A Review of Small Off-Grid Electricity Systems

Chris Moller, The Open University, Milton Keynes, UK.

Results of a small-scale Internet survey undertaken in May-June 2016, covering Small Off-Grid Electricity Systems

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Abstract

An online survey was undertaken in May-July 2016, to identify technical aspects of Small Off-Grid Electricity Systems being installed in the Developing World, with a view to identifying open issues, and in particular the need for standardisation.

The sample is relatively small, and there may be scope to re-run the survey with a wider response base, to make it more representative of the sector as a whole.

The work was carried out under the auspices of the Open University, as part of a one-year Research Visitorship.

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1. Scope of the survey

Information about the survey was communicated to Small Electricity System (SES) project managers and NGOs active in the field worldwide.

The survey was undertaken using SurveyMonkey, during the period 22May-10July2016.

A total of 25 responses were received. A list of projects is given in Table 1 overleaf.

If the information is considered valuable but the sample too small, there is scope to re-run the survey with greater publicity.

It may also be possible to generate more responses by studying the websites of other SES projects.

1.1 Definitions

Project – Each Respondent replied for a particular project. A project will typically install a number of systems to the same technical standard in different locations. Two organisations replied twice, for different projects that they are running.

System – A geographically localised solution to the provision of electricity, comprising energy source(s), transmission, control and serving one or more households within a small community. A system may serve a single isolated household, or interconnect several up to several hundred. (A solution in which each house has an electricity supply that can act in isolation, but which can also sell electricity to neighbouring households because they are close by and all operate to the same standard is considered a single system.)

Household – A family unit with a single individual bill payer. Usually, a household will be a single building, perhaps with several rooms used for different purposes.

1.2 Which systems are included?

The acronym SHS usually stands for a "Solar Home System" – comprising a small roof-mounted solar panel, wiring down to a system controller located indoors, to which are connected a number of LED lamps, a mobile phone charging socket, and perhaps a TV. However, in this report, we use the acronym SES (Small Electricity System) to include all off-grid electricity systems up to systems shared between a few houses, regardless of whether the systems relies on solar panels or some other source or combination of energy sources. Systems that include a connection to an intermittent national grid or a petrol/diesel generator in addition to a renewable energy source are also included.

As the focus is on how the electricity is used, the survey would be valid if all small-scale unconventional electricity systems were included.

1.3 Methodology

Respondents were asked how many systems have been, or are planned to be, installed and how many households are connected on average to each system. These two figures were multiplied together to give a total number of households for each project. This is obviously an approximation, and if the survey is re-run, it may be necessary to be more rigorous about this.

1.4 Presentation of results

In presenting the results, sometimes we indicate the number of projects that gave a particular answer, sometimes, we give a percentage of the total number of systems our respondents have installed or intend to install in the immediate future, and where the information relates to the way individual households behave, we multiply the number of systems by the average number of households each system supports.

2. The Projects

The projects reported vary considerably in size – from one or two systems through to tens of thousands.

Name	Location	# of systems	Average Households per system	Assumed total # of households
Kenfack	Cameroon	3	10	30
BBOXX	Multiple sub-Saharan countries	55,000	1	55,000
BBOXX PAYG	Multiple sub-Saharan countries	15,000	1	15,000
Mobisol	Multiple sub-Saharan countries	52,000	1	52,000
EnDevSHS	Honduras	5,850	1	5,850
SHS	Nicaragua	4,000	1	4,000
CEFA	Tanzania	0	0	0
Kalanzi	Uganda	50	1	50
MHP	Ethiopia	34	100	3,400
Solano	Afghanistan	4	50	200
Tessa Power	Niger	300	200	60,000
Desolcon	Colombia	2	16	32
Sandhya	India	10,000	1	10,000
SolarWorks	Multiple sub-Saharan countries	2,000	1	2,000
Solarsklar	Multiple continents	127	1	127
Devergy	Tanzania	12	150	1,800
BakuluPower A	Uganda	4	300	1,200
Swarm Electrification	Bangladesh	250	1	250
GoSolarAfrica	Nigeria	4	56	224
ESM Power RE	Multiple sub-Saharan countries	2,000	1	2,000
SOLShare	Bangladesh	250	20	5,000
Mera Gao Power	India	1,800	15	27,000
MeshPower	Multiple continents	40	22	880
BakuluPower B	Uganda	3	100	300
Wasini	Kenya	2	1	2
Totals		**148,735**		**246,345**

Table 1 - Projects and Countries covered by the survey

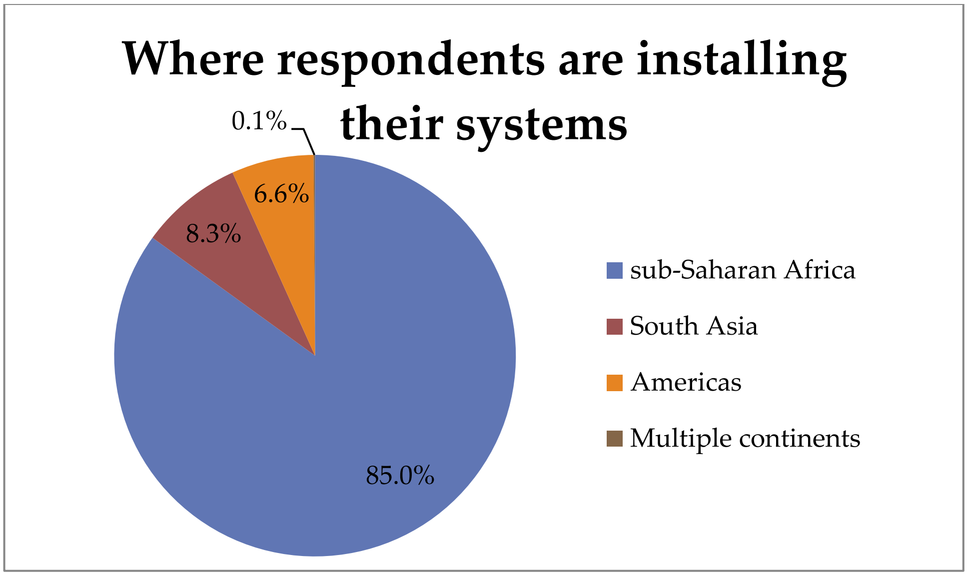

Figure 1 – Total planned or actual systems deployed by respondents by region

We were interested to know where the electronic component of the systems was manufactured. Figure 2 shows this by numbers of units. (We should perhaps have asked in which country the design authority for the system controller resides – that would have given a rather different picture.)

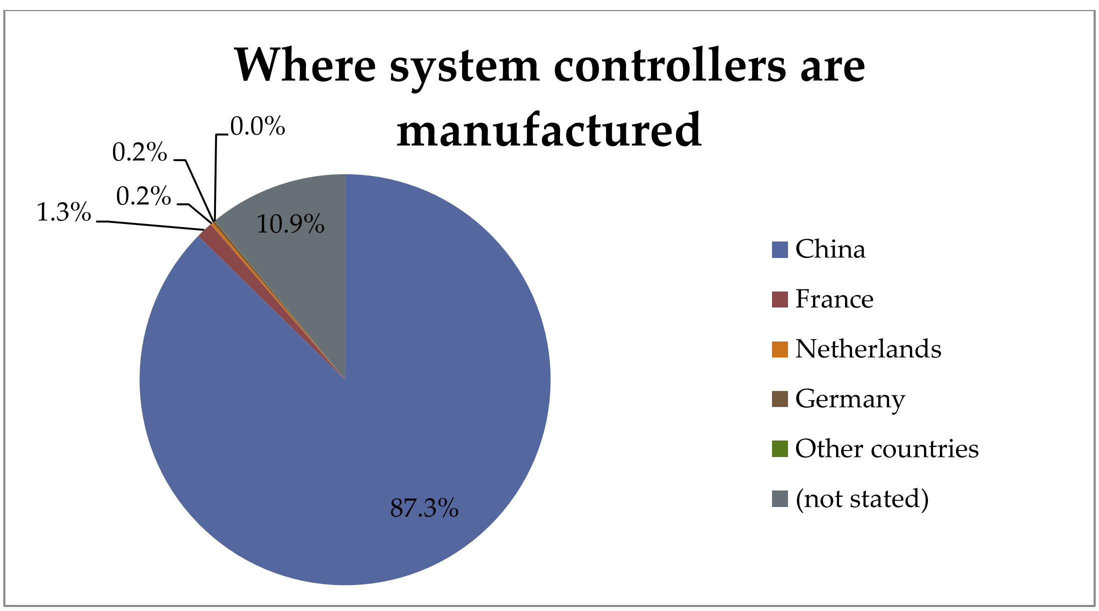

Figure 2- Countries where respondents' systems were manufactured

3. Purpose of SES

It is frequently assumed that the priority application for low-power electricity sources is domestic, but several projects reported multiple uses. The 25 respondents reported the following applications:

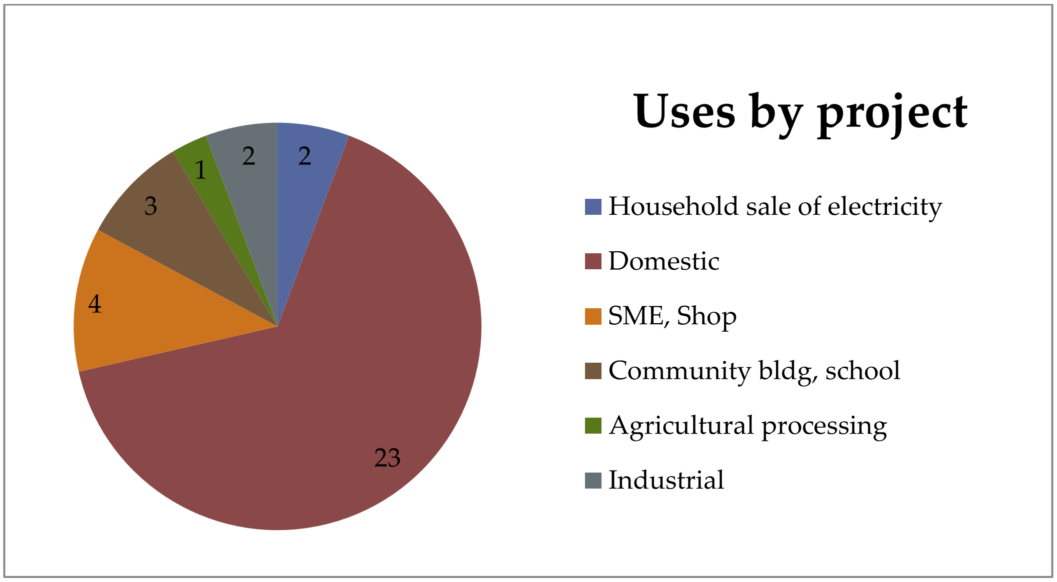

Figure 3 - Purposes to which projects are applying SES systems (NB. Each project may serve more than one purpose)

However, when weighted to account for the number of systems being installed by each project, it is clear that the largest projects are indeed focusing on domestic applications. 99.1% of all systems serve a domestic purpose. Other applications are shown in Figure 4:

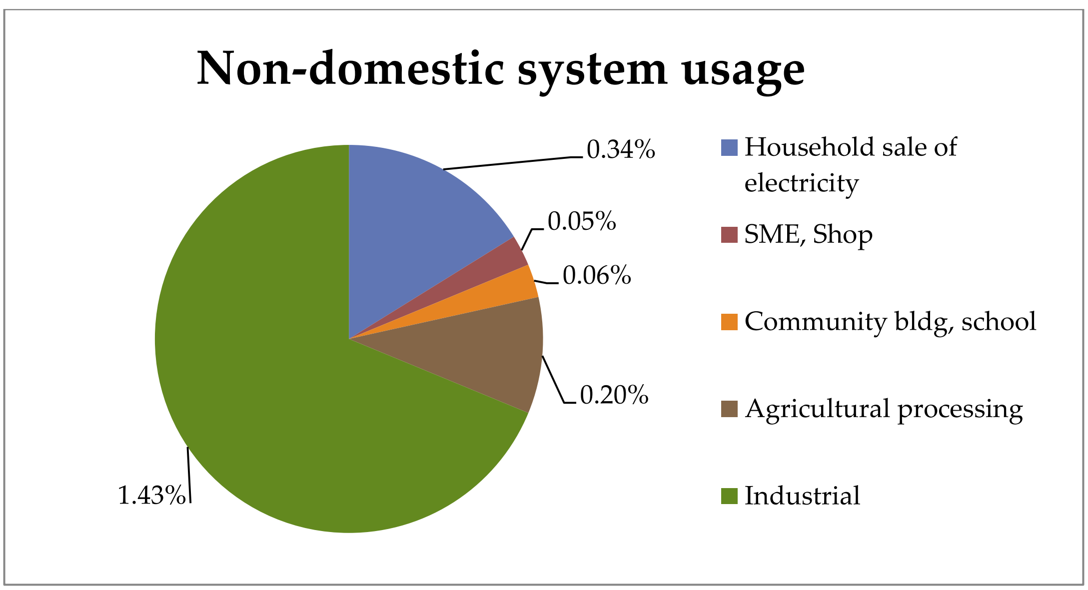

Figure 4 - Purposes to which SES systems are being applied (NB. Each system may serve more than one purpose)

The loads that are used with the respondents' SES show unexpected diversity:

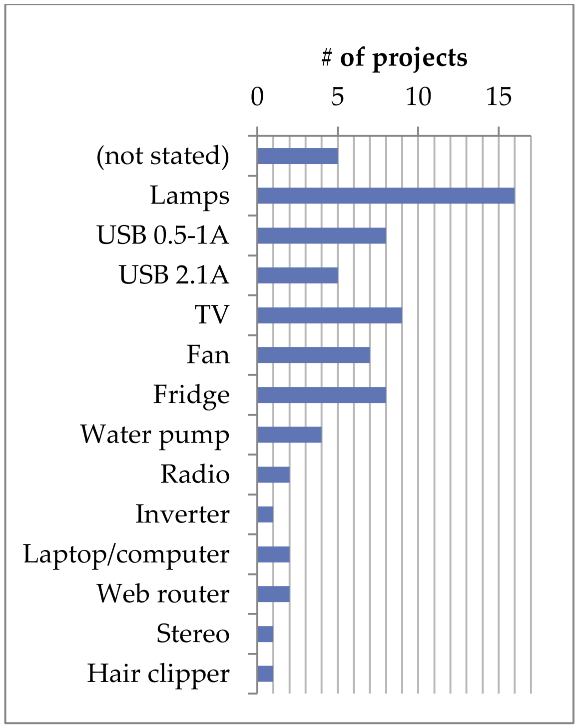

Figure 5 - Electrical load options, by project

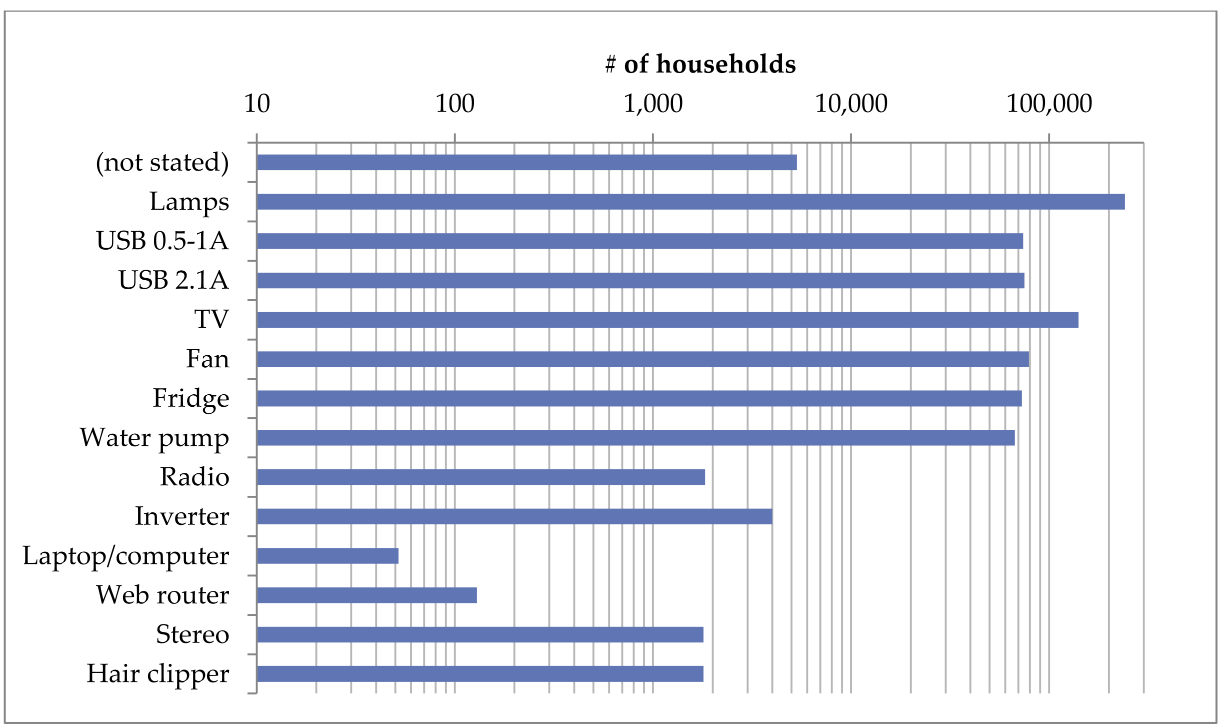

Figure 6 - Electrical load options, by total households

4. How the customer pays

Several schemes were reported – from outright purchase at one extreme, to pure Pay-As-You-Go (PAYG) equipment rental, and blended schemes in between. Figure 7 shows how this breaks down by the total number of systems installed.

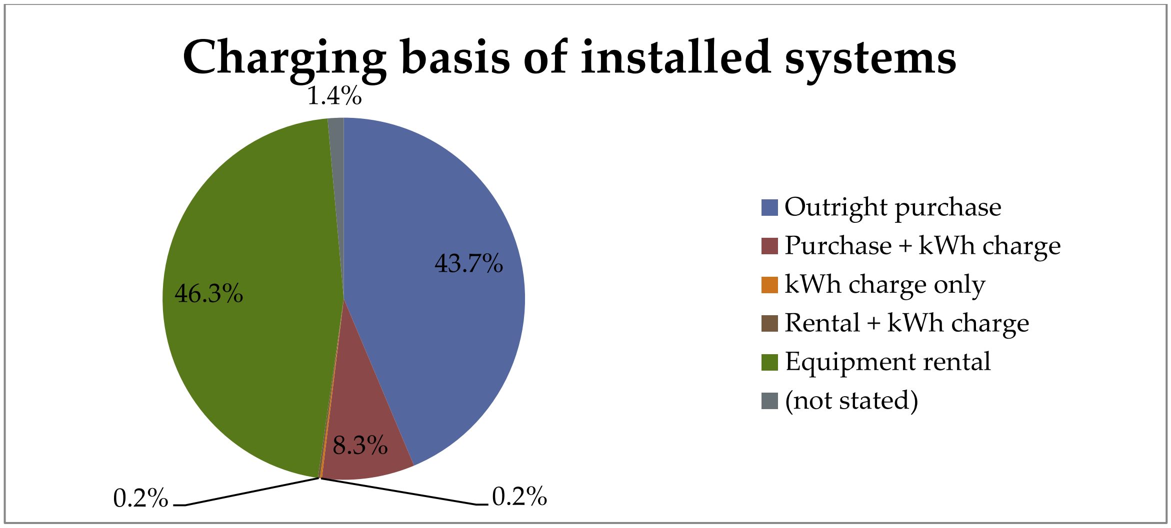

Figure 7 – Charging schemes by installed system

However, larger shared community systems show a much greater similarity with grid-based systems, where a demarcation point is defined, on the supply side of which the deal is PAYG, and on the load side, purchase. Consequently, the picture when totalled by number of households looks different - see Figure 8:

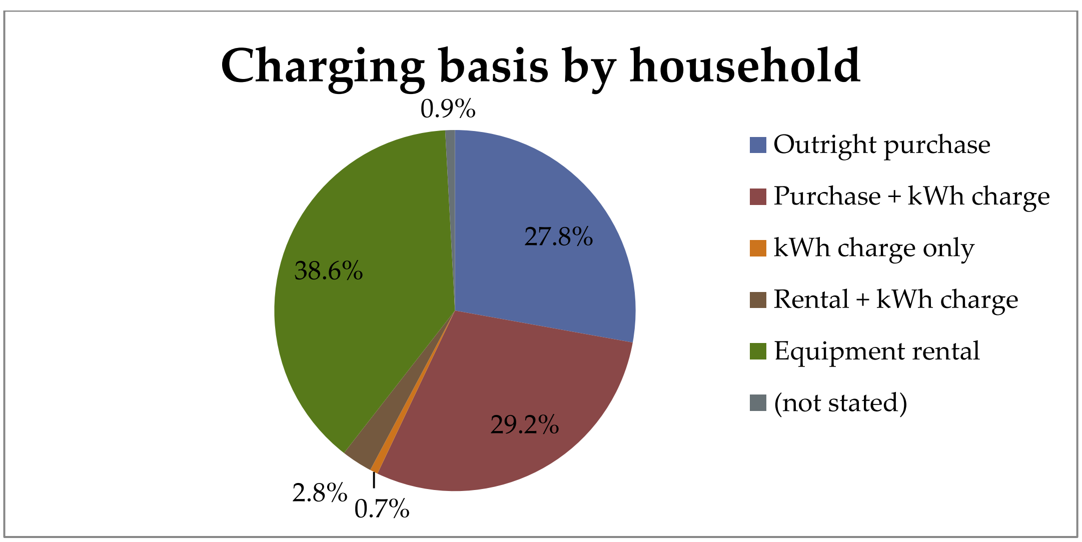

Figure 8 - Charging schemes by total households

In order to provide reassurance that the capital cost of PAYG equipment will eventually be recouped, many projects sign an agreement for a fixed term, though what happens at the end of it varies. We asked about the duration of the PAYG agreement. The projects' responses are shown in Figure 9.

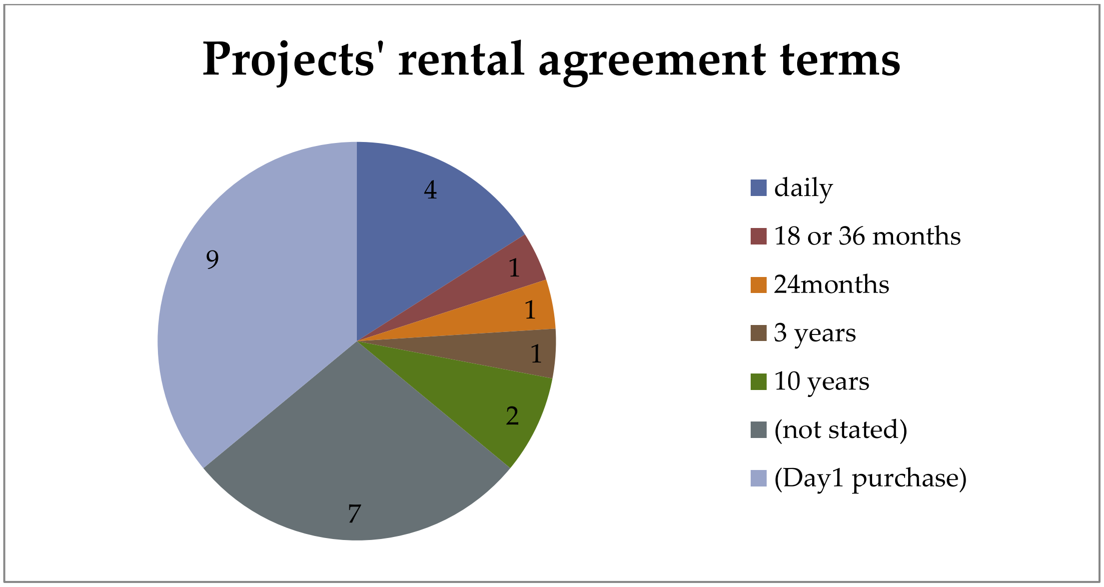

Figure 9 - PAYG Agreement Term

During the term of the agreement, the installed equipment still belongs to the provider, but there is a risk that if the consumer falls on hard times, he may sell or otherwise dispose of it. (This is particularly critical for flat-screen televisions.) Some projects are implementing technical solutions to ensure that consumer items will only work with their SES. We asked projects whether they considered this to be a problem. Three projects (all of which surprisingly were based on outright purchase or a combination of outright purchase and rental) said that this was an issue. Some projects include a remote monitoring element to mitigate this.

We asked each PAYG project whether the user gets to own the equipment (excluding any shared infrastructure or meter) at the end of the term, if their payments are up to date. The projects' answers are given in Figure 10.

It is generally viewed that eventual outright ownership is a good thing, as it rewards reliable payment and sticking with the agreement to term. However, it also gives the user absolute responsibility for the equipment at the end of the term. We did not ask whether users are putting aside money for the replacement batteries that will undoubtedly eventually be needed (we think we know the answer!) Several projects said to us that they have moved to perpetual PAYG systems, believing that they not only provide easier market entry for people of limited means, but that they are also more sustainable.

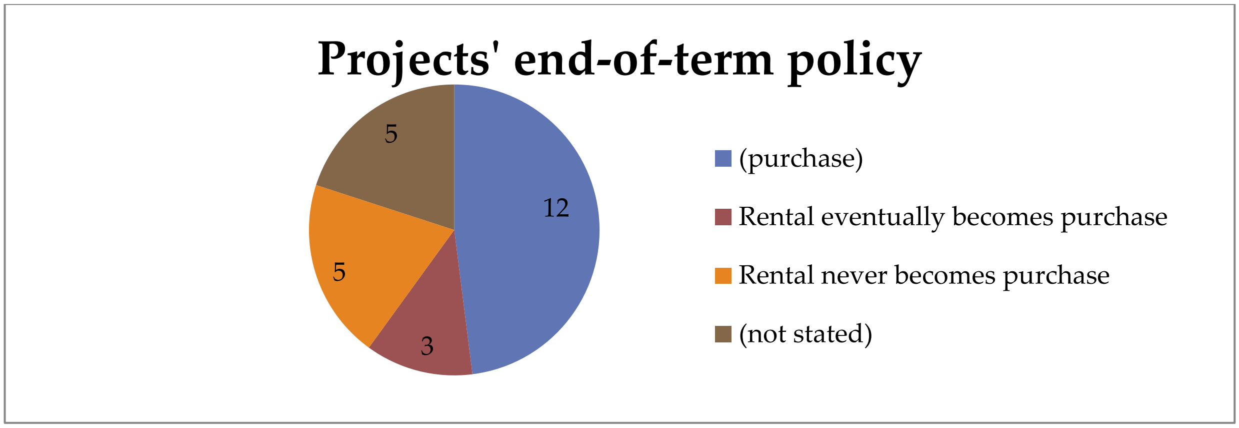

Figure 10 - Projects' end-of-term policy

We asked each project what happens if a user defaults on their payments (recognising that projects vary in how much in arrears a customer has to be, to be considered in default). The response (by number of households) was:

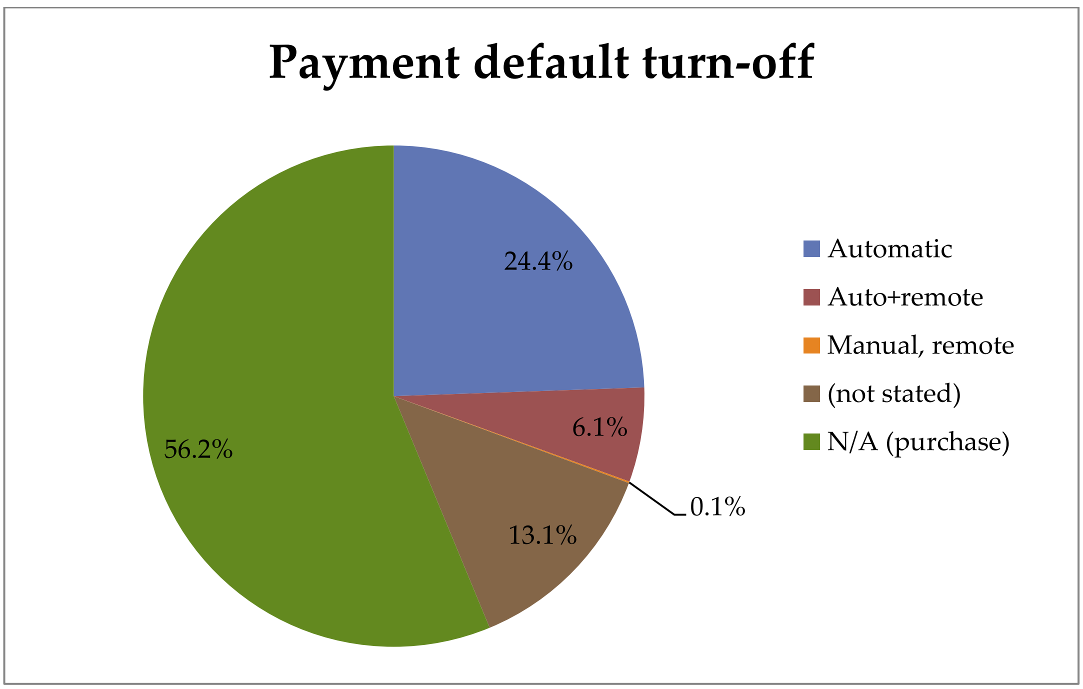

Figure 11 - PAYG Default mechanism

5. System Technical Specification

We were anxious to establish the technical parameters of the systems being installed. The respondents use a variety of energy sources:

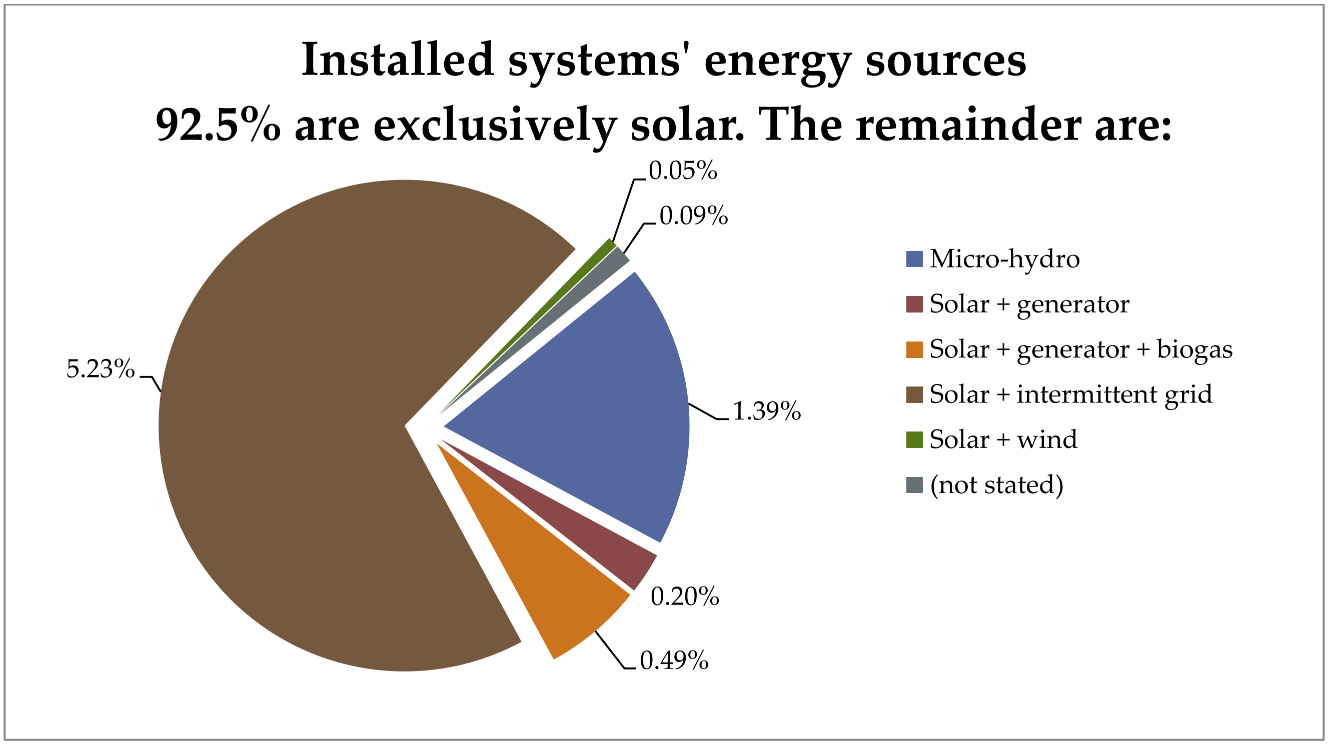

Figure 12 - Energy sources (weighted by households)

The power available to each household varied considerably between the respondents:

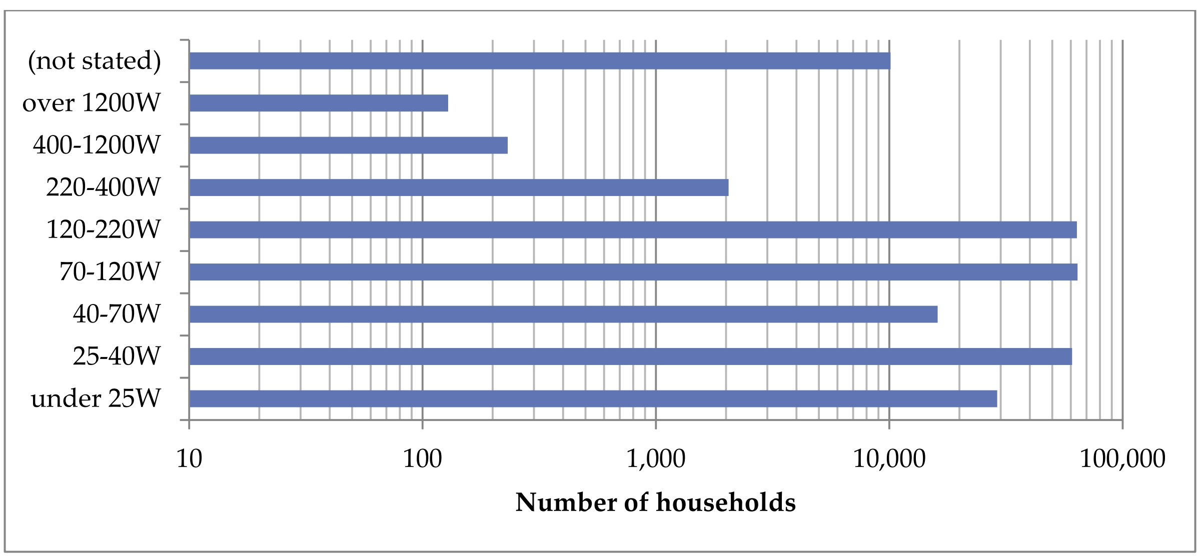

Figure 13 - Power available to each household
(some projects provide users with a choice of various power levels)

The amount of battery storage per household gave the following result:

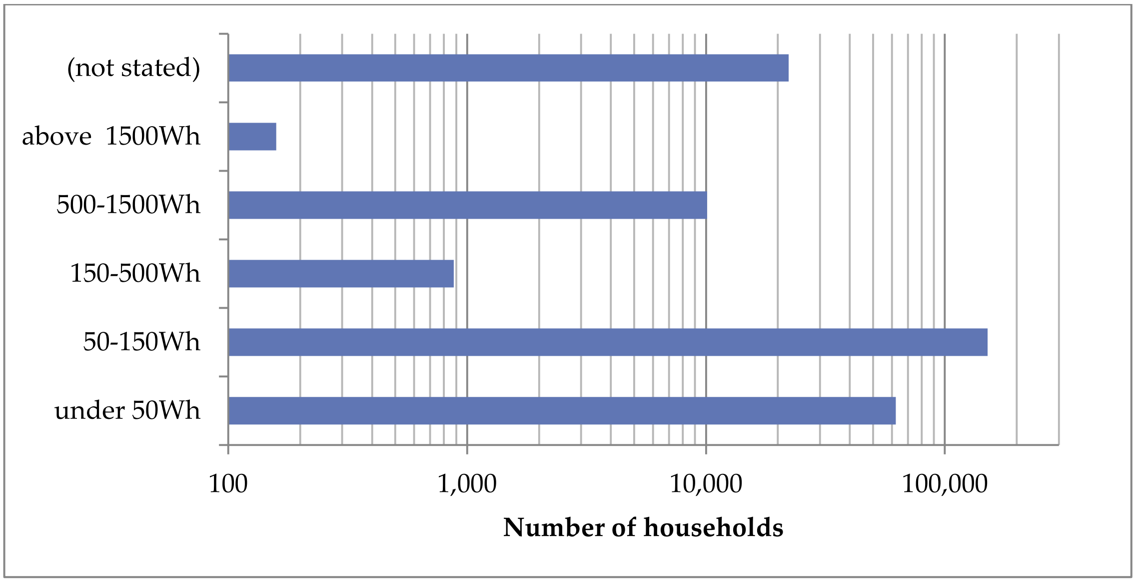

Figure 14 - Energy storage per household

(This is obviously less critical, but harder to manage, when storage is shared between several households.)

We asked what indication is provided of the amount of energy stored in the system. The projects responded:

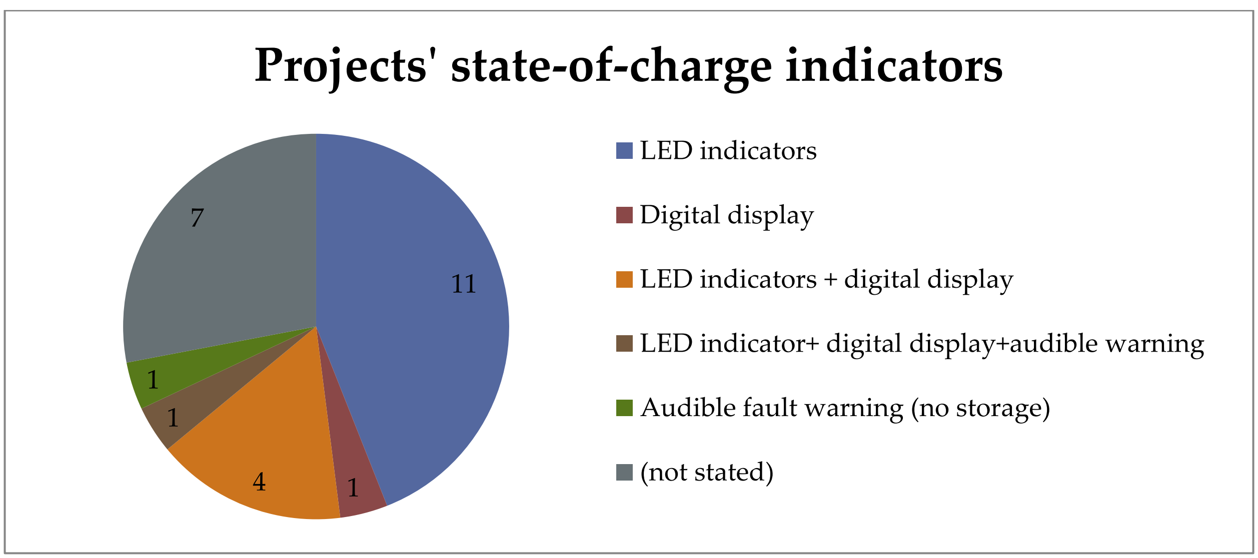

Figure 15 - Low energy warning

We also asked the projects whether any indication was provided when the batteries get old, and their amp-hour capacity gets reduced. The projects said:

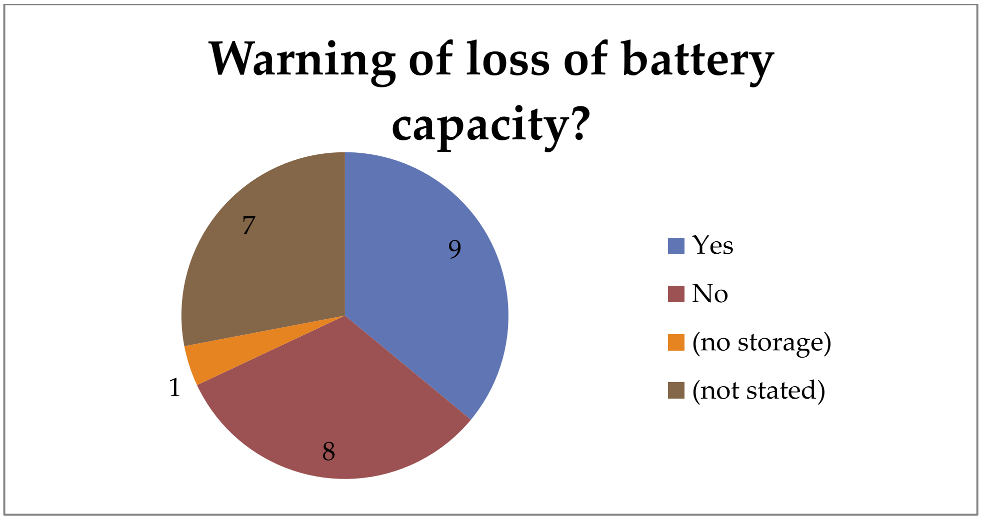

Figure 16 - Battery age warning

5.1 Users' Own Appliances

We asked each project whether users were allowed to connect their own appliances to the system. The responses were instructive!

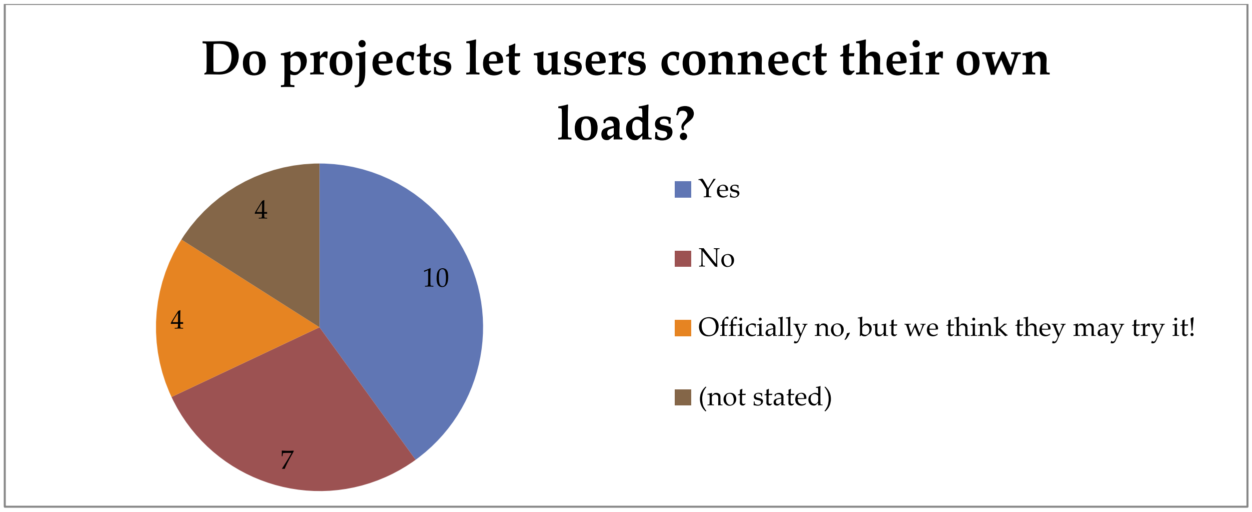

Figure 17 - Can users connect their own appliances?

5.2 DC Power Output

We asked respondents whether they provided a DC power socket (other than a 5V USB charging socket), and if they did, what voltage they provided. The projects responded with what they offer (Figure 18) which we then weighted by number of households (Figure 19).

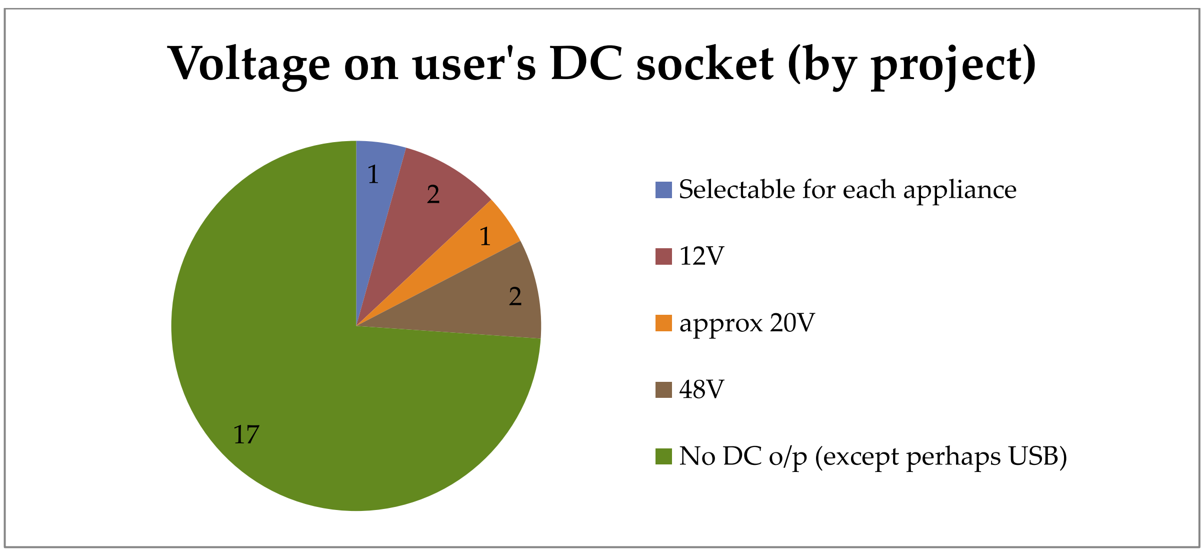

Figure 18 - DC voltages offered by projects

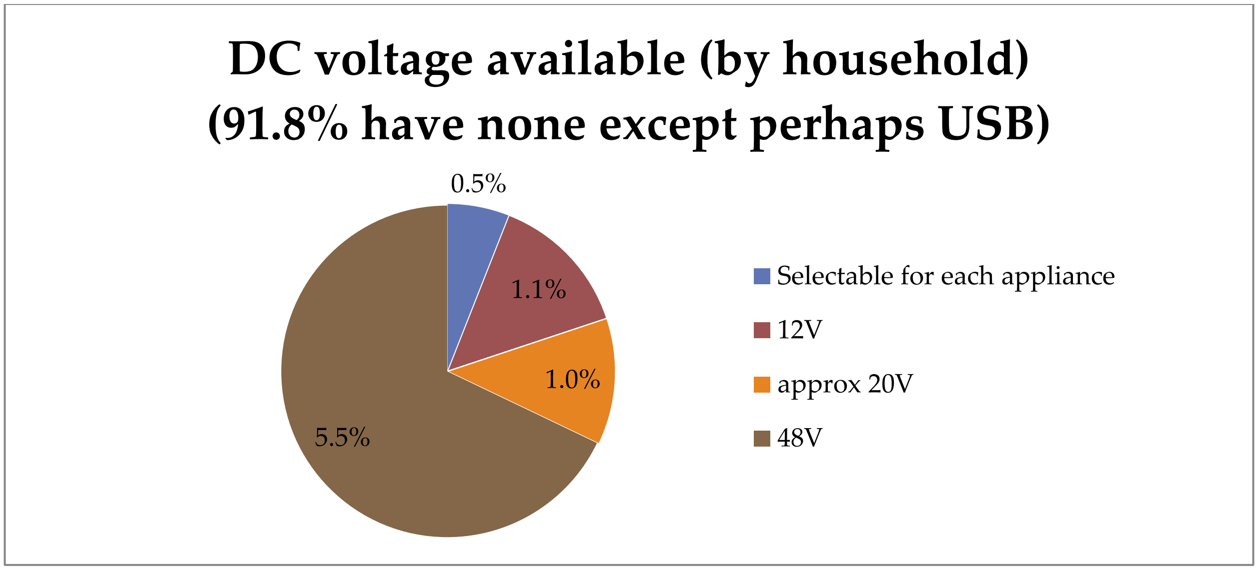

Figure 19 - Percentage of households provided with a DC socket

We asked respondents what current could be drawn from the socket. Four of the lower voltage projects responded, with 2A, 4A, 10A and 30A. Neither of the projects providing 48V answered the question.

We asked what standard of socket each project provides this DC voltage on. The two lower-current respondents used 2.5mm DC power jacks, the two higher currents car cigar lighter sockets. Neither of the projects providing 48V answered the question.

All projects providing a DC output socket said they incorporate a means of preventing the user running the battery down to flat.

We asked respondents whether they had heard of either of the emerging standards for DC power sockets for domestic applications, USB PD2.0 and Power-over-Ethernet (PoE). The results were as follows:

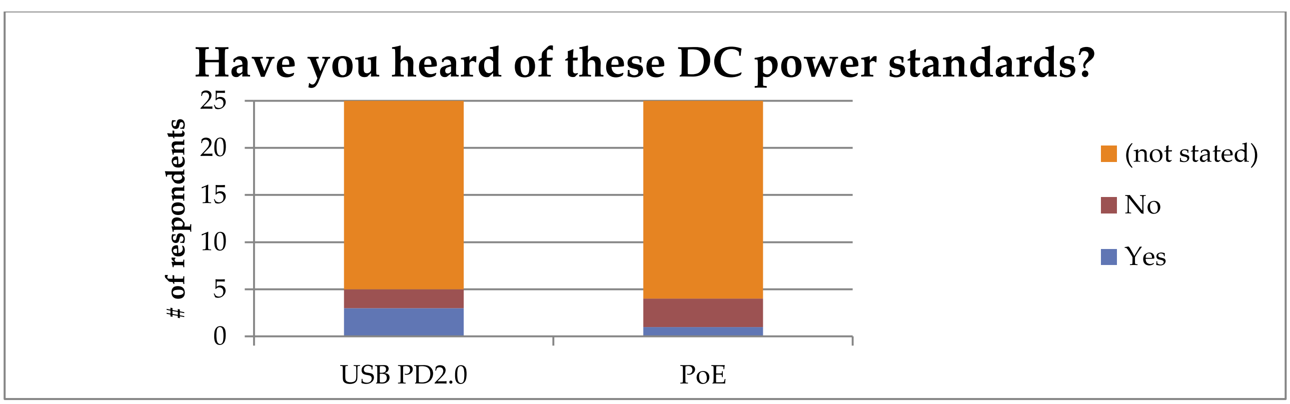

Figure 20 - Who had heard of new DC socket standards

However, those who had heard of these were very positive in their comments about them. Five of the projects (unprompted!) raised in their comments the need for standardisation.

5.3 AC Power Output

We asked respondents whether their systems could provide AC mains via an inverter, and if so, to give details. Six of the projects responded affirmatively. Their answers are given in Table 2.

# of Units	Voltage	Frequency	Watts	Socket
30	220	48	100	CEE7
60000	220	50	2000	IEC
32	120	60	360	US std
2000	220	50	100	CEE7
50	220	50	?	BS1363
2	230	50	1600	BS1363

Table 2 - AC Outputs

5.4 System Overload

We asked about the behaviour of the system in the event that the user makes a greater power demand than the system can supply. The respondents answered:

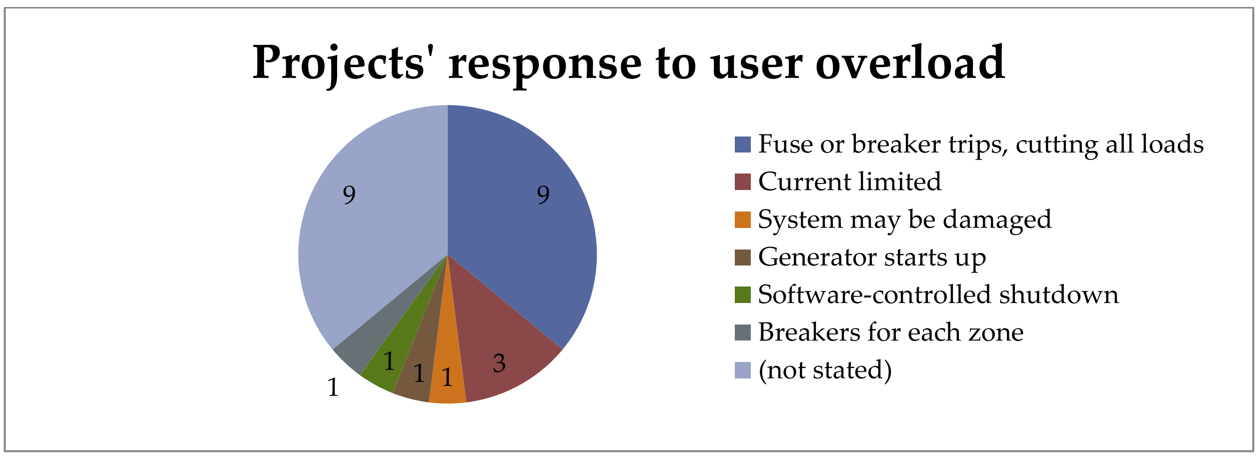

Figure 21 - System behaviour on overload

We then asked whether the users receive any training to help them understand the limitations of the system. We were told by the projects:

Figure 22 - User training about limitations

6. System installation

We were interested in the logistics of system installation – what is involved, and who does it.

We found that when weighted by the number of served households, the majority were installed in the house (and on the roof) by the respondent's own engineers:

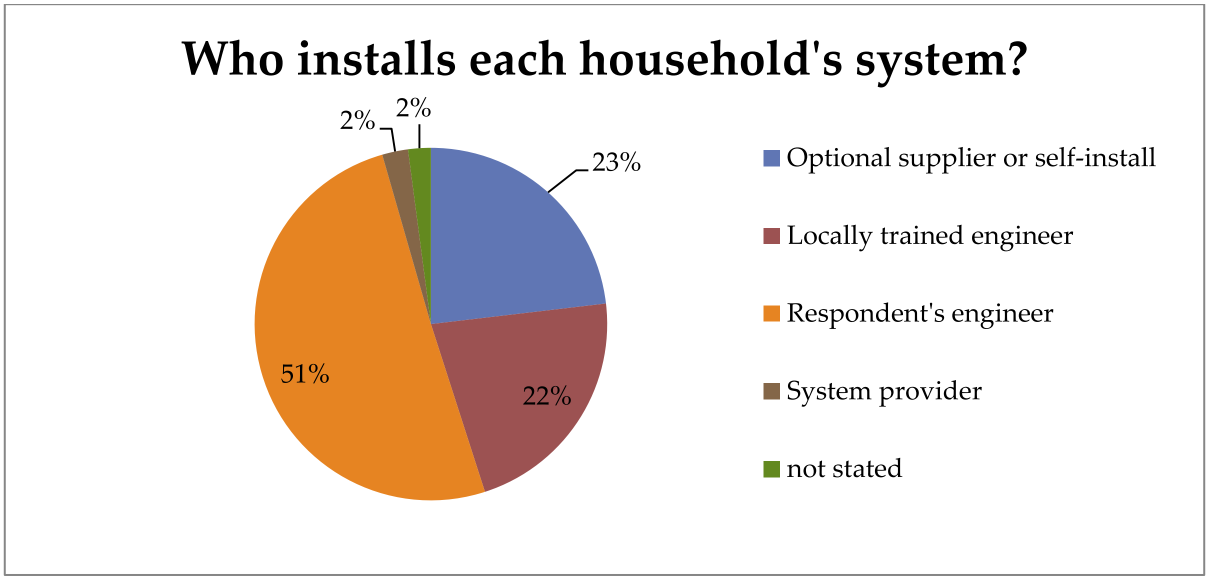

Figure 23 - Who installs the system?

It would be normal for the users to occasionally re-arrange their accommodation, and therefore need lights and other appliances moved to a different location. We therefore asked about fixed wiring to take electricity into different rooms, and whether the user could find their own electrician locally to make any necessary changes to it. The respondents said:

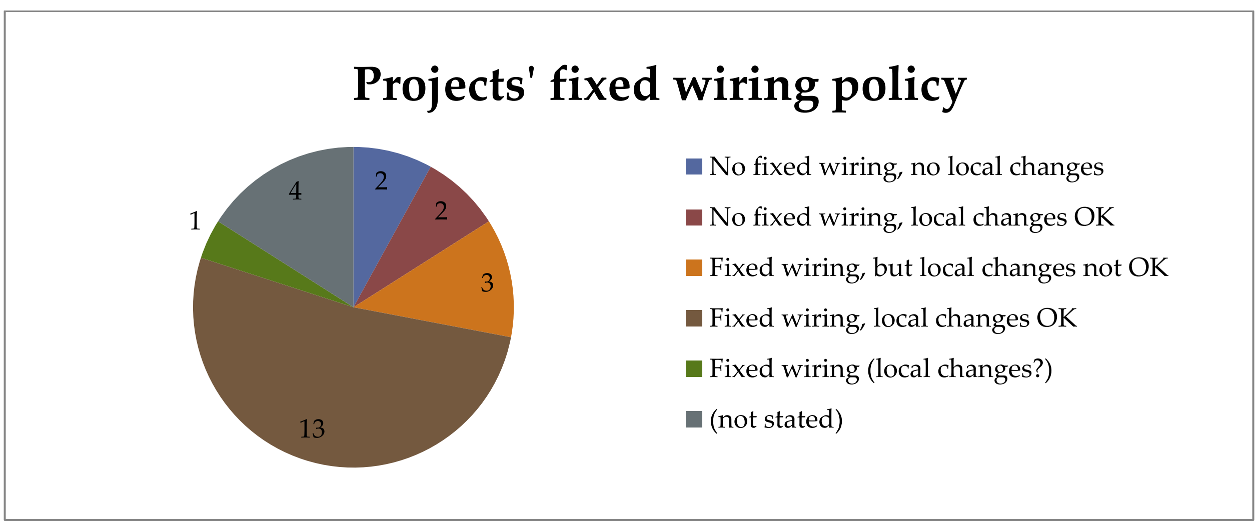

Figure 24 - Is there fixed wiring, and if so, who can change it?

7. Safety

There is an unfortunate tendency for safety to be a secondary consideration in the Developing World, but this shouldn't be the case, and we sought to find out to what extent this was true. Off-grid systems usually run at lower voltage than mains systems, so electrocution is less of a concern. However, that is not to say that there aren't other things to be concerned about.

We asked whether the user is instructed how to quickly disconnect the solar panel(s) (or shut down the turbine etc.) in the event of a fault, for example, if they see smoke coming from the controller. The respondents said:

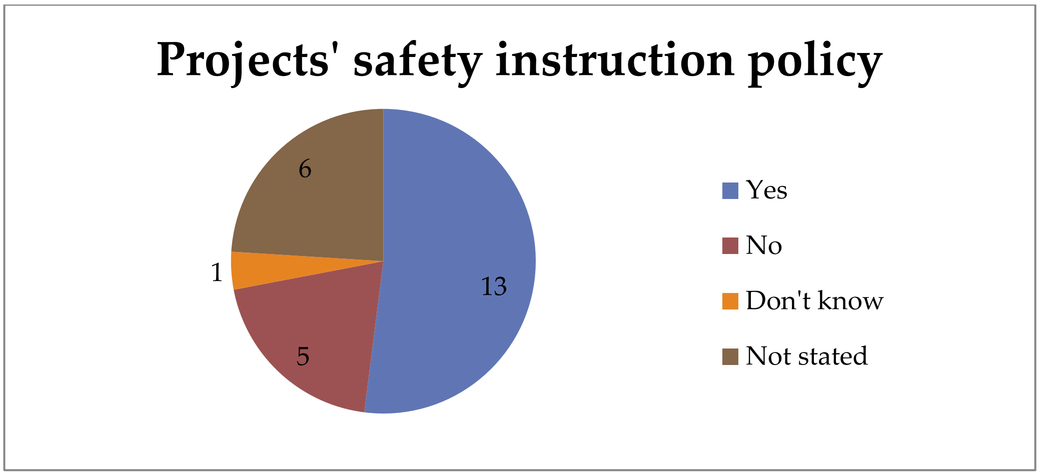

Figure 25 - User instruction for emergency shutdown?

This is somewhat concerning.

We asked about the battery technology in use. The percentages below are based on total systems.

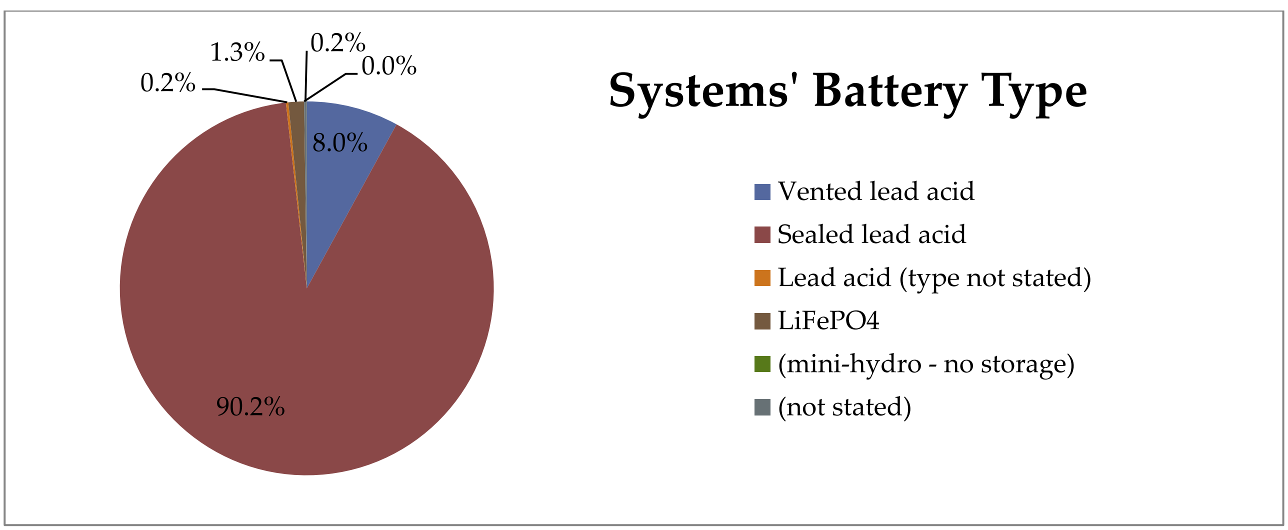

Figure 26 - Battery technology

Only four of the projects said that they provided the users with information on the issues relating to having large batteries in the house.

Many of these off-grid systems are located in regions that have relatively frequent lightning storms, and there is a real possibility of solar panels on the roof or elevated wires between houses being struck by lightning. In this event, the quality of the earthing of the system will be critical to the safety of the house. We therefore asked whether the systems were earthed to an earth rod. The respondents said:

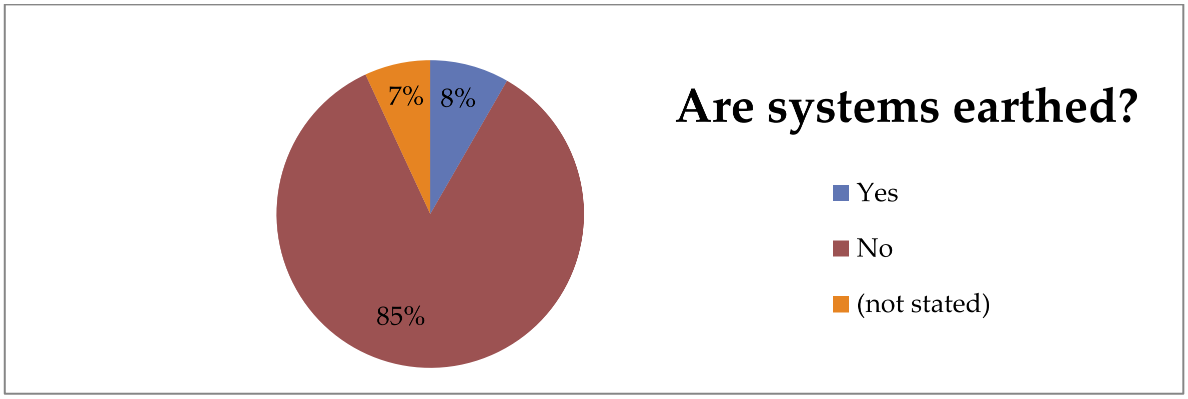

Figure 27 - Percentage of total household installations earthed

Off-grid systems do not tend to have a separate protective earth wire. There is therefore an issue with what happens to exposed metalwork on appliances used with these systems. This is especially critical when two off-grid-powered appliances are connected together by a signal cable – for example a laptop and a television. The percentage of installed systems where appliances have grounded metalwork is shown in Figure 28.

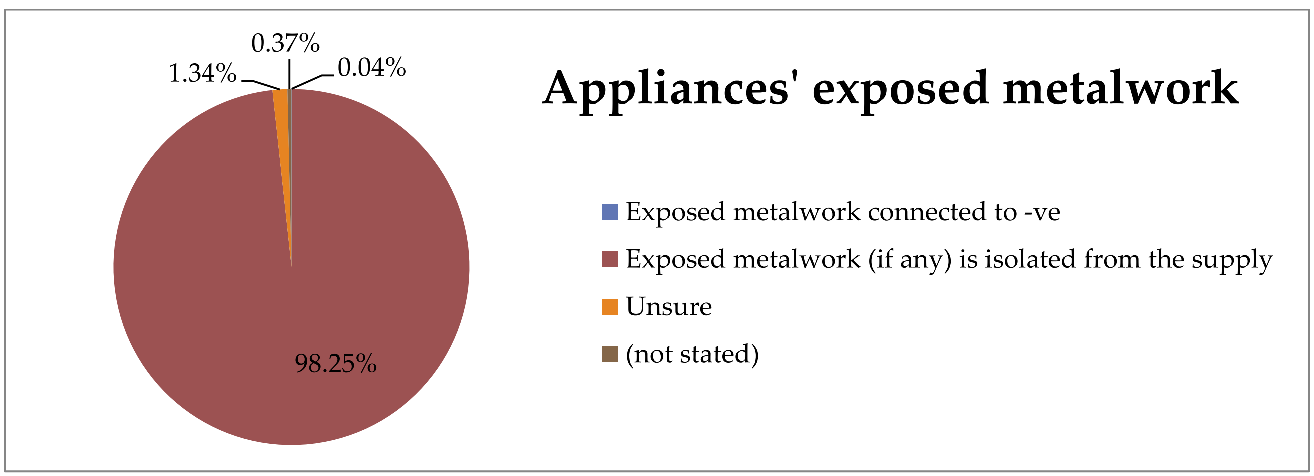

Figure 28 - Is exposed metalwork isolated?

It should be noted that most appliances designed for use in vehicles will have exposed metalwork connected to the negative terminal. ***This may render them unsuitable for use with 12V off-grid systems that need them to be fully isolated.***

8. Conclusions

This report scarcely covers a representative sample of all of the systems already in the field. However, it does indicate certain trends.

Today, there are many different approaches to the implementation of small off-grid electricity systems and the loads to connect to them. It is clear that these provide much less flexibility in the way electricity is used than grid-based systems:

- None of the systems permits the user to take the supply of electricity for granted, in the way grid users can. Users must always remain conscious of the limitations of their system – though only half the projects said they explicitly tell the consumer about this.
- In terms of benefit to the community and the economy, community buildings and small shops and craft enterprises would appear to be significant markets that are currently under-supplied.
- Many systems have a very restricted list of acceptable load appliances – and without standardisation, appliances are specific to a particular system. There is no emerging standard for off-grid appliances yet. Most projects had not heard of the two proposed DC socket standards.
- The basis of charging is not a simple binary choice between PAYG and Outright Purchase – other schemes are possible. There are good and bad aspects to what happens at the end of the PAYG agreement term, and these need to be more widely discussed.
- Safety is currently a secondary consideration, perhaps because the voltage is generally lower than on the grid. However, fire is still a risk. Overload protection is not always properly considered. Only just over half the projects said that they give the user safety instruction. At least 85% of systems are unearthed – a lightning risk. Insulation of exposed metalwork is preferred over a third protective earth wire.

It may be in the interests of standardisation to repeat the survey with a larger number of respondents, to help to identify which systems are likely to become prevalent. The sooner the degree of variation can be reduced, the quicker economies of scale will start to appear, and off-grid systems can become as cost-effective as on-grid ones.

Any enquiries about this survey should be directed to:

Chris Moller
Research Visitor, The Open University
Evonet, Cambridge CB24 8TX, UK
T. +44 1954 251819, E. chris.moller@evonet.com or chris.moller@open.ac.uk

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