WIREs Wiley Interdisciplinary Reviews

Article Title: Solar Home Systems and Solar Lanterns in Rural Areas of the Global South: what Impact?

Article Type:

- [ ] OPINION
- [ ] PRIMER
- [ ] OVERVIEW
- [x] ADVANCED REVIEW
- [ ] FOCUS ARTICLE
- [ ] SOFTWARE FOCUS

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Abstract

Assessing the extent of evidence available relating to the impact of solar energy for households in developing countries, surveys are reviewed focusing on the impact of pico-photovoltaic (e.g. solar lanterns) or solar home systems (SHS) on rural households and directly-related economic activities of their occupiers.

98 documents have been analysed. Areas of enquiry have included the impact of small individual solar photovoltaic systems on different facets of the life of households' occupiers: their education, health, finance, livelihoods and social relations.

Research on the impact of small solar systems contradicts the commonly accepted idea that small solar systems - due to their limited capacity - cannot have an impact in terms of development. In actual fact, these systems seem to have a significant impact in terms of quality of life for their users and in helping them to keep connected to the global world by supplying power to mobile phones and television sets. Nevertheless, it is not yet possible to draw definitive conclusions on their quantitative impact in specific areas, except for: 1) evidence of increase of quality lighting 2) strong evidence of cost savings when kerosene lamps are replaced by solar lighting; 3) evidence on the impact of solar lighting on the time of studying of children and quality of education.

Finally, indications are given on the kind of research which could be conducted to fill current gaps in demonstrating evidence of the impact of small individual solar systems.

Acronyms used

ECOWAS	Economic Community of West African States
HH	Households
kWp	Kilowatt-peak
LAC	Latin America and Caribbean countries
LED	Light-Emitting Diode
NGOs	Non-Governmental Organisations
Pico-PV	Pico-photovoltaic
PV	Photovoltaic
PM	Particulates Matters
RCT	Randomized Controlled Trial
SHS	Solar Home Systems
SPL	Solar Portable Lanterns
UNDP	United Nations Development Programme
W	Watt
Wp	Watt-peak

Summary Table
Impact of Small Solar Systems and Level of Surveys Outcomes Consistency

Well-established link with same findings (in 4 or more large quantitative surveys)

Increase quality of lighting
Solar use replaces lower quality lighting sources/reduces number of hours of low quality light.
Fuel savings due to a significant reduced use of kerosene
Households with solar consume 75-85% less kerosene.
Small increase and change of patterns in studying time
Solar use increases studying time between 10-35 minutes per day or leads to reallocation of study time from daytime to night-time.

Possible link quantified with same findings (in 2 or more large quantitative surveys)

Reduce lighting expenditure
Households with solar can reduce lighting expenditure by two to three.
Quality of education
Solar use increases years of schooling and school attendance.

Non-demonstrated link (not large enough quantitative survey; contradictory/different outcomes between surveys)

Differentiated impact according to the system size
Larger systems provide bigger impacts, but small systems could have a higher impact per Wp.
Income generation
Some surveys conclude that solar contributes to higher income generation (up to 12-18%) – while others surveys do not.
Reduce energy spending
Solar use reduces expenditure in candles, mobile phone charging and batteries, but monthly energy expenditures linked to SHS can also substantially increase through the usage of new electric devices.
Gender empowerment
Some surveys conclude on a differentiated impact of solar on women/girls versus men/boys and, in some cases, possible empowerment.
Impact on health
Some surveys conclude on reduced incidence of illness, but other surveys do not find significant statistical differences.
Social inclusion and communication
Solar systems tend to favour social inclusion of their owners and their connection to the world, notably by increasing access to TV.

Introduction

The dissemination of small decentralised solar photovoltaic systems in developing countries has been promoted for more than four decades with various successes. Their presupposed beneficial impact has been relentlessly put forward by their promoters but for a long time without much evidence due to the small number of systems disseminated and the poor viability of solar projects at that time. It is only in the last fifteen years that the scaling up of solar systems has taken place in a limited number of countries, starting notably in Bangladesh and Kenya, with appropriate technical support and business models improving the delivery of an effective energy service.

At the beginning of the solar industry in the 1970-80s, solar photovoltaic systems were extremely expensive and were used only to power small loads in remote areas. With the decrease of PV module prices, the average size of solar home systems has kept on increasing and solar systems are now used even in on-grid areas as back-up systems. The use of systems has also diversified with the advent of mobile technologies which enable the remote managing of a very large number of small systems (while creating a demand for small load for charging phones). Combined with financial innovations, mobile technologies have also enabled greatly reducing transactions costs facilitating the access and the maintenance of a larger number of small systems. Substantial amelioration in the quality of the products and the miniaturisation of their components has also changed the solar market, with the emergence of good quality pico-products.

The off-grid solar market in developing countries has now moved from a donor-driven approach with limited choices of products (bulky solar lanterns and commonly solar home systems sized at a standard 50 Wp) to a more market-driven approach with a considerable number of private players proposing an extended range of products. The considerable decrease in the price of solar combined with technological innovations has led to a sustained growth and diversification of the off-grid solar market. Furthermore, in the last few years the perception of policy-makers has changed: solar is now a serious contender to conventional sources for large-scale electricity generation and has become part of long-term energy planning both off-grid and on-grid. When costs of solar panels (and batteries) decrease, systems can get cheaper for the same size or providers can choose to disseminate bigger systems delivering more energy services for the same price; their impact then tends to increase. Productive use of small off-grid solar nevertheless seems limited and till now is still poorly studied.

The large-scale dissemination of solar systems has recently led to the multiplication of surveys trying to evaluate their impact. Nevertheless, the majority of surveys rely on limited samples or are satisfaction surveys and as noted by Arraiz: "*Evidence on solar programs is scarce: most of the literature studies the impact of rural electrification via grid connection*".[3 (p. 3)] This paper analyses the research conducted so far in terms of evaluating the impacts of small decentralised solar photovoltaic systems in the Global South, focusing on pico-photovoltaic systems (solar lanterns) and solar home systems for households, screening the existing documentation to present findings from quantitative surveys that rely on a substantial sample. It then concludes on what research gaps exist.

SCOPE OF THE REVIEW

What Kind of Technology is considered?

Solar systems proposed in the Global South are getting more diverse. This review focuses on documentation dealing with the impact of very small or small photovoltaic (PV) solar systems, either pico-PV systems (e.g. solar lanterns) in the range of several Watts-peak (Wp) or solar home systems (SHS) that are typically - in developing countries – in the range of 10 to 90 Watts-peak, as well as larger systems (generally between 90 Wp to 250 Wp) which can be used by better off families or health centres.

This size is far below the systems of 1-2 Kilowatts-peak (kWp) which can be found powering houses in industrial countries. In the Global South, a small power supply can help charge batteries, charge mobile phones; produce quality light; power a radio / TV, or power a fan. Less commonly, SHS can be found to power a computer, a (small) fridge, or a (small) pump. Most SHS can be found in rural areas, although they can also now be found commonly in urban settlements, either as main source of power or as a backup.

The review excludes solar photovoltaic systems external to a house for productive uses such as water pumping for a farm or for a larger demand (above 1 kWp) or systems for wealthy households sometimes connected to the grid, similar to the ones found in industrialised countries. Also, it does not take into account larger decentralised solar systems generating power for micro or mini-grids, or large centralised solar farms feeding the grid. The focus on small solar systems aims to help answer the following specific question: is the impact of these small systems necessarily negligible?

What Kind of Evidence on Impact is examined?[a]

This review looks at the direct and indirect impact of solar systems on occupiers of households: on their education, health, finance, livelihoods and social relations. Impacts have been considered on households' inhabitants and their directly related economic activities (small retail businesses, small holdings). It includes documentation evaluating ex-post any benefits but also disadvantages brought by solar systems, relying either on quantitative or qualitative surveys. It does not include evaluation ex-ante (like modelling of impact), internal evaluation of projects, evaluations relying on simple discretionary observations, satisfaction surveys and general impact surveys on the environment. It focuses on ex-post measurable impacts of solar systems once they have been implemented.

The review focuses on documents where the main purpose is an attempt to measure the impact of small solar systems, either as the main objective of a survey/research or as part of a wider survey/research. Documents where impact is just mentioned, without providing any specific quantitative or qualitative assessment have not been included. Documents have been collected through academic electronic databases, archives and the repository of institutions intervening in the field of energy access, using keywords and cross-checking bibliographical references of documents found.

A first screening has enabled us to find 98 documents which have been analysed; among these 98 documents, a second screening has led to focus on 30 substantial surveys with quantitative evidence relying on relatively large samples: the criteria for selection and the main findings from these quantitative surveys can be found in the tables in this paper (while the complete list of 98 documents from the first screening can be found in appendix 1).

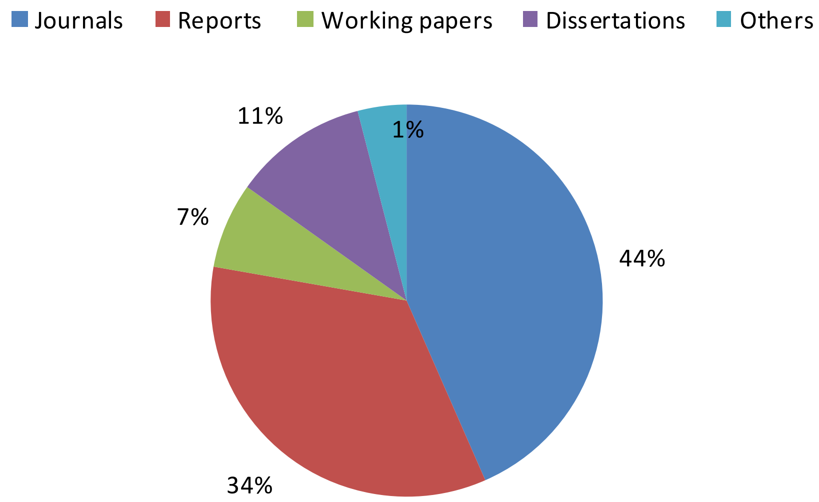
Limitations of the Review

This review aims to be fairly comprehensive on the largest quantitative surveys but is not a representative sample of qualitative impact surveys. This is because a number of small surveys with fewer interviews can be included in papers dealing with the use of photovoltaic systems in general. Conducted on-line, it deals with documentation in English and French' but no documentation on impact specifically in French has been found. The review leaves aside any documentation which may 1) exist only in other languages or 2) only through hard copies like Master or PhD dissertations in institutions without repositories or confidential consultant reports. The review includes papers publicly released till July 2017.

Preliminary Findings

As shown in Figure 1, sources have included academic papers from scientific journals, working papers, student dissertations and reports. The majority of documents are peer-reviewed academic papers followed by reports notably from consultants and non-governmental organisations (NGOs).

Figure 1. Sources of publication of the 98 documents analysed



As shown in Figure 2, there has been a notable increase in the number of surveys undertaken during recent years, linked to the expansion of the off-grid solar market. As solar systems are becoming more mainstream, the increase in the number of surveys reflects an increase in the interest on the impacts of this technology by funders and private stakeholders.

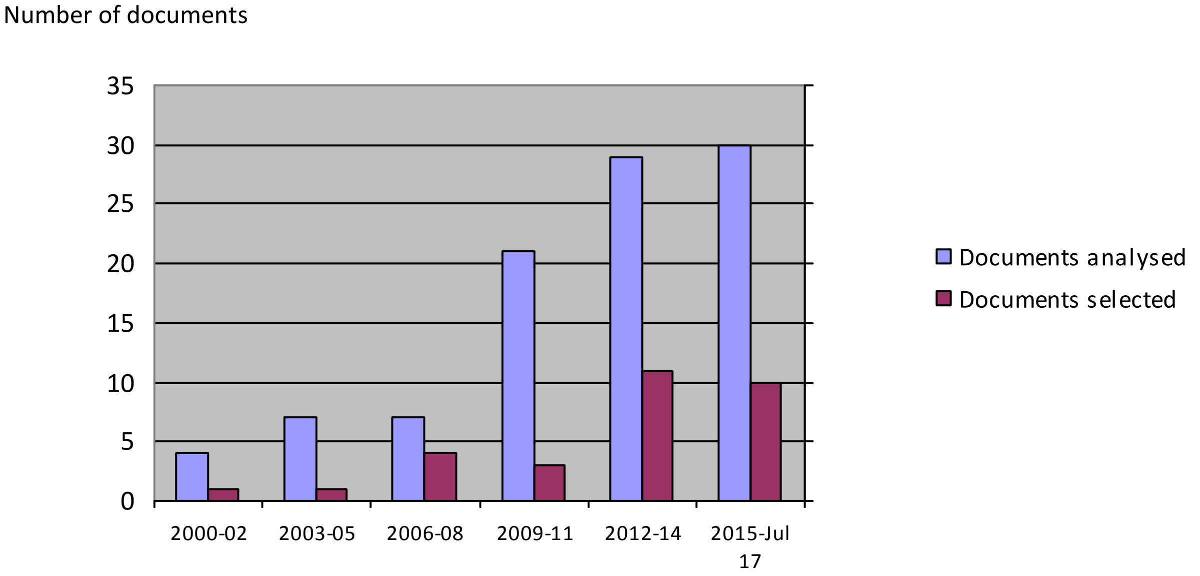


Figure 2. Years of publication of the 98 documents analysed and of the 30 documents selected

As shown in Figure 3, the majority of surveys found for this review have been conducted in African countries, mainly in Eastern African countries (22%), and in Asian countries, notably in Bangladesh (20%). These countries are the ones where the markets for photovoltaic systems have matured for a number of years and are well-studied. This graph relates to the documentation that can be found in English electronic databases. Some regions may be under-represented due to specific conditions of publications (e.g. like China or Latin America).

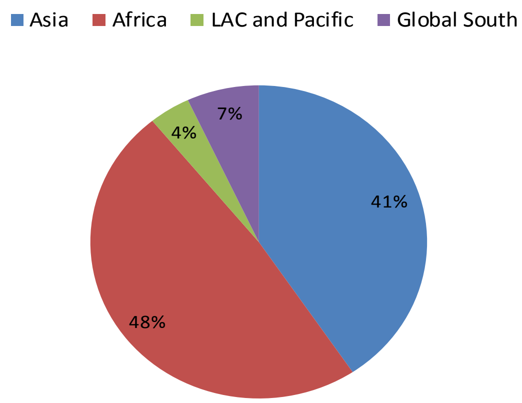


Figure 3. Geographical repartition of the 98 documents analysed

As shown in Figure 4, the majority of the documents analysed are on solar home systems and to a less extent on solar portable lanterns. Very few documents combine the analyses of both types of systems or of SHS with mini-grids.

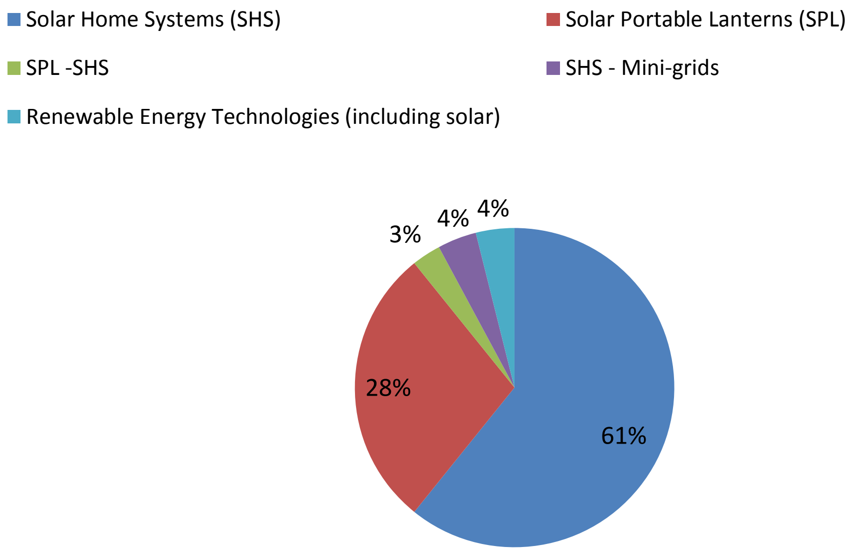
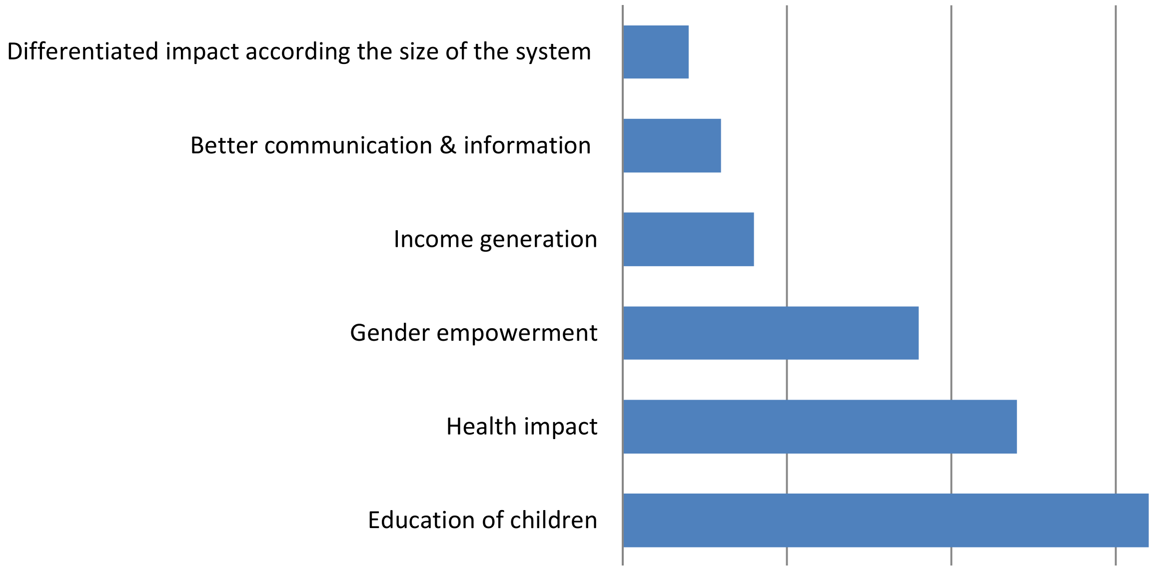


Figure 4. Type of systems in the 98 documents analysed

Two of the categories investigated were found to have a larger amount of quantitative evidence: of cost savings, notably due to kerosene substitution, and of the positive impact of solar lighting on the education of children (see Figure 5).

Few documents providing quantitative evidence of the beneficial health impact of the replacement of kerosene lamps have been found. Other sub-topics where evidence was found, although more limited were in gender and social relations, and better communication and information which favour social inclusion. Some aspects of livelihood and income generation are documented: solar systems seem to have an only limited impact on income generation linked to the extension of working hours for home businesses.

Although solar systems can now also be found in urban settlements, either as main source of power or as a backup, all surveys deal mainly with solar systems in rural areas, including rural town centres.



NB: most surveys deal with several categories so the total number of items is > 30.

Figure 5. Number of substantial quantitative surveys found per categories

Out of the 98 documents, 30 documents rely on 25 large samples (QT1) (with some documents referring to the same sample but providing a different analysis). The other 68 documents (QT2, QL1, QL2 and LR) do not provide substantial quantitative evidence of impact, sometimes only showing appreciation from users or using anecdotal evidence of change of behaviours. The latest are nevertheless useful to understand the chain of causality of impact linked to the use of solar systems. They include quantitative surveys with reduced samples (QT2), qualitative surveys with a high number of interviews (QL1), qualitative surveys with a limited number of interviews (QL2), and few literature reviews (LR).

Papers, reports, working papers and conference papers have therefore been classified according to the kind of evidence they provide and their robustness. The following criteria have been chosen:

Quantitative	**QT1** above 80 HHs with solar	**QT2** less than 80 HHs with solar
Qualitative	**QL1** above 20 interviews	**QL2** less than 20 interviews
Secondary research	**LR** Literature review	

The following sections include quotations providing quantitative assessment from **QT1**, i.e. relying on robust primary research, except when otherwise stated. Non-conclusive studies, studies with reduced samples (**QT2**) (weighted related to the kinds of outcomes), or only qualitative assessment based only on perceptions of interviewees (**QL**), or secondary research/literature reviews (**LR**), can be found in the references and bibliography list.

IMPACT OF SOLAR

It all starts with Lighting…

The main use of solar home systems is for lighting. The quality of lighting is one of the benefits of SHS, recognised by the vast majority of end-users, and very often mentioned in impact surveys; 5 documents out of the sample of 30 documents (QT1) have calculated their impact in terms of increase of lumen hours, or replacement of lower quality lighting sources/reduction of the number of hours of low quality light.[6, 7, 22, 29, 30]

Table 1. Impact in terms of quality of lighting

Location of survey	**Significant findings**	**Sources (documents are described in Appendix 1)**
Uganda (solar lanterns)	"…d.light households consumed 4.3 fewer hours of low quality light (*a 63% decrease*) and 6.2 more hours of high quality light than comparison households (*a 157% increase*), for a net result of 2.9 additional hours of lighting per day, an increase of 29%".	D.light, 2015, p. 5-6.
Senegal (SHS)	"Electrified households consume around five times more lumen hours than comparable non-electrified households. The total usage time of artificial lighting sources irrespective of their quality does, instead, not significantly differ between the two groups. This has to do with the fact that a variety of low-cost battery-run lighting devices has vastly penetrated the rural areas in Senegal".	Bensch, 2012, p. 28.

The luminosity of a solar lantern can be from 25 to 50 lumens, and up to 100 lumens for manufactured models. The luminosity of a 4 Watts (W) Light-Emitting Diode (LED) from a SHS can produce 400 lumens compared to candles that have a light output of around 1-15 lumens, or an open wick or glass covered kerosene lamp that has a light output of 10-30 up to 50-100 lumens.[b] This is better than traditional lighting found in Africa, even if a solar lantern or light bulbs from a SHS provides far less comfort than modern lighting commonly found on-grid, which can go up to 1,500 lumens for a 13 W LED. It has to be noted that the efficiency of LED is constantly improving.[c]

Quality of light is also expressed in duration of lighting. Good solar lanterns can provide light for up to 12-16 hours without recharging. SHS can provide light in several rooms of a house for several hours. Furthermore, with solar there is no time spent to clean a lamp, to refill with kerosene, recharge the lantern or find car batteries. Quality of light can be seen not only as a source of improved comfort during the night, but also during the day when some houses can be dark.

Quality of light can have multiple indirect impacts notably on health (e.g. better medical care during a night emergency), education (e.g. studying at night), increased income (e.g. work at night) and safety (e.g. reduced crime).

Cost Savings Linked to the Substitution to Other Sources of Energy

The main advantage of solar lighting using a solar lantern is its reduced cost for end-users, with service delivery measured in lumen/US$. This can be 5 to 10 times higher than with a kerosene lamp. Capital costs are higher but the payback period compared to the use of a kerosene hurricane lamp can only be a few months.

Measuring the savings linked to the implementation of SHS is more complex. Like solar lanterns, their costs can be compared to the use of traditional sources of energy for lighting, like candles or kerosene lamps. They can also be compared with the use of small dry cell batteries or car batteries for lighting, phone charging or powering a radio or TV.

In any case, the acquisition of solar lanterns tends to always go with a drastic diminution of the use of "traditional" or conventional sources of electricity like candles, kerosene and disposable dry cell batteries (although fuelwood and non-fuelwood biomass which is used for cooking remain stable) and can enable households to make significant savings for lighting, which can be re-invested, for example, in food and books for children.[24, d]

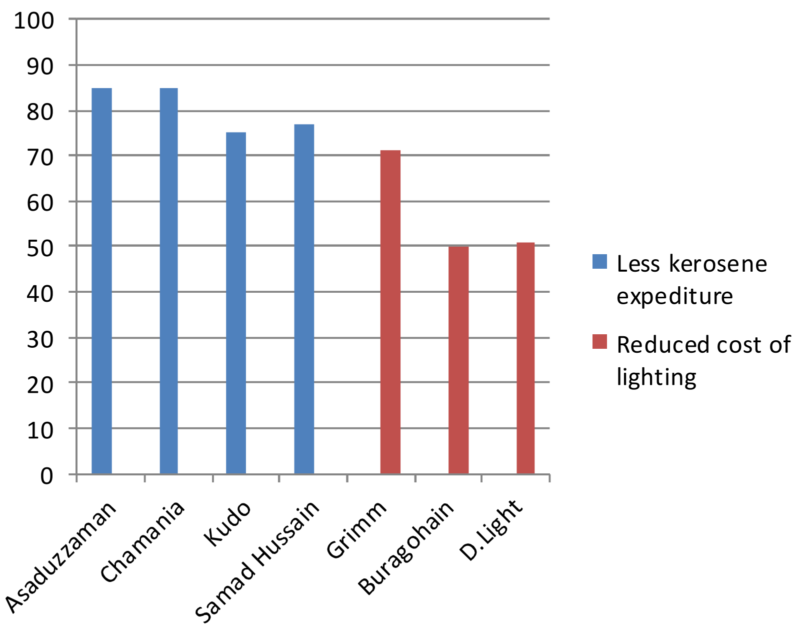


Figure 6. Decrease of expenditure in kerosene (%) and decrease of expenditure in lighting (%)

Out of the sample of 30 documents (QT1), 16 conclude to a reduction of kerosene and other lighting expenditure. The decrease of kerosene expenditure has been estimated between 85% and 75% in four surveys (Asaduzzaman, 2013; Chamania, 2015; Kudo, 2015; Samad Hussain, 2013), and cost of lighting reduced by two to three in three surveys (Buragohain, 2012; D.Light, 2015; Grimm, 2015) (see Figure 6).

However, monthly energy expenditures linked to SHS can also substantially increase through the usage of new electric devices, as most households will not use SHS just for lighting,[7] which can then have adverse effects on other expenses (e.g. reversing to the collection of "free" fuelwood[e]). Numerous surveys have managed to measure the impact of solar products in terms of fuel savings. Table 2 presents some significant findings of large quantitative surveys.

Table 2. Impact of solar electrification on cost savings for lighting

Location of survey	**Significant findings**	**Sources (documents are described in Appendix 1)**
Peru (SHS)	"…a smaller proportion of households with solar panels bought candles (76 percent less) and batteries for lighting (7.3 percent less) than those without solar panels. They also spent less money on candles (7.1 soles) and batteries for lighting (3.0 soles). While these savings seem small, they are enough to cover the fee that households pay to use solar panels—10 soles [around 3.2 USD in 2015]".	Arraiz, 2015, p. 11.
Bangladesh (SHS)	"The average level of consumption per month in non-SHS households is almost 3.5 times the average level in SHS households". "An average adopter uses 3.67 litters [sic] of kerosene less per month compared to an average non-adopter of SHS when other factors influencing kerosene use are held constant". [leaving a consumption of only 0.54 to 0.67 litters per month]".	Asaduzzaman, 2013, p. 60.
Burkina Faso (SHS)	"The share of households without solar panel who use kerosene is almost three times the share of private panel households and six times the share of Yeelen Ba households [with fee-for-service] (9.4 versus 3.4 versus 1.6 percent)".	Bensch[7], 2013, p. 20.
India (SHS)	"The expenditure on lighting has reduced by more than half in Meghalaya, Assam and Jharkhand. The reduction of expenditure on lighting is relatively less in Madhya Pradesh, Odisha and Chhattisgarh".	Buragohain, 2012, p. 336.
India (solar lanterns)	"Replacing kerosene lamps with LED and solar alternatives […] reduced the cost of lighting for impoverished rural villagers by 85% over 1 year".	Chamania, 2015, p. 595.
Uganda (solar lanterns)	"As d.light customers started using the D20g system, they spent considerably less on non-D20g lighting sources (-51%), phone charging (-84%), and transportation to purchase fuel/batteries (-93%). However, since d.light customers have been making incremental payments during the first year of	D.light, 2015, p. 5-6.

Location of survey	Significant findings	Sources (documents are described in Appendix 1)
	ownership, their overall energy costs are higher [$2.99] until the system is fully paid off. After paying off the D20g system, d.light households are expected to spend $1.41 less per week on average than the comparison group on these same overall energy-related expenditures (-73%) [for the rest of the product's life (estimated at 5-10 years)]".	
Rwanda (solar lanterns)	"Assuming that a household uses the lamp for four hours per day, the Pico-PV lamp pays off after 10 months if the LED hurricane lamp is replaced and after less than 5 months if it replaces a kerosene driven lamp". "…a control household [without a pico-lantern] pays approximately five times as much per lighting hour as a treatment household [with a pico-lantern] (950 FRW vs. 180 FRW [1.56 USD vs. 0.30 USD]) with this difference being obviously more pronounced for the price per lumen hour: a control household [without a pico-lantern] pays seven times more per lumen hour than a treatment household [with a pico-lantern] (70 FRW vs. 9 FRW [0.12 USD vs. 0.02 USD])". "This reduction in lighting costs effectively translates into a massive increase in the amount of lumen hours consumed per day in treatment households [with a pico-lantern], which is more than two times as high as in control households [without a pico-lantern]". [NB: 142 lumen hours consumed per day in the treatment group against 61 in the control group. This leads to a reduction of 71% of lighting expenses as shown in Figure 6]	Grimm, 2015, p. 10. Grimm, 2015, p. 27.
Bangladesh (SHS)	"The table shows that all of the SHS households used kerosene before installing SHS. Around half of SHS households stopped using kerosene lamps after purchasing SHS, and kerosene consumption by current kerosene users has dramatically decreased". "...of 304 SHS households in the sample, 149 households possessed rechargeable batteries before the installation of SHS. However, only five households retained these batteries after SHS installation".	Komatsu, 2011, p. 4025-4026.
Bangladesh (solar lanterns)	"…those [household] that received three […] solar products reduced kerosene expenditures in the last 12 months by approximatively 75% [and 50% when they received one solar product]".	Kudo, 2015, p. 18.
Bangladesh (SHS)	"SHS households consume less than 1 liter of kerosene per	Samad Hussain,

Location of survey	Significant findings	Sources (documents are described in Appendix 1)
	month, compared to almost 3 liters per month consumed by the non-adopters".	2013, p. 12.
Sri Lanka (SHS)	"It was recorded that after the installation of SHSs the expenditure on kerosene dropped to zero in 103 households out of the total sample of 112".	Wijayatunga, 2005, p. 7.

Solar lights (when they are in sufficient number[51 (p. 4025)] and can be located even outside kitchens or power security lights[97 (p. 37)]) can almost be a complete substitute to kerosene lamps, candles and batteries, as they are less expensive, less polluting, less dangerous and provide far better lighting; their adoption by households seems quite straightforward in a few weeks.[1 (p. 1091)]

Differentiated Impact According to the Size of the Systems

Solar lanterns vs Solar Home Systems

There are not many surveys on the differentiated impact between solar lanterns and SHS or between different sizes of systems.[4; 12; 13; 41] The question of the location of light with SHS (normally in the kitchen) while solar lanterns are easy to move from one room to another could be raised. But, according to a survey with a reduced sample (QP1) conducted in East Timor:

"*The findings of the research indicate a very clear preference amongst most users for SHS rather than solar lanterns, raising the question as to why portability, the prime advantage of lanterns did not make lanterns more attractive". "…there was no statistically significant difference between the study patterns for students in households with access to working lanterns and those in households with access only to a single, working SHS*". [12 (p. 1080)]

Small Solar Home Systems vs large Solar Home Systems

Large SHS have a greater impact than small SHS. Nevertheless, it seems that a small system could provide "*much of the development impact of the larger system*"[13 (p. 708)] and therefore could be better value for money than large-scale SHS.

Table 3. Differentiated impact of solar according to the size of the system

Range of size of systems tested	Differential Impact	Sources
20-85 Wp - Bangladesh	"Does size of SHS matter in deciding how much kerosene is consumed? Hardly, as for 20-55 Wp range the average per month varies little with a range from 0.60 to 0.67 liters. Only for the 60-65 Wp range does it fall substantially to 0.54 liters".	Asaduzzaman, 2013, p. 62.

Range of size of systems tested	Differential Impact	Sources
	"…in SHS households where there is a TV [mainly SHS of over 40 Wp], the incidences of certain diseases are in fact lower".	Asaduzzaman, 2013, p. 65.
10-80 Wp - East Timor	"The research findings showed that the small, 10Wp SHS provided much of the development impact of the larger systems". "UNDP households, with the 'medium' sized systems [40 Wp], were more likely to report that study/reading had increased 'much more' with installation of their SHS". "Use of these lighting sources [candles and home-made kerosene lamps for study/reading] was found to have been completely eliminated in households with the 'large' RDTL [Government of East Timor] systems [80 Wp]. A small number of CER [Communidade Edmund Rice] ('small') [10 Wp] and UNDP ('medium') [40 Wp] households […] continued to use these sources even though their SHS were functioning". "Most groups for the medium and large systems reported that carrying out domestic tasks was 'easier' or 'much easier' as a result of their SHS. The response for users of the small systems was more complex". "Respondents from all projects overwhelmingly perceived their SHS as being 'useful' for running an existing home business or potentially running a business in the future. Ninety per cent of existing businesses involved activities requiring area lighting such as running a small shop (50% of all businesses), agricultural processing (20% of businesses) and household-level bakeries (10% of businesses). For these activities the area lighting of small and large systems provides similar benefit".	Bond, 2012, p. 699. Bond, 2012, p. 702-704.
40-85 Wp - Bangladesh	"The average kerosene saved by 40, 50, 60-65 and 80-85 Wp systems were around 15.20, 20.16, 22.48, 32 liter/month respectively".	Hoque, 2015, p. 710. NB: QT2 survey.

As demonstrated by Komatsu,[51 (p. 4027, fig. 3)] energy expenses with bigger systems increase substantially while energy savings linked to reduction of kerosene and rechargeable batteries remain more or less stable.

Solar Home Systems as an Alternative or Complement to the (Mini)-Grid

The cost of SHS compared to the cost to grid connection for end-users will depend on the regulation and policies of the country, while the cost structure for solar systems can vary greatly according to the financial scheme in place to support the dissemination of solar home systems. As such, it is difficult to compare the acquisition cost of a solar system for end-users to a connection cost to the grid, as both are fixed according to political priorities and geographical constraints and can vary from region to region. However, benefits of SHS (see notably Tables 4 and 7) are in line with benefits of on-grid connection. For example:

"*Interestingly, the welfare effects of SHS adoption compare favourably with those of grid electrification. A recent study using 2005 household survey data from rural Bangladesh finds that grid connectivity improves household per capita income by 21 percent and per capita expenditure by 11 percent and the evening study time of boys and girls by about 22 minutes and 12 minutes, respectively*".[50 (p. 55)]

A growing number of recent impact surveys underline the use of solar systems as a back-up to an unreliable grid; which means that solar systems are considered by end-users not as an alternative, but as a complement to the grid.[38]

Not many comparisons seem to have yet been drawn between the impact of solar home systems and mini-grids, although some technical-economic comparisons exist.[f]

Use of Time, Livelihoods and Income Generation

Solar light provides better quality light which helps to give more flexibility in terms of activity allocation during the day and the night. Surveys have tried to evaluate the impact of SHS on domestic tasks and economic activities generating income (see Table 4). The impact of SHS can be positive but - due to the small size of the PV systems - limited to the increase in the number of hours of work for small businesses, except notably for fishermen who could make intensive use of solar light for fishing at night.[95]

Table 4. Impact of solar electrification on use of time, livehoods and income generation

Country surveyed	Significant findings	Sources
South Africa (SHS)	"The study reveals that illumination provided by SHS electricity has profound impact on the livelihoods of rural households". But "…the influence of SHS on household economic	Azimoh, 2015, p. 354. Azimoh, 2015, p. 360-362.

Country surveyed	Significant findings	Sources
	development is minimal […] Three quarters of all the households reported that SHS has not led to any job creation or increased chances of employment”. “The only perceptible economic impact of SHS revealed by this study is related to illumination provided by SHS electricity. Those who have benefitted economically from SHS are those who use illumination from it to extend business hours into the night”.	NB: qualitative survey QP1
Peru (SHS)	“Although women spend less time farming [and more time to take care of their children, cooking and chore activities] and men more time on home business activities in households with SHSs than in those without, these changes have had no evident impact on income or poverty”.	Arraiz, 2015. p. 0 and detailed calculation p. 13-14.
Kenya (SHS)	“In the 2003 survey (n = 76 households), 32% of ‘‘solar’’ households reported using lights for income generation or work-related activities, and smaller percentages indicated income- or work-related uses of solar-powered televisions and radios (23% and 22%, respectively […]). In total, 48% of the households in the sample reported some sort of work- or income- related activity that was supported by the use of solar electricity”.	Jacobson, 2007, p. 152. NB: quoting a survey conducted by the author in 2003.
Bangladesh (SHS)	“SHS adoption indeed has positive impacts on household income and expenditure [...], although the scale is smaller than that of grid electrification impacts. […]. The impacts on expenditure and income are about 4–5 percent and up to 12 percent, respectively. An additional year of SHS adoption increases household per capita income by 2.5 percent and per capita expenditure by about 1.6 percent. Household ownership of domestic goods can increase by 23–27 percent because of SHS adoption”.	Khandker, 2014, p. 49.
Kiribati (SHS)	“For approximately 62% of the households, SHSs had not contributed to the income generating activities in any way. For the remaining 38%, SHS had helped in income generating activities”.	Mala, 2009, p. 361. NB: qualitative survey QP1
Cambodia (SPL)	“37% of customers claim they earn an additional income directly linked to the use of the solar lamp. On average, those 37% can earn an additional 1421 PHP per month, which represent 18% of their income”.	Stiftung Solarenergie (StS) & Hybrid Social Solutions (HSSi), 2011, p. 52.
Kenya & Uganda (SHS)	“[…] over 90% of those we surveyed used their SHS for domestic purposes, viewing it as a means of improved comfort and lifestyle rather than as an opportunity to improve the family's financial situation”.	Stojanovski, 2017, p. 39.

The creation of jobs linked to the solar lanterns and SHS value chain could be considerable.[62; 65] According to Mills, 2014.[62 (p. 3)] *"The study estimates that employment from kerosene distribution represents approximately 20,000 full-time jobs throughout ECOWAS [Economic Community of West African States]"…"The potential jobs-to-population ratio for alternative technologies and associated value chains is 30 jobs per 10,000 people living off-grid, which corresponds to the possible creation of 500,000 new, lighting-related jobs throughout ECOWAS. In this region, increased market penetration of solar lanterns, for example, could create approximately 30 times more jobs—and often higher-quality jobs—than fuel-based lighting does".*

Gender, Social Inclusion and Empowerment

As shown in Table 5, solar systems have an impact on social relations sometimes differentiated by gender, as they allow women to do some domestic tasks like cooking better when there is quality light.[4 (Section 4.10 and chapter 5); 12 (p. 1081)] As noted by Samad Hussein in Bangladesh, *"female-headed households are more likely to adopt SHS panels than male-headed households and also to adopt SHS units with higher capacity.*[92 (p. 22)]

Women (and children) who spend more time in houses may get greater benefits from solar lanterns and SHS than men.[4 (p. 67); 11, (p. 107)] TV and radio contribute to women empowerment.[4 (p. 84)] Lighting can also increase the sense of safety, especially for women.[14 (p. 337)] However, only one survey has tried to quantify security objectively (and found no difference).[6; g]

Table 5. Impact of solar electrification on gender empowerment

Country surveyed	Significant findings	Sources
Peru (SHS)	"Members of households with solar panels spent more time awake than members of households without solar panels—on average, 25 more minutes in the case of men and 42 more minutes in the case of women […] women in households with panels spent 1 hour and 38 minutes less in productive activities outside their homes than women in households without panels—a difference that is due to a reduction in the time spent on agricultural activities".	Arraiz, 2015, p. 13.
Bangladesh (SHS)	"…respondents from the female headed households (80.8%) clearly indicate that they receive information about the outside world taking advantage of SHS compared to 75.2% in the male-headed households. It might be the case that male members get information from outside home. But as women are constrained in mobility by social norms, SHS is a window to connect to the world with the help of connecting TVs, radios or mobile phones".	Azadussaman, 2013, p. 75.
Bangladesh (SHS)	"Among the schooling outcomes, boys' completing schooling years is positively affected by the duration of SHS use, and girls' schooling years by electricity consumption". "…women spend about 0.11 hour less per day on fuel collection,	Khandker, 2014, p. 49.

Country surveyed	Significant findings	Sources
	which translates to a weekly time savings of about 46 minutes. […] women spend more time in study/reading and tutoring children as a result of SHS adoption […]. SHS adoption increases women's study/reading time by 0.36 hour per day, which is equivalent to 65 minutes of reading per week".	Khandker, 2014, p. 53.
	"…SHS adoption enhances women's empowerment in numerous ways, including mobility and a wide range of decision-making abilities, which women can do independently […] SHS adoption improves women's decision-making on children's and other family issues. Women's decision-making on purchases of own and household goods also improves as a result of SHS adoption. Finally, women's decision-making ability on family-planning issues increases [...] because of SHS adoption".	Khandker, 2014, p. 53-54.

Access to TV and the increased possibility of using a mobile phone (without having to charge it outside) are important benefits of installing SHS (see Table 6).

Table 6. Impact of solar electrification on social inclusion & communication

Country surveyed	Some findings	Sources
Burkina Faso (SHS)	"Neighbours or friends are the sole primary source of information for households without a solar panel, whereas radios play a similarly important role for households electrified by Yeelen Ba or private solar panels". "…the two electrified groups of households are more accustomed to use their mobile phone for credit transfers. According to matching, they are almost twice as likely to do so as households without a solar panel" […] "Compared to households without an electricity source, Yeelen Ba customers do not listen more to the radio". "The average duration of TV watching per day in Yeelen Ba households is 65 minutes for heads of households and 40 minutes for their spouses compared to 17 and 7 minutes in households without solar panels".	Bensch,[7] 2013, p. 27-29.
Bangladesh (SHS)	"After sunset, the occurrence of social gatherings seemed to be highly influenced by the availability of electric lights and television sets. Figure 36 reveals that most SHS households stated to frequently host social gatherings in the evening, as neighbours were attracted by good lighting and TV facilities. In contrast, households not having solar electricity were more seldom receiving visitors in the evening hours".	Blunck, 2017, p. 102. NB: part of the survey which is qualitative survey QP1

Bangladesh (SHS)	"…the number of SHS households that obtained a TV increased, with more than 75% of SHS households now having a TV. In contrast, only 13.3% (41 of 308) of non-SHS households have a TV". "Moreover, 68% of households said neighbours frequently came to their home, indicating that the benefits of TV expanded to households without TV".	Komatsu, 2011, p. 4027.
Bangladesh (SHS)	"The use of SHS also has an impact on access to information in general, particularly through TV in cases where people did not have a TV before. 62% of the households found that their access to relevant information has improved due to the SHS".	Kürschner, 2009, p. 32. NB: Qualitative survey QP1

Social network effects may reduce the gap between households that have a SHS and the one that do not. The impact on rural-urban migration seems to be marginal.[11 (p. 104); 102 (p. 12)]

Education

Surveys have tried to estimate the impact of solar products on the education of children. Surveys collected tackling the impact on education - except one surveying the impact of (apparently low quality) solar lanterns[26] with increased study time of 30 minutes but lower academic results – tend to conclude to a small positive impact of the use of SHS in terms of extended number of minutes of studying per day and sometimes better academic results (see Table 7). The use of SHS at home enables children to study after dusk in better conditions compared with the use of kerosene lamps, either at home where children congregate in houses with solar home systems[13 (p. 702); 94] or at schools equipped with SHS which can even offer night classes.[34 (p. 1298)] SHS installed in schools and accommodations of teachers could also help to attract better motivated teachers which will have a positive impact on the education of children.

Table 7. Impact of solar electrification on education

Country surveyed	Significant findings	Sources
Peru (SHS)	"Children spend more time doing homework, which has translated into more years of schooling (among elementary school students) and higher rates of enrolment (in secondary school)". "children in households with panels have gained an edge in terms of years of schooling: a difference of 0.4 years of schooling for children enrolled in elementary schools and who have been exposed to electricity for an average of two years and nine months*". [*We believe the difference is due to the extra time they devote to doing homework, but more importantly to the quality of the light they use while doing their homework.]	Arraiz, 2015, p. 4. Arraiz, 2015, p. 15.

Country surveyed	Significant findings	Sources
Bangladesh (SHS)	"…the boys and girls on average study 10-12 minutes longer with solar lights than those without it". [school attendance is slightly higher: 77.5% against 73.2 for boys; 81.2% against 77% for girls and grade completion is higher: 3.6 years against 3.2 years for boys and 3.8 years against 3.3 years for girls]	Asaduzzaman, 2013, p. 64. Asaduzzaman, 2013, Table 4.8 p. 65.
Bangladesh (SHS)	"The overall time spent on studying per evening was on average 21 minutes longer in SHS-households (133 minutes) in contrast to households without solar electricity (112 minutes) in the same village. Interviewees confirmed that improved lighting conditions seemed to motivate rural school children to spend more time studying, whereas children working under the light of kerosene lamps were not tempted to exceed education-related activities".	Blunck, 2017, p. 96.
Bangladesh (SHS)	"Children's study time and completed schooling years are better in SHS households than in their counterpart non-SHS households, while the difference is not statistically significant in the case of school enrolment". […] "Children's evening study time increases because of SHS adoption, and it appears to increase more for boys than for girls (by more than 14 minutes versus 7.7– 12.4 minutes, respectively)".	Khandker, 2014, p. 47.
Cambodia (SPL)	"The average studying time per child has increased since children work with the solar lamp: it is 1.5 times longer than before (about 35 minutes)".	Stiftung Solarenergie (StS) & Hybrid Social Solutions (HSSi), 2011, p. 55.

The small increase of time for studying is not automatic, as there can be competitive uses of solar lanterns - and even more so for SHS which can be used for instance to watch TV (although some TV programs can also have a positive impact on education[11, (p. 99-100)]) and children do not always have priority access.[94] Furthermore, the increase of studying time during the night can go with a decrease of daytime studying.[30]

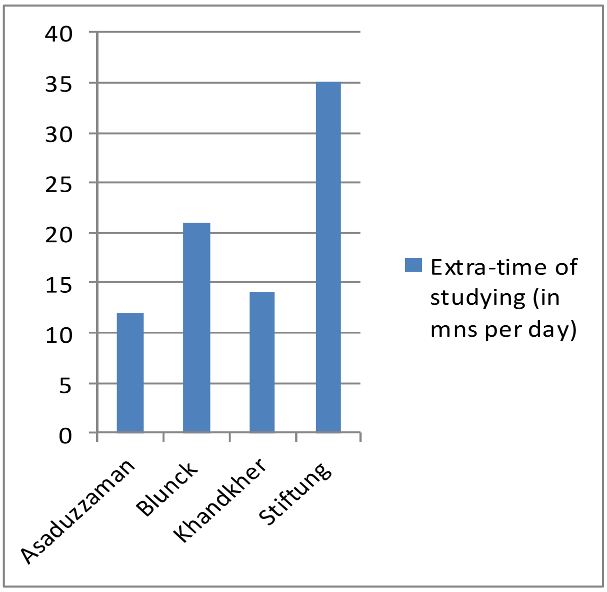


Figure 7. Extra-time of studying (in minutes per day)

The increase in minutes per day when it occurs seems to be marginal, but is actually comparable with the increase found in some studies on the impact of grid electrification.[h] Nevertheless "… *the main impact in this [rural] context is the improved quality of lighting […] instead of a change in the quantity of studying*."[7 (p. 31)]

There also seems to be a slight increase in terms of enrolment and years of schooling (see Table 6). However, as noted by Furukawa, *"providing higher incentives [like scholarships] is generally more effective than providing better study environments in improving children's learning outcomes".*[26 (p. 6)] Disseminating solar lanterns can only make a small contribution to better education.

As noted by Samad Hussain in Bangladesh *"... higher education of either adult males or females means both a higher probability of adoption and the adoption of a larger-capacity SHS".*[92 (p. 22)] Children with solar systems may often benefit from an already more favourable socio-economic background, the solar system being just a part of a broader strategy from educated and supportive parents of giving a better education to their children.

Health

Burns linked to overturned kerosene lamps are a major issue in developing countries.

"*In India, around 2.5 million people (350,000 of them children) suffer severe burns each year, primarily due to overturned kerosene lamps*."[16 (p. 600)]

The use of kerosene could also lead to poisoning of small children. Very small quantities of kerosene can be lethal when ingested and kerosene looks like water and, in some countries, is often stored in soft drink bottles which can easily be reached by children.[i] Furthermore, *"some studies suggest that kerosene is associated with health effects comparable with those of biomass burning for cooking, although a wider evidence base is needed to firmly establish this"*.[55 (p. 7)]

It seems that very few attempts have been able to measure the impact of substituting solar systems for kerosene lamps, looking at the decrease in burns and fires. According to a survey in Uganda, "*As compared to the control group, d.light households reported experiencing an 88% reduction in the reported incidence of burns (-6.4 percentage points) and a 93% decrease in reported incidence of fires (-6.0 percentage points)"*.[22 (p. 6)]

As using kerosene lamps can be linked to respiratory problems[i] and the PM (particulate matters) emissions from kerosene lamps are being generated near the person studying/working, solar lanterns replacing kerosene lamps shall have a beneficial impact on children/adults. As noted by Grimm: "*Although the relative contribution of kerosene lamps to household air pollution is rather low compared to firewood and charcoal usage for cooking purposes, it is the immediate exposure of people sitting next to a wick lamp for studying purposes, for example, that makes kerosene a substantial health threat"*.[29 (p. 35)]

However, few surveys have found significant evidence of an impact on health and some quantitative surveys find no impact due to the small incidence of respiratory diseases. It is when SHS powers a TV that a statistically significant impact on health can be found, linked to access to awareness campaigns (Table 8).

Table 8. Impact of solar electrification on health

Country surveyed	**Significant findings**	**Sources**
Peru (SHS)	"… We, however, cannot detect a difference in the incidence of respiratory diseases between the groups or in the incidence or number of burn accidents; the proportion of people reporting being affected by respiratory diseases or burn accidents was less than 1 percent in both groups".	Arraiz, 2015, p. 18.
Bangladesh (SHS)	"…the SHS that has the capacity to run a black and white TV and that actually the use of one may help reduce such incidence [of disease] as various TV programs indirectly and a few commercials directly inculcate the prevention procedures of a few endemic diseases". "The incidence of several types of preventable illness such as general ailment, respiratory diseases, and GI [Gastro-Intestinal] illness was lower among the members of the households that purchased a SHS". But "the adopters [of SHS] are economically and socially somewhat better off than non-adopters. Hence the situation regarding disease prevalence may also arise due to the better	Asaduzzaman, 2013, p. 65 & 73.

Country surveyed	Significant findings	Sources
	economic situation and greater awareness due to higher levels of education".	
Bangladesh (SHS)	"There is no consistent pattern in the incidence of diseases among women and children by SHS adoption, and differences between adopter and non-adopter households are not statistically significant". "While recent fertility in SHS households is higher than in non-SHS households, the difference between the two groups is not statistically significant, much like the descriptive statistics". "The results show that SHS adoption alone does not improve health outcomes of women and children and fertility outcomes of women; however, in conjunction `with TV ownership, it does matter to those outcomes".	Khandker, 2014, p. 50-51.
Ghana (SHS)	"The study results indicated that solar PV lighting is likely to reduce the proportion of household members being affected by indoor smoke from kerosene lanterns by 50 %. Furthermore, solar PV lighting is likely to reduce the proportion of household members who get blackened nostrils from soot associated with kerosene lanterns by nearly a third".	Obeng, 2008[79, p. 55.]

Research has also been conducted on the possible negative health impact on children of the use of vented lead acid batteries for SHS. These kinds of solar lead batteries - located inside houses - could contaminate their immediate environment and could expose young children to lead poisoning with blood lead level higher in children who live in the houses with batteries than those who do not.[99] Tampering with solar systems could also cause fires linked to short cuts.[84]

Solar lighting and solar powered fridges for vaccines are also important for health centres and further contribute to maintaining qualified staff in rural clinics.[60; 39; 80]

LIMITATIONS AND GAPS OF RESEARCH

In conclusion, while there has been work done on the impact of SHS, there has been insufficient documentation to draw definitive conclusions on the impact of SHS in specific areas. Qualitative assessments tend to have increased but there are only a few substantial quantitative surveys. There are nevertheless: 1) strong evidence of cost savings when kerosene lamps are replaced by solar lighting and 2) large quantitative surveys on the impact of solar lighting on the education of children.

Out of the 30 documents selected after the second screening, most surveys can only measure the short-term impact of solar systems on directly visible indicators (e.g. time studying, black nostrils), and cannot measure their long-term impact. This is because of the short duration of the study and/or the reduced sample and/or the lack of rigorous methodology to separate the long-term impact of solar systems on better education or health (for instance, from other causes like the initial education of household heads or their income). The difficulty in building large cohorts over a long period is a clear limitation.[j]

Based on the publications found in this survey, if a small positive impact on education seems to have been demonstrated, the health impact of SHS is currently lacking in evidence to date. Gaps in the literature seems to include the lack of substantial quantitative research: 1) to provide evidence on improved health linked to access to awareness campaigns permitted by TV and radio powered by solar, 2) on better access to vaccines with solar fridges, and 3) on the reduction of burns and poisoning cases linked to the replacement of traditional lighting with solar lighting.

Overall, the quantification of the impact of access to electricity on social relations within communities seems to also be an under-researched field, notably on the social dynamics around the introduction of solar systems in a community and the potential increase of inequalities between owners of solar home systems and those who are left in the dark. Most surveys mention the importance of gender and found quantitative evidence of differentiated gender impacts in terms of time use. Communication and information impact are mentioned but not really quantified yet, apart from in terms of satisfaction or better access to media.

The implications in terms of the impact of the irruption of new market trends like synergies with mobile phones or the decrease of cost of solar panels, seems to not be well documented yet. For instance, no substantial research seems to have been conducted on income generation linked to access to SHS of over 90 Wp which can now be more often found in some countries due to the decrease in the cost of solar panels. There is little documentation dealing with the differentiated impact of solar according to the sizing of the systems, but as the range of solar products on the market gets broader, this area will probably be the subject of more surveys: as the price of solar goes down, does it make sense for donors and state agencies to support programs which propose solar home systems of small size at a cheaper price to reach a higher number of people, or to take the opportunity of the reduction of the cost of solar cells to increase the size of solar systems.

Differentiated impact linked to the delivery mechanisms of solar systems could also be analysed: some organised delivery models where technicians regularly visit properly installed systems cannot only guarantee a better functioning of the solar systems, but could also help to manage expectations of users; end-users in regular contact with technicians could better understand how to use their system compared to spontaneous solutions where they buy their systems over the counter. In the sample of 30 documents based on large quantitative surveys, almost all surveys on SHS deal with SHS disseminated through some kind of organised delivery models (e.g. micro-credit scheme, fee-for service scheme) and/or subsidised by the government, but actually - in a growing number of countries - SHS can be bought over the counter. Almost all documents surveying the impact of solar lanterns actually deal with solar lanterns donated for the purpose of the research (by the research project or by a solar company). Once again, the experience of end-users who purchase themselves their solar lanterns may differ.

Actually, most impact studies tend to focus on the technology and forget to describe operations on the ground and to take into consideration the social interactions between end-users of solar systems and installers (and also with non-users). The way the product is introduced to end-users and scaled-up has an influence on the long-term sustainability of the off-grid market in an area/country. The accumulation of counter-references notably linked to the dissemination of sub-standard products can modify the perception of solar systems and therefore their impact. If existing research is already sufficient in demonstrating that very large-scale dissemination of solar systems in the Global South can potentially make a contribution to the improvement of the well-being of its inhabitants, research is needed on the evolution of the behaviour of solar system users at different stages of the development of the off-grid market, and how to maximise the impact of solar systems once they are installed.

Furthermore, there has been little research conducted to date on the negative impact of solar home systems linked to the presence of lead batteries in households and on the lack of recycling capacity in developing countries. The scale of the environmental impact linked to the use and disposal of batteries seems unknown. The multiplication of imports of sub-standard quality products with reduced life-cycle could be detrimental in countries with no recycling policies.

Gaps can also be found in research on the SHS value chain, and the potentialities in terms of job creation at a local level have only just started to be researched. This is because researchers tend to produce globally projected models of job creation per number of SHS, and do not survey local creation of jobs by solar companies and retailers; parts replacement and recycling of solar systems (notably batteries) could be matters of substantial research in the future.

Conclusion

It has been commonly accepted in the arena of aid for development that solar photovoltaics - due to the high cost of solar panels - could only fulfil small electricity needs, mainly in remote places, and could not be a substitute for grid connection; therefore it was assumed that solar had limited impact, or that its impact could not be measurable. This review which deals with documents produced from 1999 to July 2017 shows the contrary; it captures partly the evolution of the solar industry which - as costs of solar photovoltaics are decreasing steadily - tends to provide a more diversified range of products from pico-photovoltaic systems (e.g. solar lanterns) to solar home systems of different sizes.

The multiplication of very small pico-photovoltaic systems like solar lanterns has an impact. Solar lanterns contribute to substantial financial savings and reduce the time spent in solving energy supply issues for lighting. They provide better lighting than petroleum lanterns, which improves studying conditions for children in schools and at home. Better lighting also helps women (and men) to do more activities at home. Studies conclude significant changes in uses of time, notably between daytime activities and night time activities, with an increase of time spent inside the house and with a differentiated impact on children, women (who spend more time in households) and men. Solar light gives members of households more flexibility to allocate time for activities during the night.

Solar home systems' impact is more complex to apprehend as – on top of the impact of better lighting – they can for instance power a radio and a TV which provide entertainment, but also access to information, and therefore have an impact on education and health. However, energy expenditures of households with solar home systems, even though solar home systems help to reduce costs linked to the use of traditional fuels for lighting, can be substantially higher than those for households without a solar home system; even if financial schemes with subsidies can try to mitigate this, solar home systems are often found among the wealthiest and most educated households.[4 (p. 45 and 57); 51 (p. 4029, fig. 6); 54 (p. 29); 77]

As solar systems become more widespread, research on the impacts of solar tends to multiply. There are nevertheless no quantitative surveys conducted on long-term impacts of solar systems due to a clear limitation of the current research framework when it comes to epidemiological surveys. Furthermore, surveys conducted on the impact of solar are often on small samples of less than one hundred systems. More quantitative research conducted on large samples of households is needed. Future research could notably be conducted on large cohorts of pupils to confirm the presumed long-term positive impact of solar on children's education. In the same manner, the impact of solar lanterns and solar home systems is likely to be positive on the reduction of burns and fire hazards by replacing petroleum lanterns. However, to confirm the impact on health from this aspect, and also the impact linked to better internal air quality, would require research on a large sample over a sufficient duration.

To conclude, the impact of solar lanterns and of solar home systems is high in terms of quality of light, change of use of time, and on cost savings on candles, dry cell batteries and kerosene. Additionally, for some households, solar systems help a little to increase income. Solar systems lead to better conditions for studying (but demonstrated quantified impact of improved lighting remains minor on grade completed) and (even if the impact is not yet quantified) is likely to have an impact on health improvement (better air quality, reduction of burns, awareness campaign); the impact could be high in terms of social relations and communication, with a greater impact on women, more noticeably through better access to radio and TV programs and a sense of increased safety at night.

For the benefits of solar systems or products that have been proven by the surveys that have been reviewed, there are obvious limitations. First, the question of impact could also be formulated in terms of value for money for funders and policy-makers: few surveys have tried yet to compare the respective added value of solar lanterns, solar home systems, micro and mini-grids and connection to the grid to help policy-makers elaborate their strategies of electrification. Shall funders continue to favour the massive scale dissemination of solar portable lamps as a first step of electrification to reach the maximum number of people, or shall they put their efforts on solar home systems with bigger impact or productive use of solar with mini-grids? Comparisons with other sources of energization are also missing.

Second, most surveys focus on the direct short-term individual impact of small individual solar systems without being able to evaluate the long-term influence of solar in a community. Notably, the social dynamic that solar can lead to – by introducing a technology – does not just partly replace old ones, or reduce cost and time allocated to get a particular energy services, but can lead to a series of unexpected positive or negative changes. For instance, little research seems to have been conducted on the social impact of solar, for example on the increased inequalities between those who can afford solar systems and those who cannot, or in terms of technology literacy between those who understand the technology and those who, even equipped, cannot properly manage their system. This is because current research - especially that funded by solar companies - tends to implicitly accept the idea that individual systems mainly have an impact at an individual level.

Lastly, and as a result of the second point, the ethical aspect linked to solar seems evacuated from existing research, which considers the current energy transition as necessarily desirable. The introduction of solar can destabilize "traditional" communities: by being a vector of the consumer society, solar can create an ecosystem of technologies perpetually initiating new needs that can lead to high level of debts. However, critical discourses about solar are rarely elaborated on under the pretext that new low-carbon technologies are intrinsically good for their users.

Notes

a On the different definitions of impact and how to measure it: Hearn S, Buffardi AL. What is impact? MethodsLab, ODI, February 2016.

b 50 ways to end Kerosene Lighting, REEEP, Barefoot, May 2009.

c Sekeyre CKK, Forson FK, Akuffo FO. Technical and economic studies on lighting systems: A case for LED lanterns and CFLs in rural Ghana, *Renewable Energy*, 2012, 46: 282-288.

d There can be variations according to the financial acquisition scheme, for instance if solar panels are acquired privately or via a subsidised scheme (see[7 (table 8, p. 13)]).

e See for grid and solar electrification in South Africa, Madubansi M, Schackleton CM. Changing Energy Profiles and Consumption Patterns Following Electrification in Five Rural Villages, South Africa, *Energy Policy*, 2006, 34: 4081-4092 or[84, (p. 43)]. Actually, the whole structure of spending can be altered with access to electricity, with more spending on education, communication and less on food (but this is partly linked to the fact that household without solar are poorer); nevertheless existing quantitative surveys on solar tend to focus on savings on traditional fuels or do not dissociate impact of solar from other causes.

f For instance, Azimoh CK, Klintenberg P, Wallin F, Mbohwa C. Electricity for Development: Mini-grid solution for Rural Electrification in South Africa, *Energy Conversion and Management* 2016, 110: 268-277; Chaurey A, Kandpal TC. A techno-economic comparison of rural electrification based on SHS and PV micro-grids, *Energy Policy*, 2010, 38: 3318-3329.

g Otherwise there is no quantification of effective impact on reducing crime or reducing animal attacks; surveys collect only anecdotal evidence or try to quantify perception of safety (sense of safety which can be as important for well-being and improved social relations as objective data).

h For instance Khandker Barnes SD, Samad H. Welfare Impacts of Rural Electrification. A Case Study from Bangladesh Policy Research Working Paper 4859, World Bank, Washington DC, 2009.

i UNEP – CCAC (2014) Scientific advisory panel briefing: kerosene lamps & slcps and[62 (p. 11)].

j Furthermore, households with SHS tend to be wealthier than the ones without SHS as noted by Komatsu S, Kaneko S, Shrestha R, Ghosh P. Non-income factors behind the purchase decisions of solar home systems in rural Bangladesh. *Energy for Sustainable Development,* 2011, 15, p. 286 or Bensch.[7] Household heads may also be more educated;[7] notably bigger SHS are more likely to be found in households where at least one female member has primary education as noted by Asaduszaman.[4 (p. 59)] This has an initial impact on the education of children and on health which needs to be isolated from the one specific to SHS.

Acknowledgements

I would like to thank three anonymous peer-reviewers for their useful comments. This paper has been proofread by Mr Daniel Kerr and by Ms Nandi Mbazima. It has been initiated during a small scoping review for the UK Department for International Development (DFID) and written during the course of research projects co-funded by UK aid from the UK Department for International Development (DFID), the Engineering & Physical Science Research Council (EPSRC) and the Department for Energy & Climate Change (DECC).

Appendix 1

Type of systems

SPL: Solar Portable Lanterns (includes Solar Portable Kits)
SHS: Solar Home Systems
MG: Mini-grids
RET: Renewable Energy Technologies

Type of documents

R: Report	J: Academic journal	WP: Working paper
D: Dissertation	P: Proceedings conference	NA: Not analysed
PPT: PowerPoint		

Topics

G: Gender	E: Education	H: Health & safety

I: Increased income generation / Productive use
S: Increased savings / Cost savings (of kerosene)
DZ: Differentiated impact size of system
C: Communication / Social connectivity (information, social relations)

Classification of documents

Quantitative measure of concrete impact on households
QT1 above 80 HHs with solar QT2 less than 80 HHs with solar
In bold when quantitative impact QT1 with exploitable results – otherwise standard fonts

Qualitative data (perception/satisfaction/change) on the impact of solar
QP1 above 20 interviews QP2 less than 20 interviews

Secondary research *LR Literature review in italic fonts*
Most papers include a literature review – only the ones which include mainly a literature review are marked LR

Topics in brackets () when QP1/2 or LR; or brackets [] when QT2; or {} when QT1 with non-exploitable results (i.e. not enough details, no split between SHS and other RETs, non-impact survey) / non- rigorous surveys (e.g. no baseline survey)

When a document:
- refers to the same survey but with a different analysis: this is mentioned in the column “Continent/country (year of survey)”
- is the same version with just a new format of a previous one, this is mentioned in the column “Classification”

Author	**Type of systems**	**Year of publication**	**Type of doc**	**Continent/country (year of survey)**	**Topics**	**Classification** QT1 except when otherwise stated
Adkins[1]	SPL	2010	J	Malawi (2008)	(S)	54 HH with a LED lantern, 43 without = QT 2
Alstone[2]	SPL	2011	R	Ethiopia, Ghana, Kenya, Tanzania, and Zambia (2008)	{G H}	5,000 HH; 2,500 small enterprises = marketing survey
Arraiz[3]	**SHS**	**2015**	**R**	**LAC – Peru (2013)**	**G E H I S**	**1,320 HH**
Asaduzzaman[4]	**SHS**	**2013**	**R**	**Bangladesh (2012)**	**G E H S (C DZ)**	**4,000 HH**
Azimoh[5]	SHS	2015	J	South Africa (2013)	(E I S)	88 interviews HH in 7 villages = QP1
Bensch[6]	**SHS**	**2012**	**R**	**Senegal (2009)**	**G; E; security**	**82 treated HH with solar and 81 HH in control group**
Bensch[7]	**SHS**	**2013**	**R**	**Burkina Faso (2010; 2012)**	**G E (H) S C**	**1,100 HH semi-structured interviews**
Bensch[8]	SHS	2013	‘	‘	‘	See Bensch, 2012 on Senegal
Bensch[9]	SHS	2015	‘	‘	‘	Printed version of Bensch 2013 on Burkina Faso
Biswas[10]	Solar	2004	J	Bangladesh (?)	(I)	No indications
Blunck[11]	**SHS**	**2017**	**D**	**Bangladesh (2006)**	(G H I C) **E S**	**178 interviews = QT1**/QP1
Bond[12]	SHS; SPL	2010	J	East-Timor (2007)	(DZ)	76 interviews = QP1
Bond[13]	**SHS**	**2012**	**J**	**East Timor (2007?)**	**(G) DZ**	**Participatory evaluation 400 users**
Buragohain[14]	**MG; SHS**	**2012**	**J**	**India (2008; 2010)**	**{G E H I} S**	**10,000 HH**
Chakrabarty[15]	SHS	2011	J	Bangladesh (n/a)	(I S)	6 cases = 6 HH =QP2
Chamania[16]	**SPL**	**2015**	**J**	**India (2012; 2013)**	**S {H}**	**Users of 670 LED lamps, and 372 solar lamps**
Collings[17]	SHS	2016	R	Rwanda (2011)	(E H I S)	177 interviews = QP2
Cornelissen[18]	*RET*	*2013*	*R*	*Global South*	*(E H I S C)*	*LR*
Denizart[19]	SHS	2016	R	Cambodia (?)	{E H S}	112 HH
Djamin[20]	SHS	2001	J	Indonesia (n/a)	(I)	One pilot project
Djamin[21]	SHS	2002	P	Indonesia (2001)	{S}	175 questionnaires
D.Light[22]	**SPL**	**2015**	**R**	**Uganda (2014)**	**(I) S H**	**494 with SL + 1,483 HH without SL**
Eckley[23]	SPL	2014	R	Kenya, Malawi, Tanzania and Zambia (2014)	(E S)	Small number of interviews = QP2
Esper[24]	SPL	2013	R	Kenya, Tanzania (2012-13)	(E)	19 interviews = QP2
Furukawa[25]	SPL	2012	‘	‘	‘	First draft of 2013
Furukawa[26]	**SPL**	**2013**	**D**	**Uganda (2011)**	**G E H**	**155 upper primary school students +**

						26 + 26 siblings of students
Gengnagel[27]	SPL	2013	R	Tanzania (2012)	(S I)	113 individuals in 21 interviews
Goras[28]	MG; SHS	2016	D	Kenya (2016?)	(G E H)	Case studies – 8 interviews = QP2
Grimm[29]	**SPL**	**2013**	**R**	**Rwanda (2011-12)**	**H S C**	**300 HH (150 with pico-PV kit; 150 control group) for RCT and 66 real users survey**
Grimm[30]	**SPL**	**2015**	**R**	**Rwanda (2011-12) = refer to same sample as Grimm, 2013**	**G E (H) S**	**300 HH (150 with pico-PV kit; 150 control group) for RCT**
Gubbins[31]	SPL	2011	R	Indonesia (2011)	(E H S)	43 HH; 62 respondents = QP 2
Gubbins	SPL	2012	‘	‘	‘	See Gubbins 2011
Gustavsson[32]	SHS	2004	J	Zambia (2001; 2002) 3 solar companies Nyimba, Chipata, Lundazi	{E}	400 systems + neighbours = 640 questionnaires
Gustavsson[33]	SHS	2004	J	Zambia (2001) 1 solar company Nyimba	(E)	92 clients = QP1
Gustavsson[34]	**SHS**	**2007**	**J**	**Zambia (2001; 2002)** 3 solar companies Nyimba, Chipata, Lundazi	**E**	**406 systems – questionnaires 269 HH with solar + 114 neighbours + 49 potential clients**
Gustavsson[35]	SHS	2007	J	Zambia (2001; 2002) 1 solar company Lundazi	(E)	Two surveys 31 then 152 systems
Gustavsson[36]	**SHS**	**2008**	**J**	**Zambia (2001-2002)**	**E (I)**	**406 systems - PhD thesis binding previous articles**
Halder[37]	SHS	2015	J	Bangladesh (?)	(G E I S)	6 case studies = QP2
Harish[38]	SPL; SHS	2013	J	India (2011)	(S)	66 HH from 10 villages = QP1
Harrison[39]	*SPL; SHS*	*2016*	*R*	*Africa*	*(E H I S C)*	*LR*
Harun[40]	SHS	2015	D	Bangladesh (2015?)	(E H I S C)	90 HH = QP1
Hoque[41]	SHS	2015	J	Bangladesh (2011-12; 2013)	(S I C DZ)	102 micro-utility = QP1
Islam[42]	SHS	2013	J	Bangladesh (?)	(I S)	6 cases = 6 HH = QP2
Issa[43]	SPL	2017	R	Niger (2016)	(E H)	20 beneficiaries out of 250 HH
Jacobson[44]	*SHS*	*2004*	*D*	*Kenya*	*(G E S I C)*	*Quotation of various surveys*
Jacobson[45]	*SHS*	*2005*	*WP*	*Kenya*	*(E S C)*	*LR*
Jacobson[46]	SHS	2007	J	Kenya (2002-2003)	{E I C}	1,512 HH + 1,755 HH
Jewaro[47]	SPL	2017	R	Ethiopia (2017)	{E}	500 HH - Focus group discussion with 228 students and 98 parents

Kent[48]	SHS	2014	R	Uganda (2014)	[E]	8 schools 72 children = QT2
Khan[49]	SHS	2014	J	Bangladesh (2012?)	(G E)	25 HH + 8 grocery stores = QP1
Khandker[50]	**SHS**	**2014**	**R**	**Bangladesh (2012)**	**G E S H**	**Econometric modelling + cases studies = 4,000 HH**
Komatsu[51]	**SHS**	**2011**	**J**	**Bangladesh (2009)**	**(E) S C DZ**	**304 HH**
Komatsu[52]	SHS	2013	J	Bangladesh (2009)	(E S C)	305 HH
Kudo[53]	**SPL**	**2015**	**WP**	**Bangladesh (2013-14)**	**E S H**	**1,292 HH**
Kurschner[54]	SHS	2009	R	Bangladesh (2009?)	(E H I S C)	260 HH = QP1
Lam[55]	SPL	2017	R	Kenya (?)	(H)	20 HH = QP2
Laufer[56]	SHS	2011	J	Sri Lanka (2008)	(I)	40 HH = QP1
Lemsomboon[57]	SHS	2011	J	Thailand (2010)	(S)	17 experts = QP2
Mair[58]	SPL	2009	D	Kenya (2009)	(E H I S C)	118 interviews + 8 qualitative interviews = QP1
Mala[59]	SHS	2009	J	Kiribati (2006)	(I)	43 HH = QP1
McCarney[60]		2013	J	Africa (various)	{S}	Cost comparison refrigerators
Mehta[61]	--	2004	NA	India	--	--
Mills[62]	*SPL*	*2014*	*J*	*Tanzania (2012)*	*(S H)*	*113 interviews; 48 + 73 trials = QP1*
Mills[63]	*SPL*	*2014*	*R*	*Global South*	*(H)*	*LR*
Mills[64]	*SPL*	*2014*	*R*	*Global South*	*(H S)*	*LR + field test*
Mills[65]	*SPL*	*2016*	*J*	*Global South*	*(I)*	*LR + model*
Mishra[66]	SHS	2016	J	India (?)	(G E H S) C	Focus group discussion = QP2
Mleczko[67]	**SPL**	**2015**	**D**	**Haiti (2014)**	**E**	**2 schools – 100 solar lanterns**
Mondal[68]		2009	NA	--	--	--
Mondal[69]	SHS	2010	J	Bangladesh (2004)	(S I)	Six case study = QP2
Mondal[70]	--	2010	NA	--	--	--
Mondal[71]	SHS	2011	J	Bangladesh (2004-05)	[E S I]	56 HH – 10 micro enterprises = QT2
Monjur[72]	SHS	2015	D	Bangladesh (?)	[S]	52 HH – 6 cases studies = QT2
Naah[73]	SHS	2015	J	Ghana (2011)	{E H}	250 HH and rural clinics
Naah[74]	SHS	2015	J	Ghana (2011) same sample as previous	{I S H C}	250 HH and rural clinics
Narasimha[75]	SHS, MG, RET	2016	R	India, Nepal (2016?)	(G E H I S)	LR + 98 HH with SHS surveyed = QP1 (part of a large survey on RET)
Nieuwenhout[76]	SHS	2000	R	Global South	(E H I S C)	Small LR previous 2000
Obeng[77]	**SHS**	**2008**	**J**	**Ghana (2005-06)**	**S**	**96 HH electrified and 113 HH non-electrified**
Obeng[78]	--	2008	NA	Ghana	--	--
Obeng[79]	**SHS**	**2008**	**J**	**Ghana (same as Obeng, 2008)**	**H**	**96 HH electrified and 113 HH non-electrified**
Obeng[80]	*SHS*	*2009*	*WP*	*Global South/Ghana*	*(E H)*	*LR*

Obeng[81]	SHS	2010	J	Ghana (2005-06)	[S I]	50 micro-enterprises = QT2
Peters[82]	*SHS*	*2014*	*WP*	*Benin, Burkina Faso, Indonesia, Rwanda, Senegal, Uganda, Zambia*	*E I S*	*LR + different surveys on SHS*
Peters[83]	SHS	2015	WP	‘	‘	LR + different surveys on SHS. See Peters, 2014
Pricewaterhousecooper[84]	MG; SHS	2013	R	Mali, Uganda, South Africa (2012-13)	{E H I S C}	849 interviews = QP1/QT1
Pueyo[85]	*RET*	*2013*	*WP*	*Global South*	*(G E H I)*	*LR (but for all RET)*
Radecsky[86]	SPL	2008	R	Kenya (2008?)	S I	50 small businesses
Rahman[87]	*SHS*	*2013*	*J*	*Bangladesh*	*(E H I S C)*	*LR*
Rajeshwari[88]	SPL	2015	PPT	India (2015-16)	[H]	50 HH = QT2
Rao[89]	SHS	2015	P	India, Nepal (2016?) same sample as Narasimha, 2016	{G H E}	859 HH (among them 98 SHS) + 75 businesses
Reiche[90]	SPL	2010	R	Bolivia, Nicaragua, Uganda (2008-10)	(G H E) S	?
Rom[91]	**SPL**	**2017**	**R**	**Kenya (2013)**	**G S**	**1,400 HH**
Samad Hussain[92]	**SHS**	**2013**	**WP**	**Bangladesh - same sample as Asaduzzaman, 2013**	**G H E I S**	**4,000 HH**
Sengendo[93]	SHS	2005	R	Uganda (?)	(G E H S I C)	102 HH = QP1
Smeets[94]	**SPL**	**2013**	**R**	**Tanzania (2011-12)**	**E**	**18 schools – 43 interviews + 309 surveys**
Smith[95]	SPL	2014	D	Liberia (2013)	(E) I	90 fishermen = QP1/QT1
Stiftung Solarenergie[96]	**SPL**	**2011**	**R**	**Philippines (2011)**	**E H S I**	**134 customers**
Stojanovski[97]	**SHS**	**2017**	**J**	**Kenya, Uganda (2013-15)**	**S I**	**500 SHS**
Svensson[98]	SHS	2010	D	Tanzania (2010?)	(S I)	37 interviews of business = QP1
Swaddiwudhipong[99]	**SHS**	**2013**	**J**	**Thailand (2012)**	**H**	**254 children screened**
Urmee[100]	SHS	2009	J	Asia (2008?)	(E H S C)	27 organisations in charge PV programs = QP1
Wamukonya[101]	SHS	1999	WP	‘	‘	See Wamukonya, 2001
Wamukonya[102]	**SHS**	**2001**	**J**	**Namibia (1998)**	**S (E H)**	**371 HH**
Wang[103]	**SHS**	**2011**	**WP**	**Bangladesh (2005)**	**S**	**1,000 HH with solar**
Wijayatunga[104]	**SHS**	**2005**	**J**	**Ski Lanka (?)**	**S**	**125 HH**
World Bank[105]	SHS	2014	R	Mongolia (2012)	(E H S I C)	800 HH + 12 interviews = QT1/QP2
Yakhnis[106]	*SHS*	*2015*	*D*	*Tanzania*		*LR for future RCT*
Yarime[107]	**SPL**	**2015**	**P**	**Kenya (2010)**	**S E H**	**209 HH**
Zahnd[108]	SHS	2009	J	Nepal	(S E H)	Preliminary survey

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