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How solar household systems contribute to resilience

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Key messages

- Solar lamps and solar home systems (SHS) are increasingly seen as a route to electrification in rural areas of sub-Saharan Africa and Asia. Much of the population they serve is vulnerable to climate variability and extremes.
- The resilience of the energy services provided by solar lamps and SHS is partly determined by their durability and portability, and partly by diversity in their supply chains.
- The principal energy services provided by solar lamps and SHS – lighting and communications – can contribute directly and indirectly to the anticipatory, absorptive and adaptive capacities that are essential for resilience.
- Policy-makers should consider the potential of households' existing solar lamps and SHS when formulating strategies and plans for disaster preparedness, including early warning systems, communications during recovery, provision of health care and ensuring safety.
- Policy-makers responsible for electrification should be made aware of the potential for solar lights and SHS to contribute to the resilience capacity of vulnerable populations.

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Acronyms

HAP	Household air pollution
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	Kilowatt-hour
LED	Light-emitting diode
ODI	Overseas Development Institute
PAYG	Pay-as-you-go
SDGs	Sustainable Development Goals
SHS	Solar home systems
SP	Solar photovoltaic
Wh	Watt-hour
WHO	World Health Organization

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Executive summary

Solar lamps and solar home systems (SHS) are increasingly seen as a route to electrification in rural areas of sub-Saharan Africa and Asia. Much of the population that would be served by such systems is vulnerable to climate variability and extremes. However, there has been very little research on how access to electricity from solar lamps and SHS can contribute to the resilience of households facing climate and other risks. This paper explores the relationship between the energy services provided by solar household devices, and the resilience of their users to the effects of climate change.

The resilience of the energy services provided by solar lamps and SHS (e.g. lighting and phone charging) is partly determined by the resilience of the supply of electricity from these devices. This is dependent on the products that generate and use solar electricity, and on the supply chain for these products. Durability and portability are key characteristics of solar products. Diverse supply chains, varying according to the relationships between market actors and the financing mechanisms used, are a response to the risks for suppliers of developing and sustaining their markets.

The evidence available suggests that lighting and communications, the principal energy services provided by solar lamps and SHS, can contribute to the anticipatory, absorptive and adaptive capacities essential for resilience. Solar-powered communications enhance anticipatory capacity by, for example, improving access to warnings about extreme weather events; absorptive capacity by facilitating communications after disasters; and adaptive capacity by enabling access to new knowledge. Lighting from solar lamps and SHS contributes, directly and indirectly, to resilience capacities.

There are two conclusions for policy-makers from this exploration of the links between resilience and access to electricity:

- Policy-makers responsible for electrification should be made aware of the potential for solar lamps and SHS to contribute to the capacities necessary for resilience.
- The potential of households' existing solar lamps and SHS should be considered by policy-makers when formulating strategies and plans for disaster preparedness.

Key questions for further research, given the lack of empirical evidence about the links between resilience and the use of solar lamps and SHS, are: how are these devices already being used by affected households before, during and after disasters? How do different levels of access to electricity affect the resilience capacities of different social groups? And, how does the resilience of energy services from solar systems and from grid electricity affect households' adaptive capacity?

1. Introduction

Across the world, one person in five still lives without access to electricity in their home. The great majority of the 1.1 billion people without access to electricity live in sub-Saharan Africa and South Asia. Over 80% live in rural areas and rely on kerosene, candles and battery torches for lighting (IEA and World Bank, 2017).

People living in poverty are more likely to lack access to electricity than those with higher incomes. They are also more vulnerable to extreme weather events and slow onset events, and may be more exposed to climate hazards, living in places where there is a high risk of floods, landslides or drought. To the Intergovernmental Panel on Climate Change (IPCC), a disaster 'signifies extreme impacts suffered when hazardous physical events interact with vulnerable social conditions to severely alter the normal functioning of a community or a society' (Lavell et al., 2012: 27). Disasters can impoverish people and undermine their resilience to extreme weather events and other shocks (Wilkinson and Peters, 2015).

For this reason, the 2030 Agenda for Sustainable Development includes a target to 'build the resilience of the poor and those in vulnerable situations, and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters', by 2030 (United Nations, 2015: Target 1.5). The Sustainable Development Goals (SDGs) also include the target of universal access to affordable, reliable and modern energy services, by 2030. Although access to energy is a key enabler for achievement of all the SDGs (ICSU, 2017), the world is currently not on track to achieve universal access to electricity by 2030 (IEA and World Bank, 2017). The conventional approach to electrification – extension of the grid – is not delivering access to electricity fast enough to meet the global target. On current projections, 674 million people will still be without access to electricity in 2030 (IEA, 2017).

Off-grid solutions, particularly solar lamps and SHS, are increasingly seen as a route to electrification in Africa and Asia. Worldwide, an estimated 89 million people now have at least one solar lighting product in their household, which is equivalent to 7% of the total off-grid population (Orlandi et al., 2016). By 2016, over 44 million solar lamps and SHS had been sold globally (ibid.), and in 2016 nearly 8.1 million off-grid solar household systems were sold (GOGLA et al., 2016). Plummeting costs of solar photovoltaic (PV) technology, combined with innovative financing mechanisms, such as pay-as-you-go (PAYG) schemes, make them an attractive option. However, detractors point to their limited power capacity when compared to grid electricity.

The expansion of decentralised renewable energy to households vulnerable to climate and other risks draws attention to the contribution of energy to the resilience of communities and households. However, in the energy sector, discussion of resilience is usually in relation to the energy system, or part of the energy system, such as electricity generation or fuel supply. The contribution of distributed, grid-connected, solar PV generation to resilient energy systems is addressed in the literature, but little attention has been given to the resilience of off-grid household electricity solutions, such as solar lamps, in developing countries. There is a dearth of studies of how solar household solutions contribute to the resilience of their users.

To begin to address this knowledge gap, this paper explores the relationship between the use of small solar power systems by low-income households and the resilience of these households to the impacts of climate change. It provides an analytical framework to enable understanding of how solar lamps and SHS can contribute to the resilience of households and communities that are vulnerable to the effects of climate change. By relating evidence about the impacts of solar lamps and SHS to capacities that are essential for resilience, the paper provides insights into how basic access to electricity helps resilience.

Section 2 provides an analytical framework. This draws from both literature about the development impact of household access to electricity and resilience literature. Section 3 outlines key factors affecting the resilience of energy services provided by solar lamps and SHS, to note that this kind of resilience has a bearing on the effects of their use. Section 4 addresses the relationship between the energy services provided by solar lamps and SHS and the resilience capacities of households. Some general conclusions and pointers for further research are provided in Section 5.

2. Understanding resilience and access to electricity

The starting point for this paper is an analytical framework to understand the role that access to solar lamps and SHS can have in improving people's resilience to climate shocks and stresses. This framework needs to include a way to categorise and measure household access to electricity, and the effects of the use of electricity on people's activities. It also needs to include a way to measure or assess the resilience of households. The framework, therefore, draws concepts from two distinct bodies of research and analysis, bringing these together to outline the relationship between access to electricity and household resilience. The section begins with access to electricity.

2.1. Electricity access

The effects of electricity are felt through what it enables people to do, through services such as lighting, heating, cooling, phone charging and production. The quantity of electricity consumed determines which of these services, and how much of a particular service, is available to a household.

The Multi-Tier Framework was developed by the World Bank to provide a means to measure access across a range of levels of service, referred to as tiers (Bhatia and Angelou, 2015). The energy services available at each tier are shown in Figure 1, ranging from task lighting and phone charging at Tier 1 to the full range of possible energy services, including the use of appliances with high power ratings, at Tier 5. Figure 1 also shows the tier of access that different solar products can provide. Although the Multi-Tier Framework includes the attributes of reliability and durability to categorise different levels of access to electricity (ibid.), these are not applied to the levels of access provided by solar lights and small SHS (Tiers 1 and 2).

As seen in Figure 1, the energy services made possible at Tier 1 and Tier 2 access, through solar lamps and SHS, are limited to lighting, phone charging and powering low-power appliances, such as televisions, radios and fans.

SHS generally comprise a solar PV module or panel, one or more light-emitting diode (LED) bulbs, a battery, a charge controller and, other than in the smallest systems, an outlet for phone charging or appliances. In solar lamps, these are integral to the product, while in SHS they are generally separate components. Small solar lights (often called pico-lights) have a capacity of 1–10 watts (GOGLA et al., 2016), but those with less than 3 watts do not provide access to electricity at Tier 1, as defined by the Multi-Tier Framework. SHS tend to have 10–1,000 watts capacity, and can be connected to low-wattage appliances, such as televisions and fans (IRENA, 2015).

Figure 1: Services and consumption levels at different tiers of access to electricity

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Energy services		Task lighting & phone charging	General lighting & television & fan	Tier 2 & any medium-powered appliances	Tier 3 & any high-powered appliances	Tier 4 & any very high-powered appliances
Consumption (daily)		Up to 12 Wh	Up to 200 Wh	Up to 1 kWh	Up to 3.4 kWh	Up to 8.2 kWh
Solar product	light only	light and charger	Solar home systems			

Note: Whs = watt-hours. kWhs = kilowatt-hours.
Source: adapted from Bhatia and Angelou (2015).

The development impacts of electricity can be defined as the social, economic and environmental opportunities that arise from access to electricity and, in this case, solar lamps and SHS. Broadly, five main categories of impact from the use of electricity can be identified from the literature (World Bank, 2008; Pueyo et al., 2013; Bonan et al., 2014; Pueyo and Hanna, 2015; Lemaire, 2016). These are:

- savings on expenditure for energy services substituted by electricity (e.g. kerosene, candles, batteries and phone-charging fees)
- changes in time use made possible by electric lights or appliances (e.g. time spent on studying, working and leisure)
- social welfare impacts (e.g. educational and health benefits, entertainment, and better access to information and knowledge)
- changes in productivity and incomes (e.g. from home-based businesses)
- reduction in greenhouse gas and black carbon emissions (e.g. through the substitution of electricity for kerosene lighting), when generation is from renewable energy sources.

In Figure 2, the energy services enabled by electricity from solar lamps and SHS are shown in the second row. Below this, the effects these have on household activities are shown in the middle column. These changes in activities and behaviour can lead to development impacts, shown on the right, and changes in key resilience capacities, on the left.

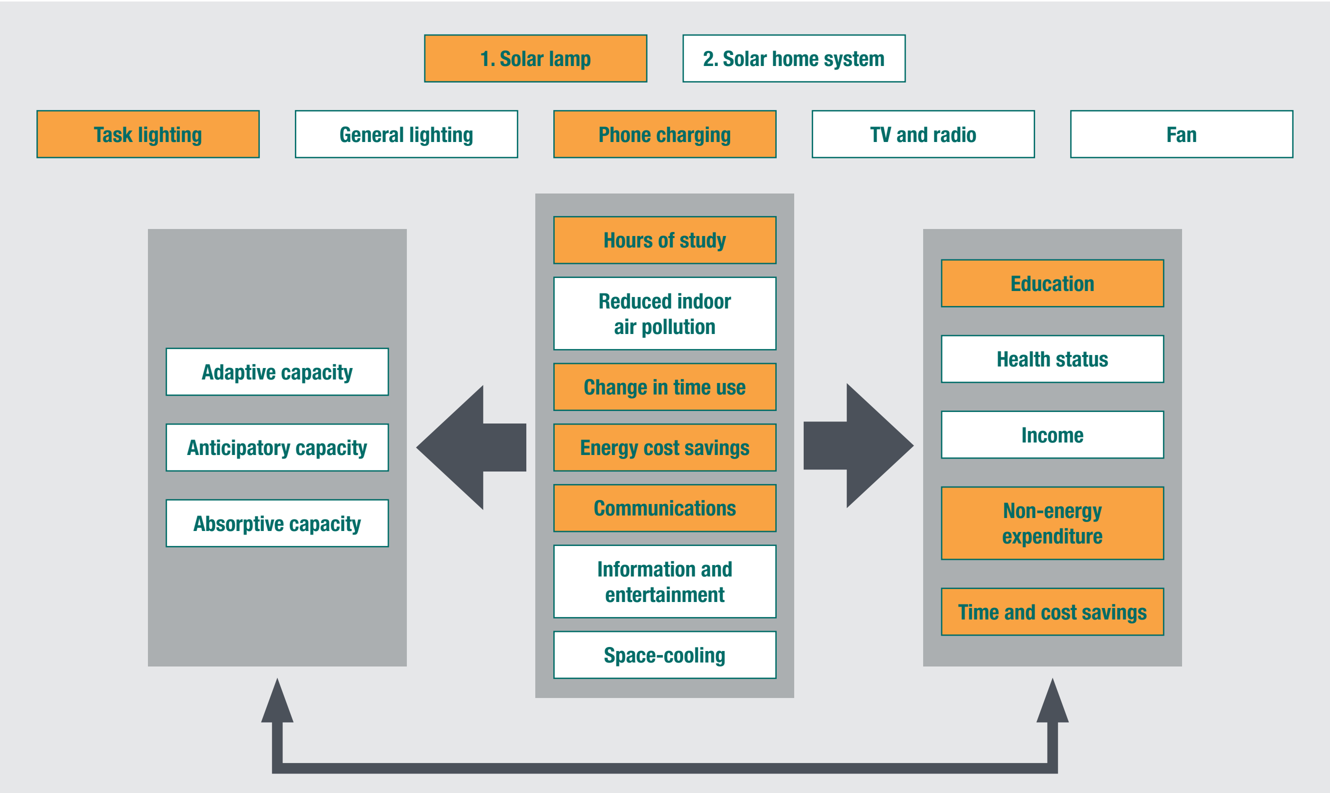
2.2. Resilience

Resilience has been defined and interpreted in numerous ways, for different purposes and audiences (Tanner et al., 2017). In the energy sector, discussion of resilience is usually in relation to security of the supply of electricity or fuel. In the context of international development, most definitions of resilience focus on the preparation and management of processes of change to deal with changing circumstances (Resilience Measurement, Evidence and Learning Community of Practice, 2016). For the focus of this paper, the definition of resilience as 'the capacity to ensure that adverse shocks and stressors do not have long lasting adverse development consequences' (Constas et al., 2014: 6) is relevant. At the household level, resilience can be interpreted as the household's capacity to respond, recover and adapt to shocks and stressors (Jones and Samman, 2016).

To understand the relationship between the use of electricity and resilience, the framework considers three types of capacity which are required for resilience (Bahadur et al., 2015):

- Adaptive capacity: 'the ability of social systems [including households] to adapt to multiple, long-term and future climate change risks, and also to learn and adjust after a disaster' (Bahadur et al., 2015: 13). This includes the ability to recover in such a way as to reduce vulnerability to future events, and to 'build back better'. Adaptive capacity is strengthened and made manifest when emergencies are not current.

Figure 2: A conceptual framework



Note: The full range of services and effects can be provided by SHS. Those provided by solar lamps are in shaded cells. Source: Authors' analysis.

- Anticipatory capacity: 'the ability of social systems [including households] to anticipate and reduce the impact of climate variability and extremes through preparedness and planning' (ibid.: 23). This capacity is demonstrated when households and communities forecast shocks and act to reduce their impact before the event. Action tends to be focused on specific, known shocks and stresses.
- Absorptive capacity: 'the ability of social systems [including households] to absorb and cope with the impacts of climate variability and extremes' (ibid.: 30). Absorptive capacity is shown after a shock, in the reduction of the impact on livelihoods and the ability to maintain wellbeing.

These capacities are reflected in multiple potential processes and activities. Absorptive capacity, for example, can include social cohesion, disaster preparedness, safety nets and hazard insurance (USAID, 2013). Adaptive capacity includes social networks, livelihood diversity, asset diversity, innovation and access to financial services. Anticipatory capacity includes disaster preparedness, responses to weather forecasts and warnings of hazards. Each of these activities may entail the use of energy services which can be provided by solar lamps and SHS, as shown in Figure 2. In Section 4, the principal energy services lighting and communications are discussed in relation to the three resilience capacities.

The ability of energy services to enable the deployment of resilience capacities will be influenced by the risk profile facing households and communities, and determined by the level of access to electricity (Tier 1 to Tier 5). The resilience of energy services in the face of shocks and stresses will also be a factor. This is discussed in the next section.

3. Resilience of solar lamps and solar home systems

The resilience of the energy services provided by solar lamps and SHS (e.g. lighting, heating, cooling and phone charging) is partly determined by the resilience of the supply of electricity from these devices. This can be defined as the ability of the supply to respond to shocks and stresses, and maintain or restore the energy services that people rely on. In turn, this is dependent on the vulnerabilities and risks associated with solar products which generate and use electricity, and the market or supply chain for these products. This section outlines the factors that affect the resilience of the electricity supply from solar lamps and SHS in order to highlight that this kind of resilience has a bearing on the impacts of their use.

3.1. Products

There is a wide variety of solar lights and SHS. They vary in power capacity (measured in watts), quality, price and availability. Globally, there are over 100 manufacturers and suppliers of solar lamps and SHS (Orlandi et al., 2016; GOGLA et al., 2016), but manufacturing is concentrated in a few countries, and markets are more developed in some countries and regions, such as India and East Africa, than others (Orlandi et al., 2016). Most other countries are therefore importers of solar lights, SHS and their components.

The resilience of the electricity supply from solar lamps and SHS can be considered in relation to two key characteristics of these solar products, namely, their durability and portability.

3.1.1. Durability

The widely-adopted Lighting Global durability standard considers three factors: water resistance, risk of breakage if dropped and the robustness of switches and connectors (Lighting Global, 2014). The durability of solar lamps and SHS is influenced by user behaviour (e.g. exposure to rainfall and care in using the device), as well as the technical quality of the product. Awareness and knowledge of the products, and the availability of repair and maintenance services, can also have a bearing on the resilience of their electricity supply. The provision of warranties is also one of the factors considered for quality certification by Lighting Global.

About half the solar lights sold in 2015 were not quality certified (Orlandi et al., 2016). These products are mostly low-cost, low-quality and unbranded lights, often imitations of their quality-certified competitors and lacking service warranties. However, it has been noted that these 'Generic products can break within weeks or function as reliably as quality verified products' (ibid.: 18). Although the high proportion of low-quality solar lights sold is perceived as a risk to the market by many suppliers, and a deterrent to households purchasing solar lights (Acumen, 2017), there is very little information available about the uncertified market. It is also possible that low-cost, low-quality solar lights may be chosen, on grounds of affordability, by households that are prepared to replace their lights more frequently.

3.1.2. Portability

Solar lights are usually designed to be portable single units. SHS, which have several parts, are less easily moved, but can be dismantled and transported when necessary. In the case of localised shocks (e.g. extreme weather events), smaller solar systems may be more transportable. This could enable households to take their solar system with them when displaced, and to have access to electricity in a new location. A downside of portability is a risk of theft.

There is little empirical evidence available about the transport of solar lamps and SHS by households displaced temporarily or permanently by natural disasters. This may be due to their widespread adoption being relatively recent. However, reports from Bangladesh in 2017 note that solar panels and mobile phones were among the few goods that refugees from Myanmar brought with them (*The Independent*, 8 September 2017). Though not directly climate-related, this demonstrates both the portability of SHS and their value to displaced households.

The portability of solar systems also allows them to be brought in to disaster-hit areas, for example, to provide essential lighting, communications and water pumping. In the United States, mobile solar PV systems were first deployed after Hurricane Hugo in 1989 (Young, 2006). In the state of Odisha in India, a 1 kilowatt (kW) solar 'cart' has been developed for use at cyclone shelters, a lower capacity version of the systems now routinely used in the United States after extreme weather events. Box 1 provides an example of how solar systems can be brought in and used quickly to restore electricity supplies after a disaster while damaged infrastructure is repaired.

Box 1: Community energy resilience in Nepal

Nepal was struck by major earthquakes in April and May 2015. As many as 9,000 people lost their lives, and 22,000 people were injured. Half a million homes were damaged or destroyed. The economic cost of the damage is estimated at over US$7 billion, including US$197 million worth of damage to energy infrastructure. Almost a quarter of Nepal's electricity infrastructure (both on-grid and off-grid) was damaged. Approximately 500,000 of the 600,000 households that lost access to electricity were served by off-grid systems.

Research in four earthquake-affected districts in 2016 found that the electricity supply was interrupted for all households connected to the grid or micro-hydro mini-grid systems. While repairs were being made to these systems, households relied on batteries, candles and solar lanterns and SHS for lighting. Most of the SHS were distributed as part of the relief effort to households that were awaiting repair of their micro-hydro system. The repair of micro-hydro systems required expert input and civil works, while SHS were found to be useful in meeting the immediate needs of households as 'ready-to-use' products.

Households were found to rely more heavily on informal and local structures – such as neighbours, relatives, temples and local non-governmental organisations – for access to energy services than for other sectors. For example, community members worked together to erect poles and repair grid power lines to re-establish the electricity supply. No other organisations helped villagers to re-establish the electricity supply system.

Source: To et al., 2016.

3.2. Markets and supply chains

There are five main links in the supply chain for solar lamps and SHS: manufacturers, importers, distributors, retailers and consumers. Manufacturers are usually foreign (predominantly Chinese) and outside the structure of the local market. For the latter, five kinds of distribution model can be identified, depending on the nature of the links between different market actors (Scott and Miller, 2016):

- *Institutional partnerships*, where a solar lamp or SHS company partners with an institution to market its products to that institution's customers or members.
- *Distributor-dealerships*, where the solar company sells its products through existing networks of distributors of, for example, consumer durables.
- *Proprietary distribution*, where the solar company is responsible for the entire supply chain, from manufacturer to consumer, using its own facilities and personnel.
- *Franchising*, where the solar company provides franchise agreements and associated support to micro-enterprises.
- *Rental or leasing schemes*, where the solar company rents solar products for a fee.

The variety of distribution models is greater than this when the financial relationship between market actors is considered (ibid.). This diversity is partly a reflection of solar companies' response to the risks they face in different markets. The development of PAYG models, for example, is a response to the challenge of developing markets for low-income consumers who do not have ready access to credit.

The rapidly growing solar industry is concentrated in a few markets, particularly in Africa and South Asia (GOGLA et al., 2016). In South Asia, India accounts for 91% of pico-light sales. East African countries (Ethiopia, Kenya, Tanzania) dominate the sub-Saharan African market with 66% of pico-products, in part because markets in these countries were developed first (Orlandi et al., 2016). This concentration has been attributed to a focus by companies on increasing market penetration where they operate, and the ease of expanding to neighbouring locations from an existing base (Scott and Miller, 2016). The size of the market, and the number of suppliers, will influence its characteristics (e.g. price competition, customer service, product quality, etc.) and its ability to respond to shocks and longer-term change. The longer-term resilience of markets may be affected by the availability – from suppliers or other businesses – of maintenance services for solar products.

Recent examples of shocks to solar lamp and SHS markets include the severe drought in eastern Africa in late 2016, which had devastating consequences for rural populations, reducing disposable incomes for the purchase of solar products (GOGLA et al., 2016). Reduced incomes may also affect the ability of existing solar lamp users to maintain payments for PAYG schemes. Recent economic shocks have also had an impact on off-grid solar markets, including the introduction of import tariffs by the East African Community and India's demonetisation on 8 November 2016 (ibid.).

4. Resilience of individuals and households

This section outlines how the principal energy services provided by access to electricity at Tiers 1 and 2, using solar lamps and SHS, relate to the anticipatory, adaptive and absorptive capacities necessary for resilience. The section focuses on the energy services of lighting and communications, which can contribute to actions that reflect all three resilience capacities. Illustrative examples from Kenya are provided in boxes.

4.1. Lighting

Lighting from solar lamps and SHS can have several effects on the activities and behaviour of households, as shown in Figure 2. Solar lighting provides much better quality of light than kerosene lamps and candles, and extends the number of hours in a day for domestic or productive activities. Research has shown that the number of hours school students spend studying at home is likely to increase (Pueyo et al., 2013; Lemaire, 2016); socialising and leisure time may increase (Eckley et al., 2014); and, in some households, time spent in income-earning activities can increase (Attigah and Mayer-Tasch, 2013).

4.1.1. Education

The effect of access to solar lighting on the amount of time that school students spend studying at home varies. In Ethiopia, the additional time was found to be as much as one hour a day (Barnes et al., 2016), while in Bangladesh it is less than half this (Samad et al., 2013; Brossman, 2013). The effect is not necessarily uniform across households with a solar lamp or SHS, and there may be gender differences. In Kenya, for example, one recent study found that, with the arrival of solar lamps in households, boys studied half an hour longer than before, while for girls there was no difference (Rom et al., 2017). In Bangladesh, however, girls and boys increased their home study time (Samad et al., 2013; Brossman, 2013). An increase in home study time was found in about half the households in Ethiopia that had acquired an SHS (Barnes et al., 2016), while one study in Bangladesh found that this effect was limited to wealthier households (Khandker et al., 2009).

The impact of additional home study time on educational performance appears to be subject to local social and geographical context. For example, in Bangladesh, one study found no effect on exam results in households that acquired an SHS (Kudo et al., 2015), while in Kenya a correlation with grade improvements was found (Hassan and Lucchino, 2014). Box 2 provides examples of the effect access to solar lamps can have on education.

Box 2: Solar lights for education in Kenya

Research evidence from Kenya indicates that access to solar lamps and SHS can lead to an increase in the time spent by school students studying at home. In households without access to electricity, boys and girls study at home for about two and a half hours a day. When a solar light is acquired, it was found that boys study for about half an hour longer each day, but no change was found for girls (Hassan and Lucchino, 2014; Rom et al., 2017).

This effect is illustrated by the experience of Siburi Mixed Secondary School at Homabay, in western Kenya. Before 2012, the school did not perform well academically, ranking 48 out of 67 among schools in the sub-county. The girls consistently had lower grades than the boys. Household chores after school meant that girls often had less daylight study time than boys. Students depended on kerosene for study at home in the evening or early morning. This changed in 2012, when a social enterprise, GIVEWATTS, started selling solar lamps to the school and parents. With solar lamps, students could study during hours of darkness, including girls after completing their chores. By 2015, the girls were consistently performing better than boys, and the school is now ranked second in the sub-county. The proportion of students going on to higher education increased from 5% to 40%.

Solar lamps have also been found to lead to increased studying by students from semi-nomadic communities in Kenya. For example, when a Maasai household in the Kekorok area, close to the Tanzania border, purchased a solar lamp in 2014, the four school-age children in the family increased their study time by 15% and improved their grades at school. Previously, the students used firelight from burning twigs to study after dark, because the household did not have ready access to kerosene. With firelight, reading could only be done in intervals of a few minutes and the smoke damaged their eyes and lungs.

Sources: SEforALL, 2017 and Jesper Hörnberg.

The effect of improved educational performance, due to access to solar lighting, on the resilience of households has not been the subject of published research. Literacy, numeracy, abstract thinking, problem-solving skills, financial literacy and organisational skills acquired through education contribute to resilience capacities (Muttarak and Lutz, 2014; Chigwanda, 2016). For example, education can increase people's ability to understand and respond to weather information or warnings (anticipatory capacity), respond and react to the challenges of disasters (absorptive capacity) and enhance the acquisition and application of new knowledge (adaptive capacity). Research has found that people with education cope better during emergencies, and are more likely to adapt their livelihoods to new locations or opportunities (Bird et al., 2011). Education also strengthens their ability to mitigate risks (Wamsler et al., 2012).

The effect of education on absorptive and adaptive capacity is also indirectly felt over the longer term, because people with education are more likely to have higher incomes and more assets (Frankenberg et al., 2013; Muttarak and Lutz, 2014).

4.1.2. Income and productive activities

The effect of solar lighting on incomes is felt through savings on expenditure and additional time in income-earning activities. Research in several countries has found that expenditure on lighting falls when households gain access to solar electricity at Tiers 1 and 2. For example, in Rwanda, the adoption of pico-lanterns reduced household lighting expenditure fivefold, compared with control households (Grimm et al., 2016). In India, household solar products reduced lighting expenditure by half in Meghalaya, Assam and Jharkhand (Lemaire, 2016).

Electric lighting enables the business hours of small- and micro-enterprises to be extended. Research in Uganda found that the hours of operation of enterprises with SHS increased by one hour a day, attracting more customers and generating higher profits (Attigah and Mayer-Tasch, 2013). Box 3 illustrates the effect with an example from Kenya. SHS can also enable enterprises to use low-wattage televisions and run refrigerators to sell cold drinks, both of which attract customers.

The effect of solar lamps and SHS on productive activities in the home is variable, however. In India, electricity used for lighting and communication was found to have no positive effect on incomes (Attigah and Mayer-Tasch, 2013). In Bangladesh, Brossman (2013) found little difference in the level of economic activity in the home between households with an SHS and those without. While in East Africa, access to a solar lamp does not result in significant change in the time household members spend on income-generating work (d.light, 2015; Rom et al., 2017).

Financial savings on lighting expenditure, and higher earnings from micro- and home-based enterprises, increase disposable incomes and allow higher expenditure on other goods and services (Khandker et al., 2014). Savings can also be redirected to farming inputs, or to support business development, such as establishing market stalls (Eckley et al., 2014). The effect on resilience capacities may be felt through opportunities to save and diversify income. Financial savings made possible by reduced energy expenditure or higher incomes, following adoption of a solar lamp or home system, can contribute to absorptive capacities and households' ability to respond to disasters. Adaptive capacities can also be strengthened through higher incomes and expenditure, and livelihood diversification, made possible by access to solar electricity.

4.1.3. Health

Lighting from solar lights and SHS can help improve people's health by:

- Reducing household air pollution (HAP), due to reduced consumption of kerosene for lighting. A recent study in Kenya found a 61% reduction in airborne particulate matter in the main living space of households that adopted a solar light (Lam et al., 2017). In El Salvador, Barron (2014) found a 63% reduction, leading to reduced incidence of acute respiratory infections.
- Reducing the incidence of accidental burns and poisoning following the substitution of electric lighting for kerosene lamps. In Nigeria, for example, 30% of admissions to hospital for burns are attributed to kerosene lamp explosions, while in Bangladesh 23% of burns among infants were due to kerosene lamps (Orlandi et al., 2016). Accidental poisoning, from ingestion of kerosene, affects around 80,000 children in South Africa alone (ibid.).

Box 3: Solar lamps boost working hours in Kenya

Mama Regina, a fruit and vegetable seller in the town market of Kwale on the Kenyan coast, is the sole income earner for her family. Before she bought an SHS in 2015, she sometimes kept her stand open for a few hours after dark using a kerosene lamp, but closed it if money was short. There was also a conflict between the use of kerosene for the fruit and vegetable stall, on the one hand, and her children's study time on the other.

When Mama Regina purchased an SHS, she immediately experienced a surge in her daily sales because she could stay open later into the night. The evening is a peak time for shoppers on their way home from work, and she reports her income as having gone up by 40%. The extra income allowed Mama Regina to increase the variety of her produce and begin selling higher value fruits and vegetables, increasing her income per product as well as total income. This meant she had a larger inventory, was better able to serve customers throughout the week and withstand slowdowns in demand.

Source: Jesper Hörnberg.

- Improved health care at health facilities using solar systems. Evidence from Nigeria suggests that a combination of solar lights and phone charging helps midwives to care better for their patients – through the ability to provide medical aid remotely and during the evenings (SolarAid and SunnyMoney, 2015). Research in India found that solar rooftop systems could meet the needs of lighting, refrigeration and water pumping in health facilities (Ramji et al., 2017).

According to the World Health Organization (WHO, 2015: 9) a 'healthier population [and stronger health system] will be more resilient to climate change'. When the health status of people at risk of climate variability and extremes is improved, absorptive and adaptive capacities may be stronger.

4.1.4. Safety and security

Solar lights and SHS provide an increased sense of security to households that adopt them (Orlandi et al., 2016). In East Africa, over 60% of customers surveyed by solar companies had an improved sense of security (Acumen, 2017). In Uganda, solar kits have been used by some households to provide security lighting at night (Orlandi et al., 2016), while in Kenya they have been used to deter wildlife damage to crops and livestock. In this way, solar lamps contribute to anticipatory capacity, and mitigate the risk of losses.

Solar lamps were a critical factor in reducing gender-based violence after the 2010 earthquake in Haiti (Lavelle, 2015), and are now commonly provided by humanitarian agencies for this reason. Oxfam, for example, provided solar lamps to displaced women in South Sudan to provide increased safety and security during the night (Little Sun, 2016). Solar lamps can thus enhance absorptive capacity during periods of recovery.

4.1.5. Migration

For people living in vulnerable communities, or where livelihood options are limited, a response to sudden or slow onset change may be migration. There are many factors influencing migration, including poverty, food insecurity, economic opportunity and access to public services. Access to electricity (or the lack of it) can be a contributing factor (Wollensack, 2017). This is explored further in Box 4.

Box 4: Migration and solar energy access

Temporary or permanent migration can be a response to climate risk. In 2016, sudden onset climate-related hazards displaced over 24 million people (Stapleton et al., 2017). Households experiencing disasters may decide to move, determined by their absorptive capacities. Adaptive capacities can enable migration to places where risks are lower and opportunities for secure livelihoods greater. In both cases, lack of access to modern energy services can be an indirect driver of decisions to migrate (ibid.). In Latin America, where energy access in households increased from 71% to 92.6% between 2000 and 2010, the rate of rural-urban migration decreased and migration flows reversed. Households in peri-urban settlements in Kenya were found to be less likely to move out if they had access to electricity (Wollensack, 2017).

During natural disasters, access to electricity contributes relief services and infrastructure, providing lighting, cooling of medicines and communications, enhancing absorptive capacities and potentially mitigating displacement. Access to electricity can also mitigate drivers for migration, contributing to adaptive capacities by enabling increases in productivity and incomes (e.g. through water pumping or extended business operating hours), improving education (e.g. through longer hours of study) and health (e.g. reduced HAP and improved health facilities).

People displaced by disasters often live in their new location for a long period. The great majority of refugees are hosted by developing countries and live outside camps. Only 10% have reliable access to electricity (ibid.). An estimated 80% of the 8.7 million refugees living in camps have Tier 0 access to electricity, as defined by the Multi-Tier Framework (Chatham House, 2015).

Analysis by Chatham House (2015) indicates that Tier 1 solar access by displaced people can have long-term benefits, as well as being a cost-effective means to provide electricity. However, barriers remain to the take-up of clean energy solutions for refugees, including the short-term nature of humanitarian funding and the lack of technical expertise to select appropriate energy solutions.

The experience of Jordan, which has received hundreds of thousands of refugees since independence in the 1940s, shows how these barriers can be overcome. The Jordanian government has recognised the role of clean energy solutions in addressing a national energy access crisis, which has been exacerbated by refugees (Chatham House, 2016). Under the National Resilience Plan 2014–2016, the government is promoting solar PV for households and institutions, as well as providing associated technicians and training (ibid.). Subsidies for low-income consumers have assisted uptake. Jordan is also using solar PV to provide electricity to refugee camps.

Source: Jesper Hörnberg.

4.2. Communications

Mobile phone use is widespread in most developing countries, and many households without access to electricity have mobile phones. They recharge their phone batteries at shops, or at the homes of relatives or neighbours who have an electricity connection. In Uganda, 80% of phone owners charged their phones using solar systems, suggesting that access to SHS enables telecommunication in non-electrified areas (Harsdorff and Bamanyaki, 2009).

Household access to solar lamps and SHS that have a phone charging outlet reduces the cost of recharging phone batteries. This encourages more frequent battery charging and more frequent use of mobile phones (Brossman, 2013). In Bangladesh, 95% of SHS users reported improved access to information through mobile phone, TV or radio about general news, health-related issues, weather and natural disasters (Urmee and Harries, 2011).

Access to information and communications is a significant factor in household resilience (Resilience Measurement, Evidence and Learning Community of Practice, 2016). The availability of timely, pertinent information can help to equip people with the necessary knowledge to enable adaptive, anticipatory and absorptive actions. Access to communications through mobile phones or radio and television can, for example, be important for early warning of extreme weather events. Resilient households are more likely to obtain advance information, and its availability improves resilience (Jones and Samman, 2016). As well as enabling access to weather information (an element of anticipatory capacity), mobile phone communications can provide access to medical information and expert advice during and immediately after disasters (absorptive capacity). In some countries, mobile phones also allow access to bank accounts and financial resources (Lemaire, 2016), including savings and insurance (European Report on Development, 2015). This can be critical for recovery immediately after shocks.

The combination of solar lights with phone charging, which solar lamps and SHS can provide, has been found to contribute to better health outcomes. Evidence from Nigeria suggests that a combination of solar lights and phone charging helps midwives to care better for their patients – through the ability to provide medical aid remotely and during the evenings (SolarAid and SunnyMoney, 2015). While SHS in Bangladesh were found not to improve health outcomes directly, the consequent TV ownership and knowledge of disease led to improved health outcomes (Asaduzzaman, 2010; Khandker et al., 2014). Research in India found that solar rooftop systems could meet the needs of lighting, refrigeration and water pumping in health facilities (Ramji et al., 2017).

5. Conclusions

The analytical framework presented in this paper provides a means to explore the links between resilience capacities and access to electricity from solar lamps and SHS. The absence of research on the effects of access to electricity, both grid and off-grid, on the resilience of electricity consumers prevents drawing firm evidence-based conclusions about the contribution of solar lamps and SHS to the resilience of households to climate and other hazards. However, the available evidence suggests that the principal energy services provided by solar lamps and SHS, namely lighting and communications, can contribute to the anticipatory, adaptive and absorptive capacities that are essential for resilience.

Reliable and low-cost communications enabled by the phone-charging capability of most solar household options enhance access to warnings about impending extreme weather events, i.e. anticipatory capacities. The solar recharging of mobile phones and powering of radios and televisions facilitate communications during and immediately after such events, before damaged infrastructure can be repaired (absorptive and adaptive capacities). Adaptive capacities also require communications to access new information and knowledge via televisions and phones, and to build social networks, for example through greater socialising during hours of darkness.

Lighting, from solar lamps and SHS, appears to contribute to resilience capacities through longer-term and indirect effects. Electric lighting can enhance absorptive capacities, for example, by improving safety and security after disasters. The indirect effects of improved education and health may be felt more through adaptive capacities, through their effects over time on incomes.

This brief review of the links between rapidly spreading solar lamps and SHS and resilience capacities suggests that policy-makers should take their potential into account when formulating strategies and plans for disaster preparedness. Households' existing solar lamps and SHS could be integrated into plans for early warning systems, the dissemination of climate change information and disaster recovery. Humanitarian agencies are already deploying solar lamps during emergencies, but there does not appear to be any assessment of the role for devices already – and increasingly likely to be – in the possession of affected households.

Policy-makers responsible for electrification should be made aware of the potential for solar lamps and SHS to contribute to the capacities necessary for resilience. This could influence strategies for electrification to vulnerable populations where the risk of disasters is high, strengthening arguments for the promotion of solar lamps and SHS to vulnerable households.

The absence of empirical evidence about the effects of access to electricity on people's resilience points to the need for research to address key knowledge gaps. One important area for further research is to analyse how solar lamps and SHS are already being used by affected households before, during and after disasters. This could inform local strategies and plans for disaster preparedness.

There are also knowledge gaps concerning differences between households at different tiers of access to electricity, and whether access to electricity is material to differences in their resilience capacities. Evidence relating to these questions could help target measures to improve access to electricity for different social groups. Finally, little is known about the resilience of energy services from grid electricity in developing countries, compared with off-grid, and how this affects adaptive capacities. This kind of analysis would also inform electrification strategies and the targeting of measures to improve access for vulnerable groups.

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