had improved as a result (Grimm et al., 2014). SolarAid research (2012-15) with solar light users found that 63% of customers who used kerosene lamps prior to buying a solar light experienced an improvement in their health.¹⁷ In particular, improved respiratory health and reduced coughing was reported by 37% of families, 25% reported reductions in eye irritations, 18% talked about reduced frequency of illness more generally, and 6% mentioned less frequent headaches.

Kudo et al.'s study in Bangladesh (2015) also found that children with solar lights were exposed to air pollution for significantly fewer hours compared to those without solar lights. The solar lights were seen to reduce the case of red eyes, eye irritation and watering eyes.

Burns and poisoning

Solar household systems can also keep families and communities safer by reducing the use of flame-based lighting, lighting, thereby reducing the risk of burns, accidents and fires. Due to its high combustibility, the use of kerosene as a lighting fuel also presents a serious fire hazard. For example, in Sri Lanka, 41% of the 221 burn victims treated at Batticaloa General Hospital between July 1999 and June 2001 stated that lighting was the cause (Peck, et al., 2008).

15 Based at University of Illinois at Champaign-Urbana, PhD from the School of Public Health, UC Berkeley.

16 14% of those using kerosene regularly in Zambia reported health issues associated with its use in the baseline, 60% in reported health issues in Uganda, 43% in Kenya, 34% in Malawi, and 30% in Tanzania.

17 This was higher in Uganda, perhaps due to higher awareness during the baseline of health issues associated with kerosene use, at 85% of families reporting improved health from reducing kerosene use. 67% in Kenya, 47% in Malawi and 35% in Tanzania.

The use of kerosene as a lighting fuel presents a serious fire hazard.

Poisoning also often occurs as kerosene is commonly sold in soda bottles and it can be mistaken for soda. UNICEF (2015) report that the primary cause of child poisoning in developing countries is accidental kerosene ingestion, and burns are identified as one of the leading causes of child injury. Eberhard & Van Horen's study (1995) estimate that at least 10,000 children per year were afflicted with kerosene poisoning in South Africa alone.

SolarAid conducted preliminary research in Uganda (2014-15) to identify the frequency of accidents like fires, burns and poisoning from using kerosene – 19% of customers interviewed had experienced accidents.

Nutrition

Pico-solar light customers commonly spend their savings on lighting expenditure on food, stating in particular the opportunity this provides for a balanced diet or more varied food in their children and their family's diets (SolarAid, 2012-15).

While there is no specific evidence to show this, it may be logical to assume that better health due to improved nutrition and reduced indoor air pollution will result in fewer days of missed school for children, and more productive hours of work for adults. Ill health can reduce earning capacity and entail significant costs for treatment, sometimes driving a household below the poverty line. The poor account for a disproportionate share of those burdened with disease, and this is, in part, because of the failure of health services to reach them (Wagstaff, 2002).

Health care delivery

It is not just in homes that access to energy, and even just lighting, can have an impact on health. Electrified hospitals and health facilities can provide better health care services, which can be life-saving. Medical equipment is better sterilised, hygienic standards are maintained more easily, the diagnosis of patients can be done more effectively (e.g. by facilitating laboratory work), and blood, drugs and vaccines can be kept safely chilled. Despite the importance of electricity for health care provision, over 30% of all health facilities in sub-Saharan African, serving approximately 255 million people, lack access. In Uganda and Tanzania, respectively, only 42% and 50% have electricity (Practical Action, 2013). Another study on sub-Saharan Africa concludes that in 11 surveyed countries, 26% of health facilities did not have access to electricity

'Sometimes [my son] was coming home very tired so he could not even use the kerosene lamp but the solar light motivates him to study even when he is tired.' Mashanda Michael in Tanzania

and among those that did only 28% had reliable access (Adair-Rohani et al., 2013).

Electrified hospitals and health facilities can perform better services.

Basic health facilities have electricity demands that differ from those of larger clinics and hospitals. Small clinics or health posts in rural areas demand electricity for lighting; ICT for administration, information, and aftercare services; for laboratory equipment and for refrigeration for the storage of vaccines, blood and other medical supplies. Larger clinics, of the type found more commonly in medium-sized towns and cities, while requiring electricity for all of these purposes, also need it for more energy-demanding medical equipment, such as ultrasound and X-ray machines, equipment for HIV/AIDS diagnosis, and incubators for premature babies (USAID, n.d.). Almost half of vaccine deliveries to developing countries are going to waste due to unreliable electricity connections and poor maintenance of existing solutions (Vaxess, 2012 in UNICEF, 2015). USAID calculated that the electricity needs of a larger clinic (with 60 beds) ranged from 5 to 10kWh per day – a quantity that would be cost-effective to supply through solar power or solar diesel generators in rural areas without grid access (Hogarth & Granoff, 2015).

Education

Solar lights for studying

As previously discussed, longer hours of more quality light through solar household systems can enable more productive hours after dark. One important implication of this benefit is that children can spend more time on education and homework or study-time.

SolarAid (2012-15) recently conducted focus group discussions with school children in Kenya, Malawi, Tanzania and Zambia, and found that students rated limited lighting as their top factor for what challenged their opportunities to learn and do homework.¹⁸ Only 55% of students in the discussions (512 across 31 schools) said they had bright enough light to study (SolarAid, 2012-15).

18 Limited lighting was closely followed by materials, time and money.

Students rated limited lighting as their top factor for what challenged their opportunities to learn and do homework.

SolarAid (2012-15) research shows that the most common reported use of the pico-solar lights sold by their social enterprise, SunnyMoney, is for child study: 63% of households said study was what they were used for, often not exclusively.¹⁹ A GIZ study (Harsdorff et al., 2009) also found that the main beneficiaries of the SHSs bought were children (53%), who used them to complete their homework at night. 74% of children in SHS homes studied in the evenings, compared to 64% in non-SHS homes.

There is clear evidence that better access to lighting provides children with opportunities to increase the quality and time of their study/homework. SolarAid (2012-15) data shows that before solar light ownership, children were studying for 1.7 hours on average each night, and were often constrained by lack of access to light due to money for kerosene, or candles running out. After purchasing a solar light, children in the same households were studying for an average of 3.1 hours a night.²⁰

Harsdorff et al.'s (2009) study in Uganda compared study time across households rather than longitudinally, and found that children from households with solar systems studied for 2.3 hours per evening, while those in households without studied for 1.9 hours each night.

Children in households with solar lighting nearly double their homework hours each night.

The Powering Education (2014) study found smaller increases.²¹ It identified an increase in study time at home by 10-15 minutes per day, a 17% increase. Interestingly, the study identified what appeared to be a peer effect, where students with no solar light performed significantly better if

'Performance has improved and the children now have love for the books.' Kipkoechi Konuche, teacher in Malawi

they were in a class where most students had a solar light, though of course there may be other factors to explain this.

GVEP's (2012) report on Rwanda found that 88% of households noted an increase in hours of child study following purchase of a pico-solar light. Grimm et al.'s (2014) study in Rwanda saw an increased portion of the children given a solar light studying after dark. However, the total study time did not increase; rather, children shifted their study time from afternoon hours to the evening. The study did find clear evidence of an improved quality of learning time and more flexibility in the time of day that they can study.

Unsurprisingly, this effect on child study hours is also observed for larger SHSs. Brossman (2013) found that girls aged 11-15 living in SHS homes in Bangladesh studied for 3.8 hours a day, while girls in non-user homes studied for 3.1 hours a day.²²

Improvements in motivation, attendance and performance

It might be expected that the increased hours of study enabled by solar lighting would improve educational performance. Hunt (2008)²³ reported that children who study for longer, and are more motivated, do better at school. Learning influences children's experiences of schooling, their motivations and the likelihood of dropping out of school. Children who attain better grades are less likely to drop out of school (Colclough et al., 2000).²⁴

Preliminary results are inconclusive. Kudo et al.'s (2015) study in Bangladesh saw increased study hours among school children with solar lights; particularly at night and before exams. However, there was no corresponding link to improved exam results and no evidence of improved educational attainment as a result of the solar lights. A small pilot study conducted in Uganda also found no evidence of improvements to education for children given a solar light despite increased study time (Furukawa, 2014).

19 SunnyMoney works through a School Campaign that works alongside the Ministry of Education and headteachers to raise awareness in schools about solar lighting. As a result, parents are encouraged to purchase solar lights for their homes, but particularly for their children to use for homework after dark. The reported use of solar lights for study in SolarAid's research may be shaped by this marketing activity.

20 This differed slightly per country with children in Zambia seeing the biggest change from 1.2 hours of homework each night using kerosene, candles or torches, to 4.2 hours with solar light. From 1.5 to 2.6 in Uganda, 1.7 to 3.0 in Malawi, 2.1 to 3.1 in Kenya, and 2.0 to 2.7 hours in Tanzania.

21 Those with solar lights were given the lights, which may affect behaviour change.

22 These SHS were bought by families. Higher income families may be more likely to have bought the SHS and also be more educated and therefore place more value on their children's education which may be a factor in study hours.

23 Hunt's article is a literature review (about dropping out from school, focusing on children who have gained access, but fail to complete a basic education cycle).

24 Based on school-based surveys undertaken at the school and community levels in Ethiopia and Guinea in 1995.

SolarAid (2012-15) research found that teachers at schools where community members have pico-solar lights noted seeing improved attendance, motivation, concentration and performance in class for those children with solar lights, though this improvement was reported by teachers and not evidenced.

Better education delivery/retention of teachers

Sub-Saharan Africa has the lowest rate of primary school electrification, with just 35% of schools having access electricity (UNICEF, 2015). 90 million pupils in the region attend a school with no access to electricity (citation: Practical Action, 2013). But there are wide variations in the proportion of primary schools without electricity, from just over 10% in South Africa to 98% in Burundi (Practical Action, 2013).

Sub-Saharan Africa has the lowest rate of primary school electrification at 35%.

While supporting better access to lighting for children at home appears to increase study hours, there are other ways to enhance educational opportunities relating to energy-use. A school's access to electricity may influence the motivation of its students and its ability to attract good teachers. Electricity can improve schools through better lighting; the use of fans to control temperature; more efficient administration through computers and other information and communication technology (ICT) (Practical Action, 2013). Hansen et al. (2012) noted that the application of ICTs, such as laptops, internet and music players, also facilitates higher quality education for children and may even boost their abstract reasoning. Recent research in Ethiopia showed that pupils in grade 6 and 7 using laptops scored significantly higher in finding analogies and categories than those without.

Cabraal et al. (2005) found that the presence of household electricity in rural areas can also attract more effective teachers. Though only a small sample size, SolarAid (2015) data from Kenya highlighted that 87% of head teachers interviewed thought that having a pico-solar light affected their quality of life. 36% of teachers used their solar light for school work, marketing, lesson-planning, and offering more hours of schooling for pupils. In addition, 75% of head teachers said that recruiting and/or retaining teachers was a problem at their school and 60% felt that better lighting at home would encourage teachers to live and work in rural areas.

Although there is not enough evidence, and many other factors affect the quality of teaching, it is fair to assume that if teachers are better equipped to do their jobs, they are more likely to provide a better quality of service for their students.

Practical Action (2013) estimated that the electricity needs of a school for 100 children would be similar to that of a small health centre: around 5-10kWh per day. This level of electricity could be provided economically through solar-powered or solar-diesel hybrid systems in rural areas (Hogarth & Granoff, 2015).

Linked effects: future income generation and health

In Africa, not only has education been demonstrated to increase income levels, it has also been shown to have a positive impact on other indicators of development: health, female participation in politics, and political stability (Gyimah-Brempong, 2010). A UN (2007) report states that educated girls are more capable of providing quality care for their children and make better use of health and other social services available to them. Moreover, girls who are more educated and stay in school longer are likely to start a family later and be more empowered to make decisions in the home. Relating to future income, the Government of Tanzania Household Budget Survey (2007) found that people with secondary education earn 44% more than those without suggesting that education can help to reduce future poverty status.

Environment

Greenhouse gas emissions

Estimates of greenhouse gas emissions from kerosene lighting vary with the assumptions used in their calculation. According to Lighting Africa, kerosene lighting in Africa accounts for 20 million tons of CO₂ emissions a year (IFC, 2010). UNEP estimates that the substitution of solar lighting for all traditional lighting would save about 34 million tons CO₂ a year.²⁵ For individual households, Brossman (2013) found in Bangladesh that SHS users reduced their emissions by 95.3kg of CO₂ per year, while smaller SHS users reduced CO₂ emissions by 68.3kg per year. Lighting Africa's estimate is based on 150kg CO₂ per household, while Keane (2014) cites an estimate that the emissions of a single kerosene lamp are about 200kg a year.

A solar light averts an estimated 555kg of CO₂ each year.

25 The Lighting Africa estimate is based on a conversion factor of 2.5 kg CO₂ per litre of kerosene consumed and the estimated consumption for lighting of 5 litres of kerosene per month per household, by 130 million households with inadequate lighting (IFC, 2010). UNEP's estimates are based on a conversion factor of 2.6kg CO₂ per litre of kerosene (UNEP, 2013)

Households that purchase solar household systems reduce their consumption of kerosene. Research in five African countries by SolarAid (2012-15) found that on average a household reduces their use of kerosene by 77% after purchasing a pico-solar light. For families which used kerosene as their main source of lighting before using a solar light, this reduction equates to an estimated reduction of 4.1 litres of kerosene per household per month. This reduces emissions by an estimated 123 kg CO₂ a year per household.²⁶

Harsdorff et al. (2009) found that SHS users in Uganda consumed 2 litres of kerosene a month, while the consumption of non-users was nearly twice as much, 3.5 litres. They suggested that kerosene usage was not greatly reduced for SHS users because of the stationary nature of the lights and the fact that not all rooms in the home are lit. A reduction in kerosene consumption of 1.5 litres a month would reduce the household's emissions by 45 kg CO₂ a year.

Taking a conservative 100 kg CO₂ estimate for the annual emission savings from reduced kerosene consumption following adoption of a solar light, total emission savings from sales of solar lights in Africa over the period 2011 and 2014 are estimated to be around 3 million tons CO₂ (757,000 tons a year).

Research by Lam et al. (2012) has shown that kerosene lamps are significant sources of atmospheric black carbon and emit 20 times more than previously estimated. At least 270,000 tons of black carbon per year are estimated to be emitted from kerosene lamps worldwide, having a climate warming equivalent close to 240 million tonnes of CO₂ (Lam et al., 2012), a magnitude similar to the total annual emissions of Vietnam (251 million tonnes CO₂e) (WRI, 2015).

Alstone et al.'s (2015) study on decentralised energy suggests that when the effects of black carbon are accounted for (using a 100-year global warming potential),²⁷ climate forcing from households using kerosene lighting is nearly 10 times as high as that of the typical grid-connected household in Kenya. This will vary depending on the location and source of grid electricity in other countries.

This links to a significant reduction in CO₂ and CO₂ equivalents (including black carbon) emitted into the atmosphere by homes in Africa: an estimated annual reduction in household emissions of CO₂ equivalents of 555 kg (Harrison & Lam, 2015).

Carbon dioxide has a long residence in the atmosphere, which means that today's reductions take decades to provide a substantial benefit. In contrast, black carbon has a very short residence time of just a few weeks. Near term reductions in black carbon therefore provide an immediate climate change mitigation benefit.

Waste

An increasingly discussed outcome of the success of multiple solar programmes and growth in the sales of solar household systems, is the associated increase in electronic waste. In Africa, recycling and electronic waste (e-waste) facilities are not common and tend to be based in cities. Harsdorff et al. (2009) noted that the limited knowledge of SHS users in Uganda, about the hazard of not appropriately recycling SHS batteries, poses a potential risk for the environment in future. Brossman (2013) found similar low levels of awareness, with only 8% of SHS users being aware of the battery disposal mechanism (though their level of awareness prior to SHS ownership was not reported), which they state may lead to a detrimental environmental effect from widespread informal battery recycling. Some organisations, including TOTAL and SolarAid, have started to trial recycling solutions with local centres in Africa.

Communication and information

For the solar household systems that provide more energy capability than just lighting; notably mobile-phone charging, there are additional impacts seen.

Use of and access to mobile phones

95% of SHS users in Bangladesh reported that their access to information through mobile phone, TV or radio had been improved by their SHS. Users reported that they were able to use their phones at home whenever they needed to use them (Urmee & Harries, 2011).

SHS users reported that access to information through phone, TV or radio had been improved.

Harsdorff et al.'s (2009) study in Uganda found that 80% of phone owners charged their phones using solar systems, suggesting that access to SHS enables telecommunication in non-electrified areas. The study included microenterprises where it was found that 86% of microenterprises who had invested in a SHS used mobile phones for their work whereas only 62% of the non-users did. The average SHS household had 2 phones and spent twice as much on phone credit each week (\$ 2.80) as non-users who, on average, had 1 phone per household (and spent \$ 1.40 on credit). 51% of SHS users mainly use

26 Using the conversion factor of 2.5 kg CO₂ per litre of kerosene.

27 Given the short atmospheric lifetime of black carbon relative to CO₂, the black carbon contribution is greater if you assume a shorter 20 year time horizon, and smaller if you assume a longer time horizon.

their mobile phone to facilitate their work, while 60% of non-users used their phone for communicating with friends and family members. Of course, this evidence may say a lot more about the type of person who chooses to invest in a SHS; likely being of higher income, perhaps better educated, and possibly more engaged in business.

SolarAid (2012-15) data shows that pico-solar households in Kenya, Malawi, Tanzania, Uganda, and Zambia all owned a mobile phone, and prior to solar light purchase spent \$ 0.26 a week to charge it,²⁸ on average, travelling 31 minutes one-way; this journey is likely to have been taken for other activities too i.e. not solely for mobile phone charging. Note that many of the pico-solar lights purchased do not have mobile phone charging capacity so it is likely that this cost was not eliminated with a pico-solar light. SolarAid's (2012-15) public survey data (i.e. not from pico-solar light customers) also found that households spent \$ 0.66 a week charging mobile phones, on average, travelling 28 minutes one-way. SNV (2012) found that households in Cameroon were paying \$1.93 per month on phone charging.

Solar household systems can reduce money and time spent on mobile phone charging.

A GVEP (2011) report stated that mobile subscribers in Tanzania in off-grid areas rely predominantly on charging shops in town, meaning long journeys and significant expense in order to charge a phone. Travel costs associated with charging the phone could make up 50% of a person's expenditure on their phone. The report stated that people in Tanzania were travelling 7-15km, on average, to charge a phone. After phone-charging micro-businesses were set up closer to customers, making it easier and more convenient to recharge the battery, 100% of customers reported using their mobile phone more and there was a 10-14% uplift in airtime sales observed.²⁹

Use of and access to TV

Larger SHSs enable access to larger appliances than mobile phones, such as radios and TVs. Brossmann (2013) found that 61% of SHS users in Bangladesh had a TV compared to just 6% of non-users. SHS owners in Uganda had better access to TV with 15% of household heads in SHS homes watching TV – most commonly watching the news – compared to only 4% of non-users (Harsdorff et al., 2009).

'My business is booming because funds that were spent on buying [kerosene] are now used to buy computer accessories and I charge my phone using solar to communicate with customers.'

Use of and access to radio

SolarAid (2012-15) data shows that pico-solar households in Kenya, Malawi, Tanzania, Uganda, and Zambia spent \$0.94 each week, on average, to power their radio prior to a solar light purchase, predominantly through purchasing batteries (71%). Harsdorff et al. (2009) found that SHS owners in Uganda spent less on radio charging too.

Use of and access to information

SHS users in Bangladesh agreed that by watching TV or listening to the radio they had greater access to information and were more informed about weather (tornados, cyclones) and other natural disasters (Urmee & Harries, 2011).

75% of SHS users in Bangladesh and 50% of users of small solar systems stated that their knowledge on 'general news' as well as 'health-related issues' had improved since they bought the solar systems (Urmee & Harries, 2011).

While the evidence surrounding the impact of TV and radio when it is powered specifically by solar is sparse, there is evidence that these energy services do have significant welfare benefits. As noted by a World Bank (2008) study, lighting and TV account for at least 80% of rural electricity consumption and thus the bulk of the benefits delivered by electrification. In a review of 9 rural electrification programmes, including ones in Ghana and Senegal, the World Bank (2008) found that increased access to TV and radio increased knowledge about health and contraception, which, in turn, improved health outcomes and reduced fertility rates. Access to electricity was associated with reduction in fertility rates by 1.06 children per family in Ghana and 2.00 in Senegal. Child nutritional status also improved with electricity access, but the causal mechanisms are not fully understood in this case.

Linked effects: income generation and access to finance

Access to reliable and affordable charging for mobile phones can also facilitate access to financial services such as mobile money; allowing rural and/or unbanked populations to be served.

²⁸ Mobile charging fees were similar but different in each country: \$ 0.15 per charge in Zambia, \$ 0.12 in Malawi and Tanzania, and \$ 0.09 in Kenya and Uganda.

²⁹ Small sample size of 14 customers

Livelihoods

The development of the solar market creates jobs and income-generation opportunities throughout the supply chain.

Jobs created/income opportunities (companies, agents, entrepreneurs)

UNEP's 2014 Light and Livelihood study indicated that up to 15,000 new jobs have been created in sub-Saharan Africa as a result of the transition to efficient off-grid lighting. Renewable and efficient energy create many times more jobs than non-renewable energy systems do, particularly for non-oil producing countries. In Bangladesh alone, the Africa Progress Panel (2015) found that 10 years ago there were an estimated 25,000 small solar systems in the country. There are now 3.5 million and it is estimated that the boom has created around 114,000 jobs in solar panel assembly.

Up to 15,000 new jobs have been created in sub-Saharan Africa as a result of the transition to efficient off-grid lighting.

Harsdorff et al. (2009) found that in Uganda, an increase of 1% in local solar coverage increased direct employment in the green economy by 0.02% in the respective area. This increase was attributed to the fact that SHS users experienced longer hours of operation so employment in their businesses was slightly higher than amongst non-SHS users.

SolarAid (2014-15) research reported that since becoming SunnyMoney solar light agents, 91% of respondents had seen an increase in income. On average, selling solar lights accounted for 29% of income for most SunnyMoney solar entrepreneurs. What's more, 75% of agents said that other things than income had changed as a result; 32% said it had improved their family's well-being/quality of life.

Wider development impacts

Quality of life

Changes in quality of life and well-being are particularly hard to measure. However, there appears to be a significant positive outcome associated with access to energy broadly, and solar household systems particularly. SHS users in Bangladesh agreed that using the systems resulted in an improvement in their quality of life. 82% also agreed that their SHS had increased their social status, stating that neighbours and relatives from other villages visited their houses more often to enjoy the clean lighting. They claimed that their SHS had increased the amount of time that they engaged in social activities (Urmee & Harries, 2011).

"[The solar light] doesn't have smoke and I can have quality time with my family members. We don't sleep early nowadays." Anonymous in Kenya

Solar household systems can provide increased opportunities for social interaction.

Well-being changes

Energy access, and lighting particularly, can provide opportunities for social interaction. Many pico-solar light users talk of the opportunity to spend time together as a family, eat together and share experiences of the day. All SHS user respondents of Urmee & Harries' (2011) study in Bangladesh agreed that SHS increased their time spent in relaxation and their ability to get together at night and enjoy the high quality light. 85% of pico-solar light users across Africa said that having a solar light affected the activities they were able to do at night (SolarAid, 2012-15).

Access to energy can provide access to other services and opportunities. Because solar energy can be decentralised and affordable it provides more dispersed benefits that other energy sources may not.

Financial inclusion

As discussed, pay-as-you-go (PAYG) financing opens up access to solar lights and smaller SHSs for lower-income families. PAYG financing de-risks investment in new technology and reduces the upfront capital required to purchase a solar household system. The adoption rate from SunnyMoney's pilot trials of PAYG solar lights in Kenya was 20-50% while the normal level without PAYG in the same sales channel was 10-15%, over a similar time period. This suggests roughly a doubling to tripling in sales.

PAYG can de-risk investment in new technology and enable lower-income families to access products and services.

Furthermore, the impact of having PAYG-enabled solar lights spills over to other areas, such as financial inclusion. The Consultative Group to Assist the Poor's (CGAP) (2014) recent research on linkages between PAYG solar energy and financial inclusion suggested that 30-50% of PAYG solar customers outside of Kenya were new to mobile money and opened a mobile account in order to purchase a digitally-financed energy solution.

CGAP (2014) further explained that data from PAYG products can give investors and donors financing the assets

significant insights into performance and usage, and can be used by governments and regulators to better direct energy subsidies to target populations. PAYG solar companies could potentially sell rich data on energy needs and preferences to consumer electronics companies searching for a better way to serve the off-grid market.

Urmee & Harries (2011) reported on the use of micro-credit to finance the purchase of solar systems – a model that they say is recognised as the fundamental strength of the Bangladeshi SHS programme. Urmee & Harries (2011) argued that the model allowed the SHS programme to move away from a pure reliance on cash sales and to open up the market to a much greater number of households and small rural businesses that are unable to participate in a cash sales SHS programme.

Conclusions

Empirical evidence of the impact that the use of solar household systems is increasing as more research is undertaken. The market for these products is quite young, and innovations in products and business models are occurring all the time. Despite this rapidly changing environment, it seems clear that low-income households who acquire even the smallest solar light can benefit through financial savings and the availability of better quality light. Impacts on health and education are apparent, though more difficult to measure, and it may take longer for the impact in these areas to be fully felt.

The evidence that is currently available has some limitations. New research, including the initiatives listed in the Annex, will help overcome these and contribute to a greater understanding of how solar products contribute to development objectives and improvements in the lives of their users.

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Annex: Ongoing and planned research

There is limited but growing evidence and research into the impact of solar household systems, with some key studies currently taking place. Below is an overview of key research studies that are known about by the authors.

Research on solar and poverty alleviation

SolarAid have received funding from Google for a three-year, large-scale randomised control trial into the impact of pico-solar lights on poverty alleviation. The Center for Development Cooperation (NADEL) at ETH Zurich have been selected as the research partner with Isabel Günther, Assistant Professor of Development Economics, leading and Adina Rom delivering on the ground. Kenya has been selected as the site of the study. A pilot study began in October 2014, the main study began in April 2015. Results and publication will be available in June 2016.

Research on solar and indoor air pollution and health

SolarAid received grant from Google to fund a health-focused pilot study. Dr Michael Bates, Adjunct Professor of Epidemiology at University of California, Berkeley, and Dr Nicholas Lam, Research Associate, at the University of Illinois at Urbana-Champaign (formerly at Berkeley) are delivering the research. The study will sample from 20 households and will use pollution trackers on selected household participants to form part 1 (rates of exposure) and a proof of concept for a part 2 health study (linking exposure to health outcomes). In addition, the project will design a prototype and test a light spectrum recording device. Kenya has been selected as the site of the study. The pilot study will begin in January 2016, results will be published by June 2016. The second phase (main study) is not yet funded.

Research on solar and education

SolarAid have partnered with researchers at Stanford University, in collaboration with d.light, to conduct a randomised control trial pilot study into the impact of solar lighting on education. Ognen Stojavanski and Dr Mark Thurber, Research Fellows on the Programme on Energy and Sustainable Development (PESD), at Stanford University are delivering this research. Stanford University have given a grant to seed fund the study, with DFID committing funding for the pilot study. Additional funding is needed for the main study. This study will focus on Zambia and the pilot has started in September 2015.

Research on solar and well-being

SolarAid and the Climate Justice Centre at Glasgow Caledonian University (GCU) have partnered to deliver a

study on climate justice, funded by 2020 Climate group. Dr Tahseen Jafry, Senior Lecturer, will lead the research at GCU which will be delivered in Malawi, to look at the climate justice perspective of their work; a human rights based approach to energy access. Jake Wilson and Malawi Ngwira, based at GCU, will also work on this project, alongside local partners at the University of Mzuzu, including Dr Arnold Juma, Senior Lecturer. Results will be available in 2016.

Research on solar and recycling

SolarAid and the University of Edinburgh have received funding for a three year collaborative PhD project to look at the waste, recycling and repair of pico-solar lights in Kenya, funded by the Economic and Social Research Council. Dr Jamie Cross, Lecturer in Anthropology and Development Deputy Director of the Global Development Academy, at the University of Edinburgh and Kat Harrison at Acumen are supervising the project. The study will look at existing processes in parallel markets (mobile phones) and make recommendations for a sustainable solution. The Global Off-Grid Lighting Association (GOGLA) Lifecycle and Recycling group forms an advisory group to inform, shape and support the PhD student, Declan Murray, so that the work is relevant, appropriate and of use to the whole sector. Results will be available in 2017.

Research on energy ladder

United Nations Capital Development Fund (UNCDF) are funding a pilot study to find evidence of an energy ladder; people having more of their energy needs met through larger capacity systems/products. It will also touch on the links between energy and mobile communications and financial inclusion. With intent to fund a large-scale randomised control trial study, UNCDF has created a steering committee including Acumen, GSMA, Lighting Africa, GOGLA and the CGAP to inform ongoing research and ensure dissemination and usefulness. The study will focus on Uganda and will start in January 2016.

Research on kerosene subsidies

The United Nations Development Programme (UNDP) are funding a desk-based piece of research to understand the relationship between kerosene subsidies, solar product taxes/tariffs, and the impact on government finance. Still in discussion, this research will focus on East Africa (and a wider group of countries in Africa if possible).

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Cover photo: A Malawian teenager reads outside her house using a micro-solar light purchased from her school and supplied by SolarAid. Photo by Jerry Barnett

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