# Solar Electric Cooking in Africa in 2020

## A synthesis of the possibilities

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# Executive Summary

The proposition of Solar Electric Cooking (SEC or PV-eCook) is that by 2020 the cost of using solar photovoltaic panels to charge a battery, and then using the battery for cooking as and when required, will be comparable to the monthly cost of cooking with charcoal and wood in most developing countries. This paper summarises the findings of three papers exploring particular elements of the proposition – an economic model on the costings, the lifetime of batteries, and the socio-cultural drivers and barriers relating to the uptake of such a proposition.

**The proposition sits at the intersect of two major global challenges; the use of biomass for cooking which is harmful to the household and to the environment, and the challenge to extend modern energy access to all peoples (SDG7[1]).**

This paper starts by referring to both the Improved Cookstove literature that has recently acknowledged that "The "business-as-usual" scenario for the sector is encouraging but will fall far short of potential." (ESMAP & GACC 2015). The modern energy community calls for a similar "new and transformative strategy" (World Bank 2015). The paper suggests that the proposition could significantly contribute to a new approach in both sectors and in particular to Sustainable Development Goal 7.

It goes on to describe the commissioning of three papers of which this is a synthesis of findings. In the first paper (Leach and Oduro 2015) the economics of the proposition are modelled. Using existing evidence on the way households cook in Africa, the model sets up two scenarios ('low cook' and 'high cook') which represent the range of energy consumption found in most households of 4 people. The model is based on evidence from the literature of the range of current costs for components, and most importantly the range of predicted costs. The model shows that the majority of upfront costs are invested in the battery for the system, and a second paper was specifically commissioned on the technical capabilities of current (and near future) batteries.

The second paper (Slade 2015) confirms that LiFePO4 batteries currently on the market are thought to be viable for the proposition. However, the paper draws attention to the absence of independent data on battery performance in high temperature and high discharge conditions. Slade 2015 notes that electric car manufacturers have had challenges from car owners living in the hotter parts of the USA, and are addressing the loss of performance at higher temperatures. The paper concludes that "*the research question posed is ahead of the capability of current common lithium ion battery types to deliver long term, durable performance at high (tropical) temperatures, but arguably not by much in this rapidly advancing field.*"

In order to benchmark the cost of the SEC proposition, Leach and Oduro compare the outputs with an equivalent energy consumption (and cost) of charcoal and Liquid Petroleum Gas (LPG). They create four scenarios. A low cook scenario with discount rates of 5% and 20%, and a high cook scenario with the same discount rates. The range of costs in each cost band in the figures are determined by taking an 'optimistic' model, which uses high efficiencies and low costs for each component, and a pessimistic model which uses the opposite (low efficiencies and high costs). They illustrate that while in 2015 the range of costs for the Solar Electric Cooking system is more than most charcoal and LPG markets,

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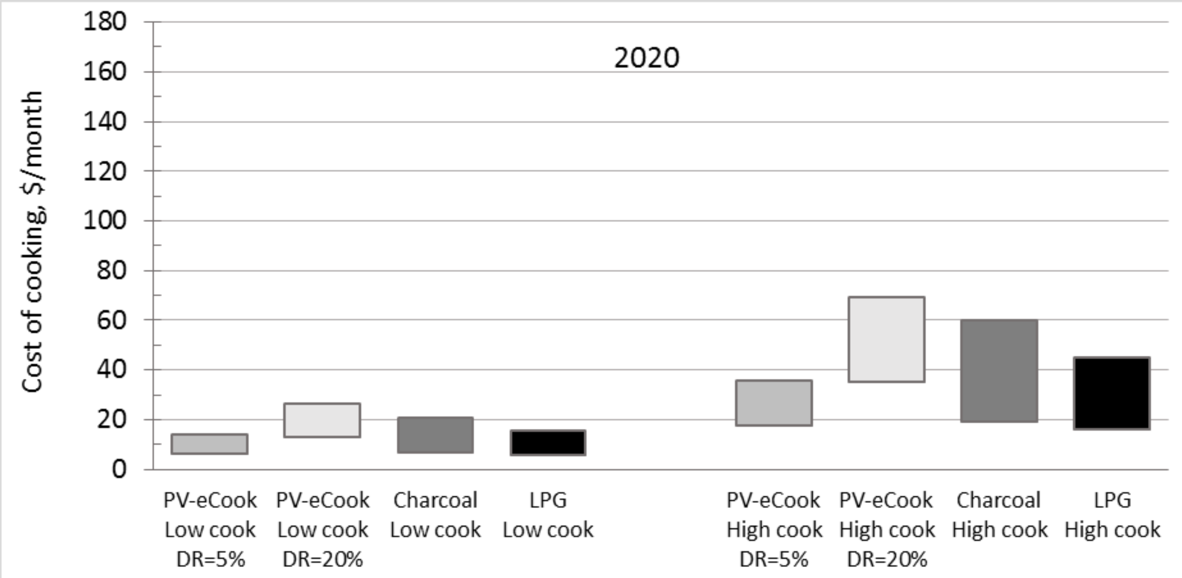
but confirm that by 2020 the monthly cost of PV-eCook is of the same order as charcoal and LPG (Figure 1).

**Figure 1 Cooking costs, 2020**




The third paper in the series (Brown and Sumanik-Leary 2015) addressed the socio cultural barriers and drivers to the proposition. Households rarely choose their livelihood strategies based on cost alone. As the ICS literature states "*low levels of consumer awareness; behaviour change obstacles to the reduced use of traditional stoves after the adoption of new solutions; and limited consumer access to appropriately designed and durable products." (ESMAP 2015)* all slow the uptake of improved stoves. How then would these factors affect a transformative shift in behaviour to PV-eCook? Brown and Sumanik-Leary explore the uptake of cooking with electricity in South Africa, the transition to LPG in some countries, the uptake of Improved Cookstoves and the uptake of solar home lighting systems to document lessons from each of these.

Their findings neither confirm nor dispute the possibilities within the PV-eCook proposition. They document many lessons about raising consumer awareness, making sure that service agents and supply chains are available, and the importance of participatory development of the market. In particular, they emphasise the role of women in taking this forward, not just as consumers, but as active market participants – as service agents that maintain the equipment. They also suggest that due to the high value of the eCook equipment (and therefore longer investment horizon for poor households), a utility business model is likely to be seen as the most attractive for poor households.

In the synthesis paper this idea of a utility model is briefly explored, illustrating how implementation of new grid supplies such as a wind farm in Turkana, Kenya, requires a per household investment of the same order of magnitude as the proposed PV-eCook. The paper also briefly considers whether loans could be enabled for PV-eCook. Brown and Sumanik-Leary also present a framework for identifying markets suitable for PV-eCook, and the synthesis paper contributes an example that shows how the proposition could apply to 80% of the Kenya population.

The paper concludes with a call for further research. The proposition could be cost effective by 2020, however there are still considerable unknowns. In addition to more detail required for refining the modelling and identifying potential markets, there are wider 'future think' studies required for exploring the impact of widespread uptake on national economies and waste disposal. The call for further work includes recommendations for a communications strategy, including convening the two ICS and Solar communities to discuss what research would enable them to adapt their approaches.

The proposition directly addresses the challenge of SDG7, and offers the potential for a step change in investment in modern energy. It is an innovation that challenges the business as usual approach of governments, donors, private sector, and consumers in Africa, and if taken forward at a measured pace could transform levels of access to modern energy. It addresses the energy trilemma of energy security, energy equity, and environmental sustainability. As such, the conclusion is clearly that the proposition merits further research, as well as discussion and dialogue among interested stakeholders and associated networks.

# SECTION 1

# Introduction

The proposition of Solar Electric Cooking (SEC or PV-eCook) is that by 2020 the cost of using solar photovoltaic panels to charge a battery, and then using the battery for cooking as and when required, will be a comparable monthly cost of cooking with charcoal and wood in most developing countries. This paper summarises the findings of three papers exploring particular elements of the proposition – an economic model on the costings, the lifetime of batteries, and the socio-cultural drivers and barriers relating to the uptake of such a proposition.

**The proposition sits at the intersect of two major global challenges; the use of biomass for cooking which is harmful to the household and to the environment, and the challenge to extend modern energy access to all peoples (SDG[2]7).**

In this paper we explore how the use of solar electric **cooking** systems could meet the twin goals of both increasing access to electricity, and providing a means of truly clean cooking to households in developing countries. While the paper focuses on Africa, the proposition is likely to be relevant to Asia and Latin America. The proposition sits at the intersect of these two challenges and potentially opens a gateway to solving both. PV-eCook is a clean cooking solution with an equivalent monthly cost to current expenditure on fuel and potentially provides an anchor utilisation of modern energy that will be a springboard for wider use of modern energy, working towards SDG7.

## 1.1 The challenge of cooking with biomass

Between 2.6 and 3 billion people (ESMAP & GACC 2015) use biomass for cooking. This pervasive use of solid fuels – including wood, coal, straw, and dung – with traditional cookstoves results in high levels of household air pollution, extensive daily drudgery required to collect fuels, and serious health impacts. Smoke from cooking indoors with biomass is associated with a number of diseases, including acute respiratory illnesses, cataracts, heart disease and even cancer. Women and children in particular are exposed to indoor cooking smoke in the form of small particulates up to 20 times higher than the maximum levels recommended by the World Health Organization. It is estimated that smoke from cooking fuels accounts for nearly 4 million premature deaths annually worldwide – more than the deaths from malaria and tuberculosis combined.

It is well known that open fires and primitive stoves are inefficient ways of converting energy into heat for cooking. The average amount of biomass cooking fuel used by a typical family can be as high as two tons per year. While there has been considerable investment in improving the use of energy for cooking, the emphasis so far has been on improving the energy conversion efficiency of biomass. Indeed in a recent overview of the state of the art in Improved Cookstoves (ICS) (ESMAP & GACC 2015) the forward aspires to a world where this situation changes but note that the use of biomass for cooking is likely to continue to dominate through to 2030 due to population growth.

2 Sustainable Development Goal 7

*"Consider, for a moment, the simple act of cooking. Imagine if we could change the way nearly five hundred million families cook their food each day. It could slow climate change, drive gender equality, and reduce poverty. The health benefits would be enormous." ESMAP & GACC 2015 Foreword by Radha Muthiah Chief Executive Office GACC*

The main report goes on to say that *"**The "business-as-usual" scenario for the sector is encouraging but will fall far short of potential."*** (ibid, our emphasis). It notes that without major new interventions, over 180 million households globally will gain access to, at least, minimally improved[3] cooking solutions by the end of the decade. However they state that this business-as-usual scenario will still leave over one-half (57%) of the developing world's population without access to clean cooking in 2020, and 38% without even minimally improved cooking solutions. The report also states that 'cleaner' stoves are barely affecting the health issues, and that only those with forced gasification make a significant improvement to health. Against this backdrop, there is perhaps a need to try a different approach aimed at accelerating the uptake of 'clean' cooking.

## 1.2 The challenge of access to modern energy

Even though improved cooking solutions are expected to reach an increasing proportion of the poor, the absolute numbers of people without access to clean modern energy will increase. Against this backdrop the new **Sustainable Development Goal 7 (SDG7) calls for the world to "*ensure access to affordable, reliable, sustainable and modern energy for all*".**

While this is laudable and much discussed, in the recent past 'access to modern energy' has meant access to electricity and cooking was often left off the agenda. Once again, key papers on **access** to electricity emphasise the need for a step change in investment finance, a change from 'business as usual'.

World Bank 2015 notes that 22 countries in the Africa Region have less than 25 percent access, and of those, 7 have less than 10 percent access. Their tone is pessimistic, in line with much of the recent literature on access to modern energy, albeit in contrast to the stated SDG7. They discuss how population growth is likely to outstrip new supplies and they argue that "Unless there is a big break from recent trends the population without electricity access in Sub-Saharan Africa is projected to increase by 58 percent, from 591 million in 2010 to 935 million in 2030." They lament that about 40% of Sub-Saharan Africa's population is under 14 years old and conclude that if the current level of investment in access continues, yet another generation of children will be denied the benefits of modern service delivery facilitated by the provision of electricity. (World Bank 2015).

*"Achieving universal access within 15 years for the low-access countries (those with under 50 percent coverage) **requires a quantum leap** from their present pace of 1.6 million connections per year to 14.6 million per year until 2030."* (ibid)

Once again the language is a call for a something **other than business as usual**. The World Bank conceives of this as a step change in investment. It estimates that the investment needed would be about $37 billion per year, including erasing generation deficits and providing additional electrical infrastructure to meet demand from economic growth. *"By comparison, in recent years, low-access countries received an average of $3.6 billion per*

[3] A minimally improved stove does not significantly change the health impacts of kitchen emissions. "For biomass cooking, pending further evidence from the field, significant health benefits are possible only with the highest quality fan gasifier stoves; more moderate health impacts may be realized with natural draft gasifiers and vented intermediate ICS"

*year for their electricity sectors from public and private sources"* (ibid). The document calls for Bank Group's energy practice to adopt **a new and transformative strategy** to help client countries orchestrate a national, sustained, sector-level engagement for universal access.

In the last few months, several initiatives have been announced, many of which include philanthropists. The Energy Africa campaign[4] was announced by the International Development Minister and the Department for International Development (UK Aid) alongside Richard Branson, Founder of the Virgin Group. They state that their campaign is built on four trends:

- the dramatically decreasing cost of solar photovoltaic panels
- improvements in battery technology – thanks to the development of lithium batteries
- improvements in the efficiency of appliances (for instance a 6 Watt LED produces light equivalent to an Edison bulb of 60 watts) and
- the spread of mobile payment systems enabling access through micro pay-as-you-go.

However, while they focus on modern energy for lighting, the press release video shows a woman using an improved biomass stove for her cooking. The press release page does not mention cooking, and their aspiration as stated seems limited by what can be achieved cost effectively by solar PV **at today's prices** (business as usual) rather than looking to the near future.

A month later another grouping of philanthropists announced the Breakthrough Energy Coalition[5] while the President of America announced Mission Innovation[6], both of which are going to increase research on clean energy for global solutions. While these latter initiatives are not focused per se on developing markets, and are looking for global game changing technology to address climate change, once again cooking by a third of the world is not mentioned. Gates states in the promotional video that "*if we could change the price of one thing that would lift the lives of the poorest everywhere it would be the price of energy; they can get to their jobs, they can buy fertiliser, they can have lights at night.*" (Gates 2015). While this is just a list or statement made in the context of a promotional video, it once again illustrates that cooking, a major energy consumption for the poor and currently a health challenge for the majority of poor people is not yet at the front of the minds of those who aspire to reach SDG7.

4 Energy Access 2015; The Energy Africa campaign was launched at Facebook's offices in London on 22 October. Attendees included: Chair of the Africa Progress Panel and Former UN Secretary General Kofi Annan, African Union Commission chairperson Madame Zuma, the Nigerian Vice President Yemi Osinbajo, and the activist Bob Geldof. https://www.gov.uk/government/news/solar-boost-to-release-africas-untapped-energy-potential

5 http://www.breakthroughenergycoalition.com/en/index.html

6 http://mission-innovation.net/

It is not that the world is not concerned with the two problems of biomass cooking and lack of access to modern energy.  It is that currently policy and private sector actors are treating these as two separate problems.  As stated above in this paper we explore how the use of solar electric **cooking** systems could meet the twin goals of both increasing access to electricity, and providing a means of truly clean cooking to households in developing countries.  The proposition sits at the intersect of these two challenges and potentially opens a gateway to solving both.  PV-eCook is something other than business as usual for clean cooking and potentially a new innovative strategy providing alternative anchorage and cost recovery for rolling out modern energy; a springboard for wider use of modern energy working towards SDG7.

# SECTION 2

## Background

A research consortium led by Loughborough University and including the University of Surrey Centre for Environmental Strategy and Gamos Ltd has been commissioned by DFID to explore assumptions surrounding solar electric cooking[7]. The commission has arisen from recent discussions between consortium members, DFID, and a number of other entities with an interest in technology options for cleaner cooking e.g. Shell Foundation and the Global Alliance for Clean Cookstoves. The concept of interest relates to a combination of battery with cooking hob, which 'opens up' new opportunities for the resource poor to transition to a modern, zero (kitchen) emissions fuel. The concept is outlined in the infographic included in Annex 1.

Solar photovoltaic cooking today is out of reach for most households in developing countries. However, it is proposed that if the current downward trends in solar photovoltaic technology costs and in energy storage costs (specifically lithium ion phosphate batteries) continue, then within as little as five years it is quite possible that for some populations a solar home system sized for cooking would have a lifetime monthly cost comparable to the monthly spend on biomass (mainly charcoal) made by a sizeable proportion of biomass users. Electricity is a top tier fuel emitting zero **household** emissions whereas inefficiently burned biomass produces pollutants, toxins and smoke. This means we should get ready to exploit the upcoming opportunities to improve cooking in developing countries. In this study we will examine not only the role of Solar Electric Cooking, but also its potential to compete with other cooking fuels in terms of costs. It is unrealistic to expect that solar photovoltaic based cooking will completely replace all other cooking fuels in the near future, but there are large populations in developing countries that may be able to take advantage of the cleanliness and convenience of cooking with electricity, whether it be from solar panels or from national grids.

In order to provide data which can complement and strengthen proposals for further work in this area that might be funded by DFID or other entities with an interest, three research papers were commissioned on specific aspects of the proposition. The Terms of Reference and the questions are presented in Annex 1.

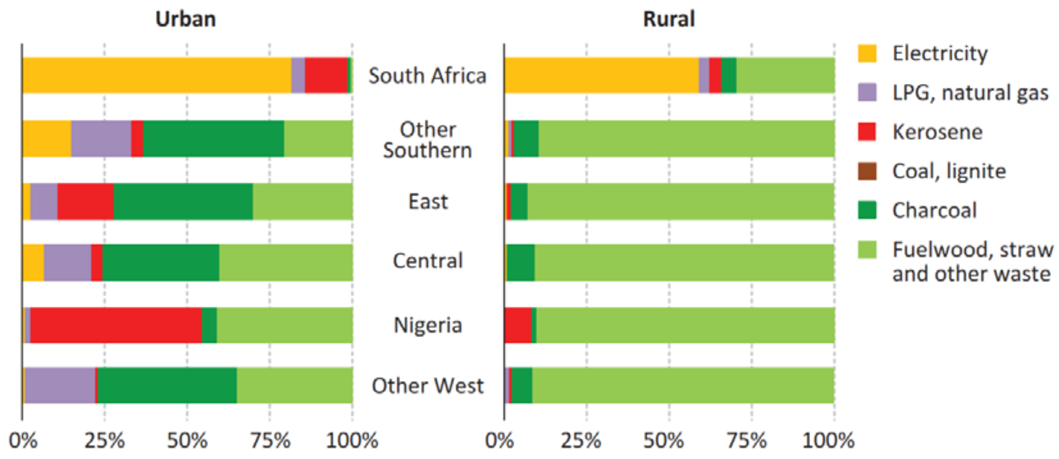
[7] The project has been commissioned through the CEIL PEAKS framework agreement managed by DAI (which incorporates HTSPE Limited) and IMC Worldwide Limited

# SECTION 3

## The cost of existing fuels for cooking

People in developing countries purchase some if not all of their cooking fuels. This is true of wood, straw and even dung, not to mention kerosene and LPG. It is also true that many people collect fuels as well, spending valuable time carrying heavy loads back to their homes.

**Figure 2 Main fuel used by households for cooking in Africa**



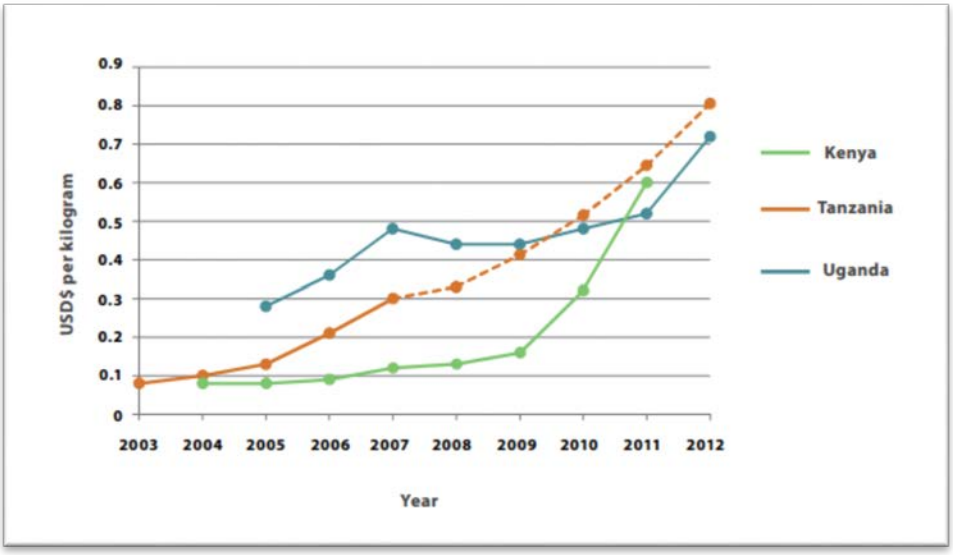

Sources: USAID (2014); Department of Energy, South Africa (2013); WHO (2013); IEA analysis.

Source: IEA (2014)

While the graph above shows that the majority of rural people use fuelwood, and might therefore be assumed to pay nothing for their fuel, specific market studies show otherwise. GVEP & GACC 2012, shows that in 2007 up to 40% of households in rural Kenya were paying more than $7 a month for their firewood. These were households operating at income levels of between $1 to $3 per capita per day. Expenditure in peri-urban areas rose to $11 per month firewood for 71% of the households surveyed, and $10 a month for peri-urban households using charcoal. Urban households averaged $12 a month. A similar range of expenditure was found in Tanzania[8], with those urban households on over $3 per capita per day spending an average of $20 per month on charcoal. Since then (2007), charcoal prices have risen dramatically, and are likely to continue to do so (see Figure 2).

8 According to LSMS 2013, the range in Ethiopia is considerably less. As the report will emphasise, more detailed research on potential markets is required.

**Figure 3 Price trends for charcoal (EEP 2013)**




Thus, people are already spending a significant amount of income on polluting fuels that are burned in inefficient appliances.

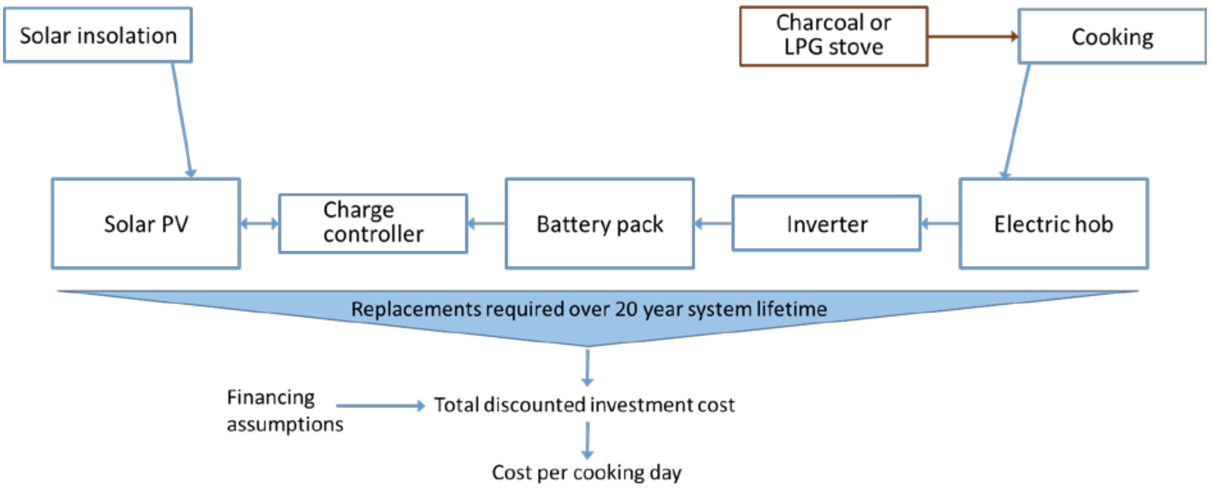
# SECTION 4

# Will solar electric cooking become affordable?

### Potential of solar photovoltaic based systems for cooking: costs and comparisons[9]


In the economic modelling paper, Leach and Oduro (2015) document the various components of a Solar Electric Cooking system (Figure 1), and using the literature consider the range of costs for the system in 2015, and a range of costs likely in 2020 (based on published data on price trends). They calculate the model 'from two ends' – taking the necessary useful energy for cooking and working 'back' to what size would the battery need to be, and taking two scenarios of insolation and working out what size a photovoltaic array would be required to keep the battery charged. They present a range of costs for systems capable of cooking a variety of meals; 'low cook' and 'high cook' scenarios[10] are used to represent the range of possible uses. These costs are then compared with equivalent costs for cooking with charcoal and LPG. The model shows that if current price trends continue, then at some point in the future the monthly cost of a Solar Electric Cooking system would indeed match the monthly costs of charcoal or LPG.

**Figure 4 Cooking system components and parameters**




9 Research question 1:- Given the trends in pricing in Solar Photovoltaic panels, lithium Ion batteries and charcoal/wood pricing in Africa, will there be a point when a suitably appropriate use of solar panels combined with battery, hot plate; control panels; with/without inverter could create a cost effective Solar Electric Cooking system which would substitute for charcoal (and wood) consumption for the same lifetime expenditure?

10 'low cook' and 'high cook' refer to lower and higher estimates of the amount of energy required to cook a meal for a family of four.



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## 4.1 Useful cooking energy – the starting point of the model

Despite years of studies, how much energy households require for cooking a real meal remains a matter of some debate. Some commentators note that Improved Cookstoves (ICS) are often designed to operate in a particular way. For many years laboratory tests simply 'brought a pot of water to the boil', however more recent tests approved by GACC have a combination of power and simmering in their efficiency measurements. Nevertheless, much of the literature is ambiguous as to whether these combinations are used in the quoted efficiencies. Much of the literature still uses older figures based on water boiling tests and there is a dearth of data on how people cook real meals with different fuels. Batchelor 2014 argued that modern energy appliances give more precise control over the cooking process, and therefore the process of cooking a whole meal uses less energy than a charcoal stove with 'limited' control.

With this debate in mind, and in order to determine their starting estimate of useful energy required to cook a meal (i.e. energy transferred to the pot), Leach and Oduro (2015) draw on two key studies, both of which made measurements on meals cooked within households. Ravindranath and Ramakrishna (1997) conducted controlled cooking tests, with housewives cooking a meal for 6 people under controlled conditions, based on rice, sauce and meat. The results for cooking a real meal range from 0.6 to 1.3 MJ per meal per capita, (0.18 to 0.37 kWh), with a mean of 0.9 MJ/capita per meal (0.24 kWh). This equates to 0.72 to 1.48 kWh per meal for a family of four. Both Leach and Oduro (2015) and Brown and Sumanik-Leary (2015) refer to Cowan 2008. As part of an EU-funded project in South Africa, Cowan (2008) conducted real meal tests of the energy used by different modern energy cooking appliances. Cowan's data varies between 0.5 to 0.7 kWh per meal for 4 people. While there are other studies that could have been drawn on, these two studies are suitably representative of the data available on energy used to cook a meal.

This is a key assumption for the feasibility of PV-eCook. In the original concept, Batchelor 2013 used the mid-point of the Cowan figures, acknowledging that Balmer (2007) put the figure nearer the higher figures of Ravindranath and Ramakrishna (1997). Leach and Oduro have handled discrepancies in the energy requirements by presenting two scenarios, calling them 'low cook' and 'high cook'. These two figures conservatively cover the range of actual possibilities.

Leach and Oduro point out that *"The difference between the two sets of estimates will reflect: differences in assumptions between the two studies about what constitutes 'a meal'; that one study is of India and one of South Africa, with very different ingredients and cooking needs; and specifically that the Cowan values refer to relatively easy-cooking ingredients. However, for the purposes of the current scoping study, the range can be taken usefully to represent a range of end uses for any new cooking system."*

The model has then been used to calculate the size of the system that would be required to fulfil this delivery of energy, and considered the variables within the system. This is described below.

## 4.2 Sizing the battery

Having decided on the required useful energy for cooking for the two scenarios, Leach and Oduro consider what battery would be necessary to deliver the energy. They discuss many features of batteries and costs, the direction of developments, and price trends in an extensive section drawing on the literature. The current, oft quoted price for lithium batteries is $500 per kWh storage capacity. Leach and Oduro document the range of predictions made by analysts, and note they vary from $100 to $350 at 2020. The battery is discussed in considerable detail in Slade (2015), and so for the moment, within the economic model, it is sufficient to note that Leach and Oduro take a range of prices representing the range of chemistry and market differences currently available and potentially available in 2020.

## 4.3 Useful solar insolation and PV panels

Having calculated the range of energy required from a battery each day to meet the range of cooking needs, they consider the size of the photovoltaic panel needed under different insolation regimes. They consider locations that enjoy minimal seasonal variations in daily peak sun hours (e.g. Kenya, Tanzania). The model is based on a panel sized to meet demand throughout the year; a sensitivity analysis also considers a system with a panel sized to demand during only half of the year.

The current often quoted price for solar photovoltaics is “50 cents per watt”. As the authors point out, this is for the rated peak wattage of the panel. However, they also rightly note that this is an ex-factory price for bulk purchase and for unmounted cells. In previous discussion of PV-eCook, Batchelor (2015) has taken the 50 cent figure as his guideline and projected its fall to around 34 cents. Leach and Oduro (2015) take a more systematic view of the potential for further price reduction. They document the many different expert analyses of the possible price reduction and conclude that by 2020 it could be between ‘staying the same’ at 50 cents ex-factory, and 20 cents ex-factory.

## 4.4 Realistic pricing

For each component, Leach and Oduro distinguish between a factory price and one which includes business components such as distribution and profit. This is important to note, particularly in the case of the main components: - photovoltaic cells and batteries.

> *“…… there are a wide range of uncertainties in the design, sizing and costing of the system. For the purposes of this section, we distinguish between parameters for which the values are uncertain due to (a) different household cooking practices; (b) system design decisions; (c) uncertainty in technical parameters; (d) changes over time; (e) financing assumptions”* Leach and Oduro

In addition to the items discussed above (a, b and d), they acknowledge that there is uncertainty in the appropriate value for many parameters. This includes technical performance (such as minimum depth of battery charge and decay rate of battery performance with cycling), losses (e.g. through cables and the inverter) and in prices (e.g. of the PV and battery). Each of these factors could be explored individually. The approach taken by Leach and Oduro for this scoping study is to explore the effect of scenarios of optimistic and pessimistic choices in a bundle of these factors, and then to interrogate the results to understand the most influential factors. By ‘optimistic’ they mean scenarios where efficiencies are assumed to be at the higher end of their range and costs at the lower end. Similarly, by ‘pessimistic’ they mean scenarios where efficiencies are at the lower end of the range and costs at the higher end.

Regarding financing costs, they consider the levelised costs of the cooking service, expressed as cost of cooking per month, delivered as a service by an investor who pays for the initial capital and any replacement capital costs over a 20 year period. They investigate the risk attitude of such investors – effectively cooking service providers – by exploring the influence of different discount rates, from 5% (equivalent to an almost risk-free rate, consistent with investment made, or subsidised, by national government) to 20% (representing a commercial investor seeking rapid return on investment). The question of business models and who might raise this investment will be covered in a subsequent section.

# SECTION 5

## Realistic battery use


Batchelor (2015) claimed that the only technical question for the system revolved around the lifetime of the battery. Can existing batteries meet the heavy demands of cooking? Solar photovoltaics, charge controllers, discharge controllers and even hotplates are all well known. While there is work to be done in system sizing and creating a ‘package’ of the system, the technical viability of these components working in Africa and Asia is not in question. However, the durability and lifetime of the battery needed expert opinion, hence the commissioning of Research Question 2[11] (Slade 2015). If PV-eCook is to contribute to SDG7, it must be reliable both in terms of its lifetime, and its ability to delivery adequate energy on-demand and daily.

Slade (2015) discusses various battery chemistries, some commercially established, others ‘in the pipeline’. His conclusion is that “*The research question posed is ahead of the capability of current common lithium ion battery types to deliver long term, durable performance at high (tropical) temperatures, but arguably not by much in this rapidly advancing field. There can be optimism that lithium ion battery packs will shortly have evolved to a point where they could realistically be taken forward to possible high power applications in the developing world.*”

### 5.1 Battery chemistries

The core challenge is that the battery of choice in solar electricity installation has largely been the lead acid type, based on its widespread use in many contexts and on its perceived robustness. Valve regulated lead-acid batteries (VRLAs) are a proven type capable of deep discharge and have a long history of use. However, in just the last few years there has been considerable development of Lithium Iron Phosphate (LiFePO4) batteries. These batteries are emerging as the battery of choice for new developments in Solar. Slade also points to Lithium Titanate batteries as a recent addition to the commercial market. They have a different chemistry construct and ‘tolerate’ higher discharge rates. While seemingly more expensive than LiFePO4 Slade notes they have a longer lifetime, resulting in perhaps a similar overall lifetime cost.

### 5.2 Operation in harsh conditions

The research question specifically asks about operational constraints in ‘harsh’ conditions. Slade dismisses concerns about dust included in the research question. The battery pack is typically sealed and so dust is not a major operational issue.

[11] ‘Given the technological development in batteries, and their current stated use, what would be the anticipated lifetime of a lithium Ion PO4 battery (suitably sized for research question 1) operating in ‘harsh’ conditions (excessive heat and dust) and discharging for between 40 mins and three hours a day.’

Of the two remaining 'harsh' conditions stated in the research question, Slade notes that the current orthodoxy is that both requirements (high ambient temperature and high discharge rate) can lead to substantial deterioration of battery durability and cyclability for both VRLA and LiFePO4, and in the case of lithium ion batteries to potential safety problems. However, with the caveat that independent verifiable data is in short supply, he goes on in his report to suggest that the deleterious effects are somewhat exaggerated and can be mitigated.

He notes that Lithium batteries continue to evolve, particularly with new battery chemistries being developed to overcome the shortcomings of existing designs (enabling higher discharge rates and seeking durability and cyclability that persist to higher temperatures). Saft (France) have developed Lithium Ion batteries that can be used at up to 125°C and that are capable of 300 cycles at 80°C, encouraging optimism for durability in elevated temperature operation in the developing world. The problem of higher temperatures is not unique to solar electric cooking and Slade refers to recent developments in electric vehicles where US consumers were losing capacity when operating vehicles in the hotter parts of the USA. In response, the vehicle industry is specifically addressing temperature issues. The response of the battery industry and OEMs to concerns as they arise encourages optimism that future strategies will, in time, overcome current problems.

Regarding the high discharge rate, the research question states between 40 minutes to 3 hours for the discharge and therefore Slade focuses on performance between 1C and $C_4$. "C rate" is a measure of how fast a battery is charged and discharged. A battery that would be fully discharged in 1 hour has been discharged at 1C, while one that would be discharged in 2 hours is discharged at C/2 (0.5 C); some show the latter as $C_2$. Manufacturers generally present the capacity of their batteries at $C_{10}$ or $C_{20}$ i.e. a slow rate of discharge.

When discussing the characteristics of batteries, Slade is presented with a key challenge. Most independently verified academic papers are several years old, and do not necessarily reflect the latest battery chemistries. At the same time, manufacturers do not publish their raw data as this is of commercial value. Slade states "Studies of the effect on cycling on battery life have been reported recently, but there does not seem to be any public domain data concerning the drop in capacity for LiFePO4 batteries at very high C rates and elevated temperature". The result is that Slade has drawn evidence from the media and internet in order to try to find some data, and recommends that an independent testing of batteries be conducted as a part of the development of solar electric cooking in order to find out the actual effect of high C rates on cycle lifetimes[12].

Slade also suggests that the effect of very high peak currents might be mitigated by Supercapacitors (SCs). The development of water-based supercapacitors that could compete with the current expensive organic solvents based ones, but at much lower manufacturing costs, is currently a highly topical research theme.

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[12] An example of a community that is using LiFePO4 at very high C rates is the model car and airplane racing community. Although not mentioned by Slade, interviews by this author with key members of this community revealed that a model car operates for 8 minutes at 7C and momentarily draws a peak starting current at 60 to 70C. Batteries sold to this community while small, have similar chemistry as the larger battery pack – being made up of multiple cells. The data provided by this community illustrate that LiFePO4 can deliver high discharge rates, with minimal loss of capacity over 120 to 150 cycles. However, since batteries are only used for one racing season, the data they provided does not shed light on total lifetime. When asked to comment Slade is cautious with this 'evidence'. "*This assertion comes without any data to evaluate and apparently from a user community rather than from a systematic, scientific/engineering study with access to peer review…… The high C rates asserted would lead to substantial heat generation but the small battery packs involved will presumably have been air cooled by forced flow due to motion of the carrier (model car or plane). The thermal behaviour (not least the removal of self-generated heat during discharge) will be likely to be different to a static larger pack in which substantial heat can be generated in the core of a working battery pack…… the assertion is interesting but needs scientific investigation and validation*" Slade email response 2016.

Finally, Slade notes that modern types of batteries have evolved into systems which can operate at reasonably high stored energy densities and can support high depth of discharge (DoD), which is the amount of stored electrical charge that can be accessed in usable charge-discharge cycles. While depth of discharge for LiFePO4 is typically quoted at 75%, data from unverified sources suggests that it can be taken to 90% with minimal degradation of the battery.

A battery management and safety system for such an array of battery packs (and also of individual cells within $LiFePO_4$ packs) is likely to be mandatory.

Slade concludes "*Battery types, packs and arrays suited to solar electric cooking appear technically possible. There is, however, a shortage of key independent data for this particular type of use and duty cycle specifically for applications with extended periods of high current use (a deep discharge at high C rate) at elevated temperatures*."

In addition to the technical considerations involved in the design and selection of a battery technology for the PV-eCook system, Brown and Sumanik-Leary also emphasise the role of a service network in the overall reliability of any system. They conclude that Solar Electric Cooking will most easily be applied where Solar Lighting systems are already established. They recommend engaging with women as service agents; "Design training programmes specifically for women, as their motivation to perform repairs will be highest, as they are the primary beneficiaries". Such local service agents could keep an eye on the system including the lifetime of the battery.

Brown and Sumanik-Leary also talk about "*Ensure early PV-eCook devices are sold with battery charge indicators and are accompanied by training/awareness raising on how to respond to the indicator to ensure that users are able to prioritise energy saving measures at their discretion*."; in the light of Slade 2015 it would seem that a temperature indicator and cut off, combined with suitable training, should also be included.

In addition to the battery performance questions discussed above, Slade raises two other important issues that need to be researched and considered before going to scale with Solar Electric Cooking. For all lithium-based batteries a possible issue is that lithium is not an abundant element, and so sustainability could become an issue in the event of steeply increasing usage. Both to address that concern and to prevent contamination of the environment Slade suggests that the potential recycling of modern cell systems has to be investigated.

In regard to these last two points Slade draws attention to recent development in sodium ion chemistries. Advance in sodium ion batteries has been rapid and led in Europe by Faradion (a SME company based in Sheffield); research has already progressed to initial battery packs. There is, however, as yet little public domain data comparing the safety of Na ion and Li ion batteries (sodium metal itself is more reactive than is lithium). High voltage, non-aqueous (water-free) sodium ion cells should not be confused with the lower voltage saltwater cells (water as solvent, aqueous hybrid ion batteries) developed and being marketed by Aquion Energy in the USA; the energy density for non-aqueous (higher voltage) sodium ion batteries will be likely to be much higher than any aqueous system.

In the author's opinion the lower energy density of saltwater cells need not necessarily be an issue for Solar Electric Cooking. These batteries are said (by manufacturers) to not be damaged by deep discharge, and while their energy density does not lend them to use in transport, they may well emerge as possibilities for solar solutions. The increased safety, possibilities of local assembly, and relatively easy waste disposal are all highly attractive features for the PV-eCook proposition. Aquion batteries were available as at December

2015 at £300/kWh capacity landed in UK. Such developments need to be explored as we move into 2020 and beyond.

# SECTION 6

## Comparison of PV cooking costs with alternatives

Returning now to the economic modelling, as expected the resulting scenarios illustrate that under most assumptions and conditions PV-eCook is not viable[13] now. There are some conditions where charcoal or LPG is at a particularly high cost when it might be possible. However by 2020, the economic dynamics change.

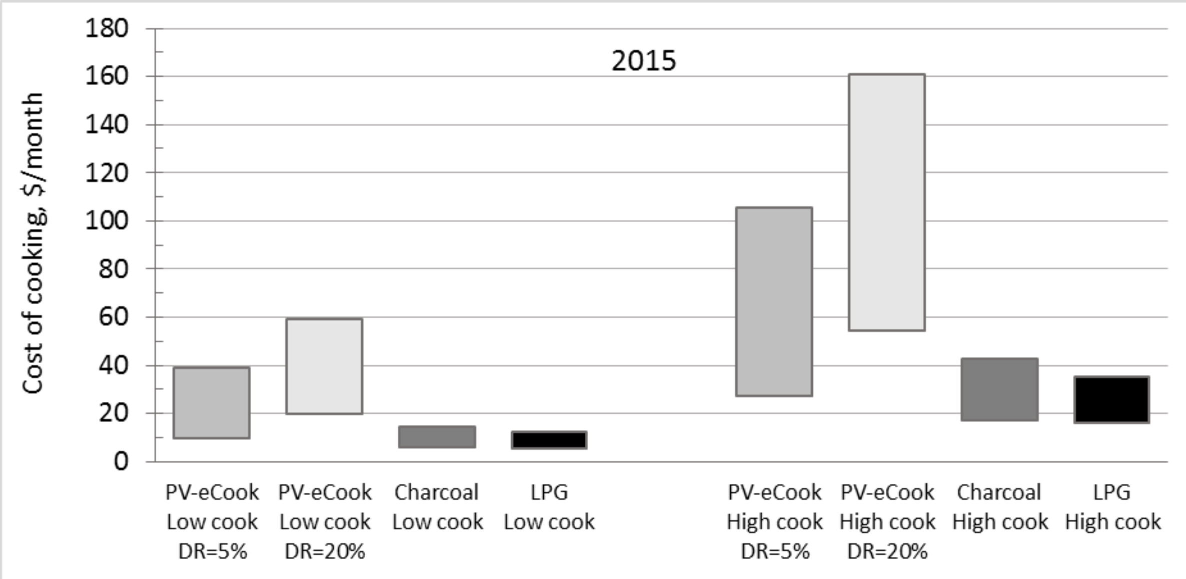
Before moving on to the output of the Solar Electric Cooking model, for completeness and to enable the model to be used for comparison with alternatives Leach and Oduro present a comparison with Charcoal and Liquid Petroleum Gas (LPG). To do this they take the useful energy required under each PV-eCook scenario ('Low cook' and 'high cook') and apply measured efficiencies for LPG and Improved Cookstoves. This enables them to calculate the cost of an equivalent amount of the alternative fuel. Once again there is some uncertainty as the price of each alternative fuel varies in different locations. They have taken low priced markets such as Ghana, and higher priced markets such as Kenya (although in order not to be seen as unrealistic they avoided the highest prices of charcoal). This enables them to present the future scenarios of comparative price without the need to segment the market by who might spend such amounts but rather by representing each scenario by a band of cost.

As we shall see below, when this cross over will occur remains unclear. The model is based on an estimated range of cooking energy required, a range of assumptions that give high and low costing scenarios, plus future increases in the price of charcoal and LPG. We have already noted that estimates could vary considerably between countries, and fuel costs will vary with different global oil price scenarios. However, for 'low cook' low cost scenarios the 'comparable' point, where a Solar Electric Cooking system is as cheap as charcoal or LPG could be as early as 2018. For 'high cook' scenarios and 'pessimistic' assumptions such as low solar insolation, seasonally variable insolation and partial year operation for the PV, the crossover point could be as late as 2023.

In 2015, the minimal overlap between the solar electric and the alternative fuel cost bands suggest this will only be the case in a small number of specific contexts where the current price of charcoal is particularly high, and import duties for solar equipment would be low e.g. peri urban areas in East Africa (Figure 2). We have already seen above that specific East African market studies conducted in 2007 indicate there are markets where consumers are paying more than $12 month for fuel and therefore, even at today's prices, the more optimistic models could cater for this group in the low cook scenario (GVEP & GACC 2012, ISSER 2015). However, these groups are not necessarily the poorest and tend to be in urban areas, and so the values presented do not suggest the proposition is worthwhile in 2015 except in very limited contexts.

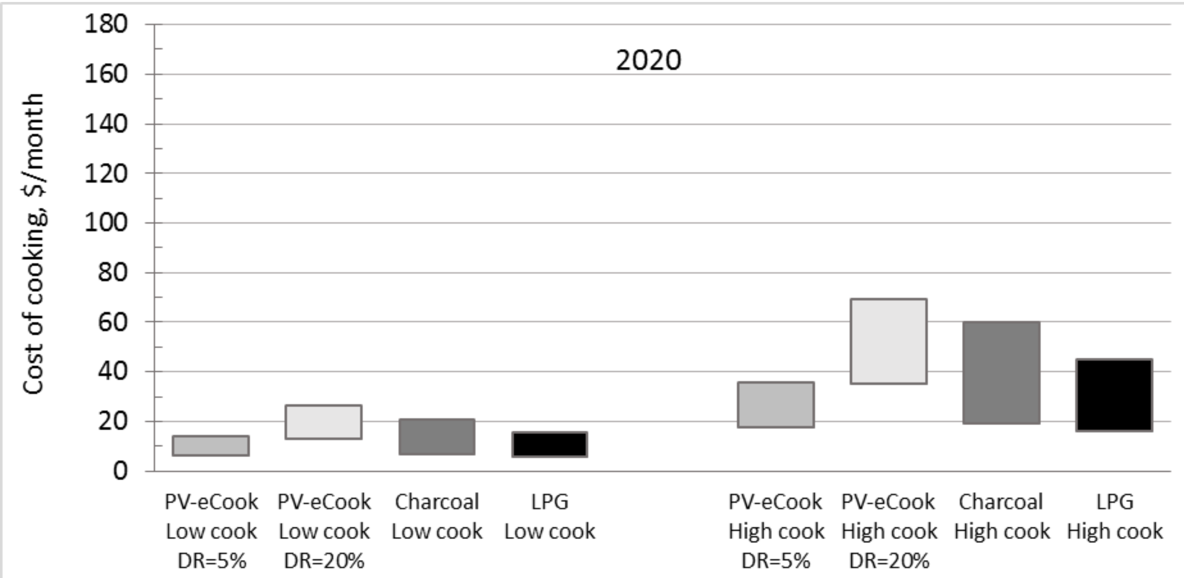
[13] i.e. the levelised monthly system costs could be less than some market segments pay for the alternatives

**Figure 5 Cooking costs, 2015**




Looking forward though, the Leach and Oduro model shows that by 2020 the whole band for both the low and high cook scenarios (at 5% discount rate) lies within the ranges predicted for alternative fuels (Figure 3). Even at the higher discount rate, there is a good deal of overlap under both scenarios.

**Figure 6 Cooking costs, 2020**




It is important to note that this does not mean a Solar Electric Cooking system would be affordable everywhere. As before, it suggests that the cost of using a Solar Electric Cooking system is 'comparable' in areas where people are paying for their biomass or LPG – but not all areas, as the specific context may mean that the alternatives are at the cheap end of the range (perhaps due to LPG subsidies for instance) while the PV-eCook may be at the higher end (perhaps due to import tariffs). It also only deals with a price comparison – money being only one aspect of a realistic scaled action. The affordability and other socio-cultural barriers and drivers to uptake will be considered below.

However, as Leach and Oduro conclude:

> "*The results demonstrate that the core concept of a PV-battery-electric cooker as a substitute for purchased cooking fuels is a realistic one. The figure [*Figure 3*] illustrates that the range for monthly cost for the system in 2020 is expected to be very similar to that for charcoal and LPG cooking, implying that a system actually realised with various levels of technical and cost performance could compete effectively with traditional fuels, in various contexts."* [14]" Leach and Oduro 2015

[14] "*The analysis has attempted to err on the side of caution, seeking not to adopt overly-optimistic assumptions that would make too strong a case for the new concept. However this suggests that there is some upside to the results: firstly, we assumed that replacement components do not benefit from ongoing technical improvements and cost reductions; logically there will be some benefit gained, acting to reduce overall costs slightly. Secondly, …. the calculations of charcoal cooking expenditure are likely to be on the low side, as efficiencies achieved in practice may well be lower than assumed." Leach and Oduro*

# SECTION 7

## Behavioural change – beyond a price point

The third paper in the trilogy of research questions (RQ3 Brown and Sumanik-Leary 2015) considered the behavioural change aspect[15].


As the ESMAP & GACC (2015) paper states:

> *"Major persisting challenges include cookstove and fuel affordability for end users; low levels of consumer awareness; behaviour change obstacles to the reduced use of traditional stoves after the adoption of new solutions; and limited consumer access to appropriately designed and durable products."*

If, as Leach and Oduro suggest, the new proposition can reach a price point that is competitive, will it then be confronted with similar issues of consumer awareness, behaviour change and consumer access? The third paper by Brown and Sumanik-Leary (2015) considered lessons learnt from various related programmes of work and sought to anticipate some of the behaviour change challenges.

The focus in their paper is on the potential uptake and sustainable use of the PV-eCook concept within the Sub-Saharan African context, although where appropriate the paper draws on relevant examples from other parts of the Global South (and beyond) and also makes some commentary on the potential prospects for electric cooking within these contexts. After reminding the reader of the significant human costs that high levels of dependence upon traditional cooking methods creates, they focus a discussion of the lessons learnt from the literature of four key transitions chosen for their relevance to the PV-eCook concept within the SSA context: the experiences with electric cooking in South Africa, attempts to accelerate the uptake of Improved Cookstoves (ICS), existing transitions to LPG for cooking, and the differential spread of solar home systems within different national contexts.

### 7.1 Electric Cooking in South Africa

South Africa is one of the few places in Africa where a significant number of people now cook using electricity. After exploring the literature, Brown and Sumanik-Leary present a number of barriers and drivers found in that context. Positive drivers supporting the transition to electric cooking in South Africa included lower purchase prices for electric stoves than LPG stoves; the high fire risk of paraffin stoves in informal urban settlements led to the government favouring safer electric cooking in national policy, and the low unit cost made electricity significantly cheaper per meal than LPG, paraffin or ethanol gel. They also note that fuel stacking[16] is common, and that reliability is often enhanced by strategic use of alternative fuels.

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15 Research question 3:- What are the possible intra and inter household dynamics among African households (including the very poor) that may affect the uptake of a Solar Electric Cooking system as described in research question 1.

16 The use of multiple fuels, each usually with a different cooking appliance.

Regarding barriers, they note that despite the latter driver, electricity was **perceived** as too expensive for cooking, even though it was in fact competitive with alternative fuels. Consumers also thought that the stoves were 'more expensive'. Brown and Sumanik-Leary note that the government introduced a policy of FBE (Free Basic Electricity) under which the first 50kWh/month was free for poor households. While this did not change the situation overnight it changed the perception of electricity costs.

Not everyone in South Africa uses electricity for cooking. Of those who have not taken up electricity, there is a context specific barrier - where collecting firewood is possible. Low income homes connected to the grid would still prefer to use firewood as it has no cash cost to the household. There are also areas of South Africa that remain unconnected - both rural and informal urban areas. However this situation is changing with the government increasing the number of relatively reliable grid connections, as national policy is focused on grid expansion. Finally Brown and Sumanik-Leary identify two other barriers that slowed uptake:- the presence of poor quality equipment (hob) and the additional peak demand that cooking placed on South Africa's already strained electricity infrastructure.

## 7.2 Improved Cookstoves

Considerable international effort has been exerted over recent decades in designing and distributing Improved CookStoves (ICS), with the aims of encouraging more efficient use of fuelwood/charcoal (reducing the pressure on local forestry resources and reducing the time spent collecting it) and reducing the damaging health impacts of high levels of indoor air pollution.

For Brown and Sumanik-Leary the literature states three clear drivers. The first is the potential for local manufacture high with its associate benefits:

- ability to offer communities the option to participate in the design and delivery of locally appropriate stoves;
- boosting local economy;
- building capacity for after-sales service;
- creating local jobs.

It is worth noting that there is a counter narrative in the literature that suggests that even Improved Charcoal Cookstoves should be manufactured in factories, where quality of the stoves can be controlled. It has been said that locally produced stoves often are poor quality and do not actually perform as promoted.

The second driver is its ability to tackle serious health and lifestyle problems, particularly for women. The driver is the negative health effects of traditional cooking methods, predominantly for women and children:

- indoor air quality;
- risk of burns;
- strong international funding interest in tackling this area.

The third is the time taken to collect fuelwood (primarily rural areas) and the cost of purchased fuelwood/charcoal which in many contexts is increasing. While the second and third of these drivers would be directly relevant to the Solar Electric Cooking system, the first would be only partially applicable.

However since the ICS sector has been operating globally for more than 3 decades, there are also considerable insights into the barriers experienced, along with enablers of uptake that can overcome those barriers.  Table 1 presents Brown and Sumanik-Leary's insights drawn from the literature.

<table>
<tr><th>Barriers</th><th>Enablers</th></tr>
<tr><td>Poor quality imitation ICS.</td><td rowspan="7">Development and enforcement of international/National standards<br>Innovative financing mechanisms:<br>• micro-credit.<br>• International carbon funding.<br>• Financing support for key sector actors and development of entrepreneurialism.<br>Strong global and national promotional framework (GACC).<br>Well-regulated market based approaches with effective social marketing strategies:<br>• Knowing the market<br>• Matching message to context-specific purchasing triggers & barriers<br>• Getting the mix right<br>• Surge of social marketing activities is required initially<br>• Early adopters who may not be the poorest facilitate word of mouth dissemination in new places<br>• Targeted awareness raising campaigns on benefits of ICS<br>• Village leaders facilitating consensus in community decision making and promotion of the technology.<br>• Evolution of designs and marketing strategies to match local cooking practices and locally available skills and materials.<br>• Development of effective after-sales service.<br>• Greater participation of women throughout the value chain, from product design to after-sales service.</td></tr>
<tr><td>Financing:<br>• Upfront cost of the stove.<br>• Poorly designed subsidies undermining end-user ownership.<br>• Lack of capital for business growth.<br>• Firewood in rural areas usually collected for free.</td></tr>
<tr><td>In many cultures, ICS benefits are mainly for women, whilst men make purchasing decisions.</td></tr>
<tr><td>User practices often different to laboratory test conditions used by stove designers & still only a partial solution:<br>• Even the best ICS still produce harmful emissions, particularly when not used as designed.<br>• Can be incompatible with local cooking practices due to lack of adaptability.<br>• Efficiencies can be lower than traditional three stone fire if not utilised appropriately.<br>• Ongoing need for firewood/charcoal.<br>• Small reductions in fuelwood use don't always translate into fuelwood collection time savings.</td></tr>
<tr><td>Policy focus on electrification, not biomass means lack of high-level political buy-in.</td></tr>
<tr><td>Lack of awareness of locally available ICS products and their benefits.</td></tr>
<tr><td>Each context different:<br>• Local availability of skills and construction<br>• Effectiveness of particular marketing messages</td></tr>
</table>

**Table 1 Key barriers preventing the transition to ICS in the Global South and (where applicable) the enablers that overcame them**

## 7.3 Liquid Petroleum Gas (LPG)

The third example drawn from existing cooking transitions literature comes from explorations of the take-up and promotion of LPG as a cleaner alternative to traditional biomass stoves (improved or otherwise). LPG is comparable to electric cooking in terms of the end-user experience and is widely used as an equivalent to natural gas in Northern regions without a mains gas supply. As a result, the literature surrounding the South's transition to LPG can offer a greater understanding of the factors that influence consumer choice when switching to a modern cooking fuel.

Based on studies from low and middle income countries, they find that a key driver for LPG programmes is the desire and aspiration for modernisation.  The data suggests a strong link between electrification and uptake of modern fuels. As with ICS they note key drivers include the increasing price of charcoal, and improvements in health from lower kitchen emissions. They also note that some local manufacture of LPG equipment is possible.

However in terms of barriers to LPG uptake, Brown and Sumanik-Leary draw out from the literature the high relative cost levels of LPG (compared to biomass). They note that subsidies are often poorly targeted, tending to benefit the rich, well-educated urban elite or in some cases motor vehicle owners. They also see barriers in various supply issues. The supply of LPG is dependent on imports in countries without indigenous resources or the expertise to exploit them, and supply chain vulnerabilities can create price volatility and even cut off supply. They note that governments have mitigated these barriers with clear marketing of health and other benefits; well-targeted subsidies, e.g. initial purchase costs (stove, cylinder, accessories) for low income rural households; and exploitation of national fossil fuel reserves where they exist or opening up markets to international suppliers and introducing effective price controls.

## 7.4 Solar Home Systems

Understanding the factors underlying the substantial growth in the use of Solar Home Systems (SHS) and smaller solar products for meeting lighting needs which has taken root to differing degrees across the Global South is of particular relevance to exploring the factors affecting the potential uptake of a Solar Electric Cooking system concept; not least because the case for PV-eCook is fundamentally predicated on the potential market for a higher capacity SHS designed to replace solid fuel burning for cooking rather than replacing kerosene/candles for lighting.

The key drivers and barriers are presented in Table 2 and 3 below.

**Table 2 The key drivers for the transition to SHS in the Global South**

| Driver |
|---|
| **Replacement of other purchased fuels, e.g. kerosene, candles** |
| **Micro-benefits highly valued by users**<br>• **Lighting for indoor air quality, safety, studying, social space, evening work**<br>• **Mobile phone charging, TV and other 'connective' applications.** |
| **Inter-household power generation differences minimal as solar resource geographically well correlated with people living without access to electricity and power production linearly proportional to the solar resource.** |

**Table 3 Key barriers preventing the transition to SHS in the Global South and (where applicable) the enablers that overcame them**

<table>
<tr><th>Barriers</th><th>Enablers</th></tr>
<tr><td>Limited range of energy services, productive uses and potential for poverty alleviation limited, so negative perception of SHS if grid extension also available</td><td rowspan="6">Growing capacity of SHS systems<br>Awareness raising campaigns targeted at specific groups of users<br>Development of effective service networks. Development of Local capacity building for small businesses and local technicians<br>• Decrease in price of LEDs and PV panels<br>• Extensive donor support for PV<br>• Enabling national policies (e.g. VAT & import tax exemption)<br>• New business models<br>• Fee-for-service with mobile payments and/or micro-credit<br>Market analyses for each new context to determine who to target and how</td></tr>
<tr><td>Theft of high value components</td></tr>
<tr><td>Awareness low in older, poorer and less well educated households</td></tr>
<tr><td>Maintenance and after sales service: success of SHS programmes frequently affected by poor maintenance, low quality products and lack of after sales service</td></tr>
<tr><td>Cost issues:<br>• High initial purchase costs and even monthly payments make SHS difficult for poor households to afford.<br>• Productive uses and hence income enhancement potential limited.<br>• Savings on low kerosene, disposable batteries etc. expenditure by poor households often not enough to cover SHS costs</td></tr>
<tr><td>Every local context unique, so significant time and effort required to find a system that works in each new place</td></tr>
</table>

Sustainable use of the PV-eCook proposition and the resulting products, systems and services, will depend on a considered approach to the consumer. Brown and Sumanik-Leary recommend *" PV-eCook should be launched on the open market with a suitable service network preferably one that already exists (most likely to be created by strengthening the existing SHS infrastructure in rural areas) and is capable of collecting feedback from end users and delivering this to relevant stakeholders. Training programmes should be focussed on women, as they are the primary beneficiaries and will therefore have the greatest motivation to see the technology succeed. Bundling PV-eCook with locally appropriate appliances in order to maximise the value of the embedded electrical infrastructure offered to households, but particularly in cultural contexts where men make major household decisions, in order to incentivise men both to purchase and keep up with repayments……. Awareness raising campaigns on the benefits of clean cooking that are tailored to the market, match message to context-specific purchasing triggers/barriers and get the mix right should pave the way for PV-eCook in new places by beginning with a surge of social marketing activities. However, in order to ensure maximum impact throughout society, longer term awareness raising campaigns should be targeted at older, less well educated and poorer households."* (Brown and Sumanik-Leary 2015).

It is perhaps interesting to note that these recommendations are common to many technologies and in particular to ICS. The peer reviewer of this paper noted that *"I have seen this recommended so many times (and even have recommended it myself!) for stoves that are of very poor quality. Once the consumer tries the stove, all this effort is for naught, because it does not perform. However, before these issues are addressed, you have to have a product to sell that provides a clear benefit vis a vis the cost to a consumer that is willing to pay for it."* The performance of a correctly sized PV-eCook will be important, and will need to match the cooking needs of the household.

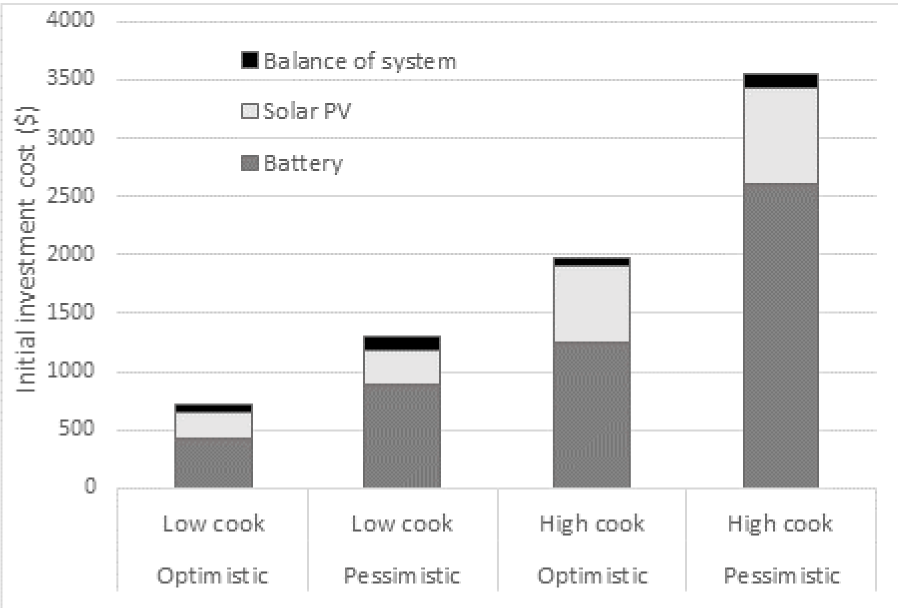
# SECTION 8

## Innovative financing

Leach and Oduro (2015) emphasise the role of innovative financing in rolling out Solar Electric Cooking, as do Brown and Sumanik-Leary (2015).


Few households would be able to afford the upfront cost of the system. Component contributions to total cost were mapped out for 2020 as shown in Figure 7.

**Figure 7 Component contributions to total cost, 2020, DR=5%**




As we can see, even with the low cook optimistic scenario, the initial cost of equipment is approximately $716, and for the pessimistic scenario it is of the order $1300. Could families pay and would they be willing to invest such amounts?

The approach taken for the Leach and Oduro study was to assume the required investment, plus ongoing replacement costs, are financed by a third party, on some form of energy services model, with the user paying a monthly fee. The different discount rates trialled were intended to represent two distinct investor types. The 5% discount rate assumes investment is undertaken by a government agency or other large institution, which is not risk averse and can borrow cheaply. The 20% rate represents the perspective of a commercial institution seeking to make a reasonable return and with some risk sensitivity. They note that 20% would be regarded as a very high rate for analysis of any commercial investment in the UK. However, they also acknowledge that even this rate will not reflect fully the perceived risks of a new technology deployed in a developing country context, especially to poor households with no collateral.

They also question the practicalities and financing of larger 'high cook' scenarios. "*A focus simply on monthly cooking cost and how that compares with traditional fuel expenditure does* *not give the complete picture: the larger systems proposed here might work technically and economically, but it is difficult to see them being accepted by poor households. Two PV panels should fit on most household roofs. Seven becomes a 'PV roof' of the sort requiring complex mounting systems. In addition, the larger the system, the larger the financial outlay, with implications for if, and how, such a system could be financed.*"

So two questions remain that were highlighted by discussion with DFID:

- Are there households that could afford Solar Electric Cooking at the 2020 price?
- Who might be willing to invest in the initial equipment?

## 8.1 Affordability

Leach and Oduro present their comparison in terms of monthly cost. They clearly show that costs of the SEC system are comparable to expenditure on charcoal. The market studies quoted above show that some segments of the market could afford monthly payments equivalent to the levelised cost of using a Solar Electric Cooking system. But what proportion of the population could afford to pay the required level of payments?

Bacon 2010 illustrated the expenditure by quintiles for a number of countries, including Kenya and Uganda. Although the publication was dated 2010, it drew on 2005 data. It shows that expenditure on biomass was between 4 to 8% of income for urban populations, and 2 to 6% for rural populations. For a country such as Kenya, at 2005, expenditure on fuels among the poorest quintile was US$139 pa, while the highest quintile was US$675 pa. Kenya has seen a 21% increase adjusted prices since 2005 (KNBS 2015). Since Bacon showed that the average monthly expenditure on biomass by the poorest urban quintile was $4 (with some collection of fuel for free), with the other quintiles paying between $8 to $10 per month, it seems reasonable to say that 4/5$^{th}$ of the urban population of Kenya could potentially switch their existing expenditure to PV-eCook (at 2020 prices) – i.e. they could 'afford it' in 2020[17]**.** In Uganda the picture is clearer:- the lowest rural quintile in Uganda were said to expend $7 a month while the highest spent $12 (Bacon, 2005 data, UBOS 2015) suggesting that in Uganda with a 20% rise in adjusted prices almost all rural households could afford PV-eCook.

This example of Kenya is intended to illustrate that the affordability (as expressed as a monthly expenditure) is there for large proportions of the population. This is not a concept that only applies to the highest wealth quintile.

Affordability is one aspect of household economics. Willingness to pay is a different matter. Could households be persuaded to pay? mKopa[18] solar lighting systems ask for $12 a month over a year (i.e. a total of 12 monthly payments) and delivers an 8W panel, two lights, a radio, battery, and charge controller. Given the uptake it is clear there are households willing to pay $12 a month if the proposition is regarded as worthwhile. Indeed this was the finding that stimulated investigations into the proposition – would the repurposing of the current expenditure on biomass fuels provide an opportunity to install modern energy? This needs further investigation.

However, while the monthly cost seems to present no greater affordability issues than the day to day costs of living with biomass, financing the initial investment could pose a challenge.

17 The rural picture has less cash expenditure due to approximately 40% of survey respondents imputing a value of zero to collected fuel. Nevertheless the average expenditure ranged from $2 (lowest quintile) to $8 (highest quintile) suggests that about 40% of rural households could afford PV-eCook.

18 http://www.m-kopa.com/ Accessed Dec 2015

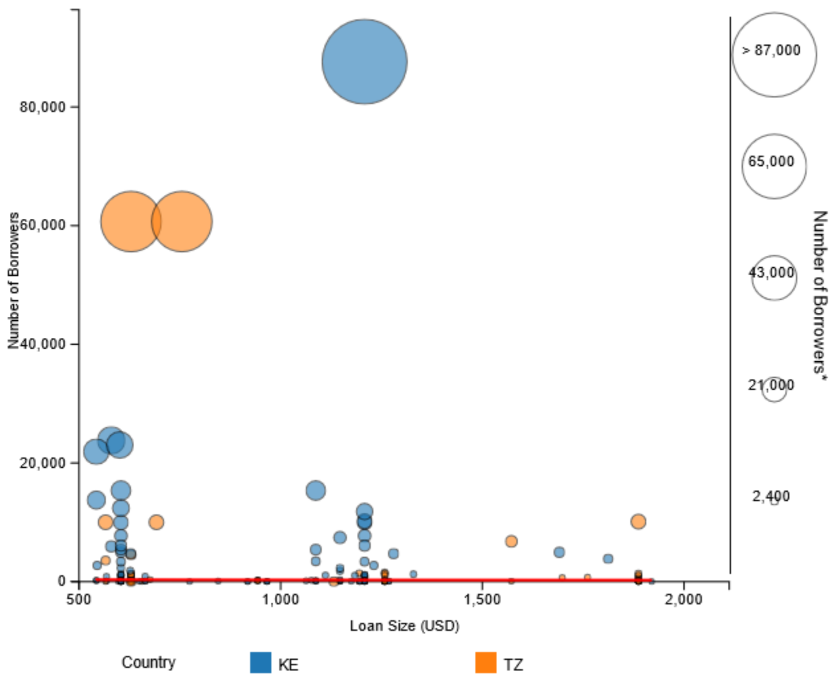
## 8.2 Who might invest?

Organisations running pay as you go solar home lighting systems have struggled to get initial investment, and improved stove agencies will point to the difficulties of getting households to invest even $30 in stoves.

There are two approaches suggested; one is to consider this in terms of microfinance loans and the other is to think of it as an alternative utility model.

There are a number of microfinance instruments that lend consumers more than $800. Figure 6 shows that microfinance institutions in Kenya and Tanzania do indeed make loans of over $500 to substantial numbers of borrowers. Almost all microfinance loan products above $500 are currently offered for a targeted purpose (e.g. agriculture or education) and require the borrower to have a business, be a salaried worker or have a reliable source of income/reliable cash flow. However, there are exceptions. For example the Kenya Women Microfinance Bank (KWFT) which allows loans between $500 and $2,000 for business but includes loans for the 'acquisition of clean energy saving cooking stoves (jikos)'[19]. It offers flexible loan amounts, flexible repayment periods, and there are no additional requirements such as income via a salary. SMEP Microfinance Bank Limited, also in Kenya, while focused on business loans would also consider 'Consumer loans' for the installation of electricity or a solar power system.

**Figure 8 Number of households borrowing between $500 and $2000 in Kenya and Tanzania (Created from http://www.mftransparency.org/ )**




While the majority of existing loans have restrictions that may preclude their use for Solar Electric Cooking, and that most agencies do not currently lend beyond 5 years, nevertheless the presence of some loans specifically for similar purposes suggests that it is a matter of

19 http://www.mftransparency.org/

creating awareness of the opportunity within banks and microfinance institutions rather than an impossibility[20].

However, this problem should not be framed in terms of the household raising the finance. Brown and Sumanik-Leary, suggest that due to the high value of the PV-eCook equipment (and therefore longer investment horizon for poor households), a utility business model is seen as the most attractive for poor households.

Investment in utilities involves significant funds and we consider one example to illustrate the dimensions. Power Africa (USAID 2015) has raised $1.1 Billion for a wind farm in Turkana, Kenya to strengthen the national grid. Assuming a 30% load factor, this would deliver 788 GWh per annum. If this were used to meet electrical cooking energy demands based on the low cook scenario of Leach and Oduro's model, it could supply 1.5 million households at a cost of $712 per household. This investment in wind energy represents the cost to feed it into the existing grid, so making a connection to the household would be an added cost. Given that connection costs can be between $300 for urban areas and $1,000 for rural areas, the sums suggest that the idea of $1000 to $1500 investment per household is within the scope of some donor organisations. A scan of costs for more discrete populations (islands in the Pacific) suggest that there have been investments of up to $2,000 per household in the recent past.

It is the case that although there may have been investments at this order of magnitude per household, the household is not 'responsible' for major equipment in a grid. It has its connection into its home, but the equipment, such as wind turbines, are managed by the implementing agency or a third party.

While we have mainly discussed home systems in this paper, there are emerging models for nano-grid systems of 10 to 20 households, operated cost effectively by a professionally trained service agent. Whether home, nano, micro, mini or national, the levels of investment per household are likely similar, and the upfront investment for Solar Electric Cooking is comparable to other utility investments.

Brown and Leary also draw attention to carbon finance stating only that international carbon finance should be investigated, ideally for targeted interventions to strengthen market based systems rather than direct subsidies. They also state that successful local micro-finance schemes should be leveraged. They highlight the fact from the literature on Solar Home Systems that each household is a dynamic unit, whose needs, wants, ability to pay and trust in the SHS change over time. Sovacool & D'Agostino (2012) found that over time, once finances allowed, most households gradually transitioned to larger systems once they became familiar with the energy services offered by SHS and the value they could add to their lives.

[20] Rwanda and Tanzania both have microfinance institutions geared to provide loans for biogas units. In the case of Rwanda these loans can exceed $500 although they are 50% matched by government grants. This illustrates that targeted loan instruments can be created if the value of the public good is strong enough.

# SECTION 9

## Markets for solar electric cooking


Both the economic modelling section and the behavioural commentary have addressed alternative cooking fuels, and pointed out that households are likely to undertake different 'fuel stacking' strategies in different market segments depending on a wide range of factors. The **affordability** of a Solar Electric Cooking system will be only one factor. Its distribution network, the maintenance requirements, awareness of consumers, and the changing prices of alternative fuels all play a part (among others) on influencing the potential take up of the PV-eCook proposition.

In their paper, Brown and Sumanik-Leary attempt to build on the systematic review commissioned by DFID on the *Factors influencing the large-scale uptake by households of cleaner and more efficient household energy technologies* (Puzzolo). By taking a similar aproach to the systematic review, they seek to situate the Solar Electric Cooking system proposition alongside other technologies.

When they focus on the barriers to initial adoption from an end-user perspective they show that PV-eCook is likely to sit alongside LPG as an aspirational cooking technology. Although they expect the cost to fall over time, strong accompanying financing schemes will be needed to allow the user to repay the value of the system over time. They suggest that PV-eCook has broad geographical reach, arguably even broader than LPG, as it does not depend on the local availability of specific fuels or feedstocks. They note that the PV-eCook system clearly requires a good solar resource which in most parts of the Global South is high.

As one might expect, each of the technologies has factors that might attract users and other factors that might turn away users. The conclusion is that there is no one size fits all, and that PV-eCook has characteristics that might make it the technology of choice in some circumstances.

### 9.1 Market segments

Brown and Sumanik-Leary conclude their paper with a commentary on potential market segments and a list of recommendations for further research. Having briefly explored the role of B-eCook (Battery Electric Cooking – see section 10.1) in urban grid connected areas, and concluded that PV-eCook should be targeting regions where SHS have already had success, thus taking advantage of the technical knowledge transfer and consumer awareness of electricity and off-grid PV systems, the authors present Table 4.

**Table 4 Categorisation of potential eCook adopters according to existing levels of energy access and assessment of each sector's likelihood of adoption**

Transition to eCook very unlikely
Transition to eCook challenging as many barriers to address
Transition to eCook possible if several barriers are addressed
Transition to eCook likely if several barriers are addressed
Transition to eCook likely if key barrier addressed

| Current Cooking appliance | | Current access to electricity | | | |
|---|---|---|---|---|---|
| | | None | Off-grid/isolated systems, e.g. Solar Home Systems (SHS) | Unreliable national grid or mini-/micro-/nano-grid | Reliable national grid supply |
| | 3 stone fire or traditional stove Solid fuel collectors | **Least likely** to transition, as technical, financial and cultural barriers greatest. | Transition to PV-eCook **possible** with locally appropriate delivery model, awareness raising showing health benefits & innovative financing*. **No obvious financial substitution**. | Transition to B-eCook **possible** with locally appropriate delivery model, awareness raising showing health benefits & innovative financing*. **No obvious financial substitution**. | **Battery not required** from end-user perspective***. Transition **very unlikely** - households have currently chosen time based collection rather than cash expenditure on energy. |
| | 3 stone fire or traditional stove Solid fuel purchasers | Transition to PV-eCook **possible** if technical training on PV systems, innovative financing*, awareness raising showing health benefits & locally appropriate delivery model offered. | **Likely** transition to PV-eCook with locally appropriate **delivery model**, **awareness raising** showing health benefits & **innovative financing*** as **fuel payments can offset cost**. | **Likely** transition to B-eCook with locally appropriate **delivery model, innovative financing***, **awareness raising** showing health benefits as **fuel payments can offset cost**. | **Battery not required** from end-user perspective***. **Possible** transition to eCook with innovative financing*, battery subsidy, locally appropriate delivery model & awareness raising showing health benefits. |
| | Improved Cookstove** Solid fuel collectors | Transition to PV-eCook **challenging** as technical training on PV systems locally appropriate delivery model & innovative financing*. No obvious financial substitution possible. | Transition to PV-eCook **possible**: locally appropriate delivery model, awareness raising showing health benefits & innovative financing* required. **No obvious financial substitution**. | Transition to B-eCook **possible**: locally appropriate delivery model, awareness raising showing health benefits & innovative financing* required. **No obvious financial substitution**. | **Battery not required** from end-user perspective***. Transition **very unlikely** - households have currently chosen time based collection rather than cash expenditure on energy. |
| | Improved Cookstove** Solid fuel purchasers | Transition to PV-eCook **possible** if technical training on PV systems, locally appropriate delivery model, awareness raising showing health benefits & innovative financing* offered. | **Most likely** to transition to **PV-eCook** as **fuel payments can offset cost**. Requires locally appropriate **delivery model** & **innovative financing***. | **Most likely** to transition to **B-eCook** as **fuel payments can offset cost**. Requires locally appropriate **delivery model** & **innovative financing***. | **Battery not required** from end-user perspective***. **Possible transition** to eCook with locally appropriate delivery model, innovative financing*, battery subsidy & awareness raising showing health benefits. |
| | LPG/Biogas** | Already have access to other forms of modern energy, but | Already have access to other forms of modern energy, but **relative** | Already have access to other forms of modern energy, but **relative** | **Battery not required** from end-user perspective***. Already have access |

| | Current access to electricity | | | |
|---|---|---|---|---|
| | None | Off-grid/isolated systems, e.g. Solar Home Systems (SHS) | Unreliable national grid or mini-/micro-/nano-grid | Reliable national grid supply |
| | **relative monetary/time costs of fuel** may drive transition to eCook. Needs technical training on PV systems, locally appropriate delivery model & innovative financing*. | **monetary/time costs of fuel** may drive transition to eCook. Requires locally appropriate delivery model & innovative financing*. | **monetary/time costs of fuel** may drive transition to eCook. Requires locally appropriate delivery model & innovative financing*. | to other forms of modern energy, but **relative monetary/time costs of fuel** may drive transition to eCook if locally appropriate delivery model, innovative financing* & battery subsidy available. |
| Electricity | N/a | Already using a form of PV-eCook. If these people exist, they warrant further study. | **Likely** to transition to B-eCook, which offers superior **reliability**. Requires locally appropriate **delivery model** & **innovative financing***. | **Battery not required** from end-user perspective***. Uptake of eCook **only possible if battery cost subsidised**. |

Assumptions:

| | |
|---|---|
| * | For some market segments eCook equal or less than current expenditure. |
| ** | User may be aware of health benefits having made transition to ICS/LPG/biogas. |
| *** | Battery only needed for national grid level system optimisation - load balancing and peak load reduction. |

Brown and Sumanik-Leary go on to discuss strategies for rolling out a Solar Electric Cooking system based on the lessons learned literature.  They include tables summarising the learning points and the action required if a Solar Electric Cooking system were to be rolled out.

Brown and Sumanik-Leary briefly mention two other markets, both of which could immediately be considered as they are less sensitive to cost:

- Larger systems for community services, e.g. schools, and small businesses.
- Specialist systems designed for rapid deployment in disaster relief scenarios.

# SECTION 10

## A variant spinoff to the idea of solar electric cooking

### 10.1 B-eCook


Batchelor (2015) developed his initial ideas to include a version of 'eCook' that does not necessarily include solar electricity generation. Batchelor argues that many grids within Africa (and Asia) have difficulty supplying peak load, but have spare capacity at other times. He cites Kenya as a typical example. Batchelor argues that by trickle charging a battery during night hours, the household would benefit by having reliable, stored energy for consumption whenever they wanted it, and the grid would benefit by effectively having decentralised storage built in to assist with load management. Indeed Batchelor goes so far as to suggest that the technology offers a potential solution that could mobilise investment that has a ready benefit to the consumer and therefore clear returns. This could enable donors and governments to achieve the step change in investment needed to increase grid utilisation of existing and new generating capacity. It also ideally fits any grid with substantial embedded renewable energy generating capacity, since the energy storage could potentially smooth peaks in supplies.

Brown and Sumanik-Leary pick up on these ideas and talk about 'B-eCook'. They suggest this has application on unreliable grids and independent grids (a collective term for mini, micro, and nano grids) and explore B-eCook in the context of relatively low unit costs of electricity. They note that uptake of B-eCook could well occur among the urban middle class who commonly have grid connections (even if they are too unreliable to cook with), have disposable income, and who experience increasing charcoal (or LPG) prices. *"Here, the awareness of and desire for access to modern energy services is likely to be higher than all other segments of society. What is more, their ability to pay for them is also likely to be high, as they are most probably in salaried employment and can also offset their savings on fuelwood/charcoal."* They note that an early adoption of B-eCook could establish service networks and the desirability of the product which could then support adoption of PV-eCook.

The papers do not explore the potential impact of B-eCook on national grids if it were taken up at scale, although Brown and Sumanik-Leary suggest this is a subject for further research.

# SECTION 11

## Conclusion

Solar photovoltaic based cooking systems could provide clean, reliable cooking that could also improve access to high quality energy for other uses. The economic modelling by Leach and Oduro (2015) confirm that even with relatively conservative assumptions the lifetime cost of a Solar Electric Cooking system will be comparable to the two main alternative fuels, charcoal and LPG, by 2020. The model includes evidence based assumptions on price ranges, which result in bands of possible costs. Whether taking a 'low energy' or a 'high energy' cooking scenario, the cost bands are comparable with the alternatives.

However, this does not mean that PV-eCook would be affordable (as a monthly cost) in all locations. Context specific policies, market conditions, service provisions, and investment strategies will all affect the feasibility of the proposition in any given location. What the modelling does clearly indicate is that this concept is worth further investigation, research, monitoring, and exploration of its potential to replace biomass fuels.

The expert opinion on battery technology by Slade (2015) confirms that the research question posed is ahead of the capability of current common lithium ion battery types to deliver long term, durable performance at high (tropical) temperatures, but arguably not by much in this rapidly advancing field. A wider scan of the emerging battery chemistries suggests that there will be a number of developments in batteries emerging over the next few years relevant to the proposition and that, based on manufacturers data, existing $LiFePO_4$ technologies could be used for the PV-eCook system and remain the current favourite.

The paper by Brown and Sumanik-Leary (2015) considered the socio-cultural barriers and drivers to the proposition. The paper neither confirms nor rejects the proposition per se. Rather it draws on lessons learned from comparable technologies to illustrate the potential drivers, barriers, and challenges likely to be relevant to the proposition. They conclude that with a strategic market based approach focusing on the supporting infrastructure there is a strong likelihood of take-up by specific market segments. In such a short assignment they have not attempted to locate the market segments geographically, but have described their characteristics. This paper has added to their work with a scan of a typical market, Kenya, and shown that the proposition could apply to the majority of households.

Regarding upfront investment, both Leach and Oduro and Brown and Sumanik-Leary suggest that due to the high value of the PV-eCook equipment (and therefore longer investment horizon for poor households), a utility business model is seen as the most attractive for poor households. This paper illustrates that the total upfront costs are of a similar order to those of existing grid and rural electrification programmes.

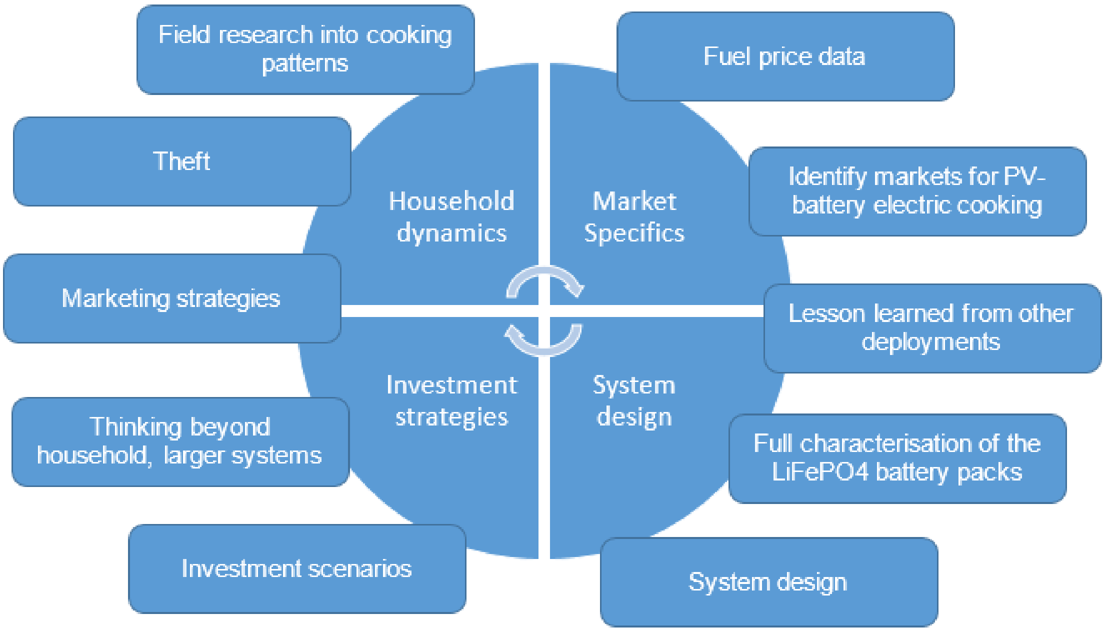
The papers do not dispute that the proposition of PV-eCook is both technically feasible and could be affordable in many markets in Africa by 2020.

**In brief the commissioned papers confirm that the proposition is worth further investigation. The proposition could be used to alleviate the impact of kitchen emissions on household health, and to contribute to Sustainable Development Goal 7.**

**The papers recommend further research to be conducted now that will enable action once the price point is reached in or around 2020.**

## 11.1 Further research, next steps

Each of the papers recommends further research and investigation of the concept. One subject often leads into another, a so an iterative integrated programme of research would best be conducted. In attempting to order the subjects, figure 7 represents how one subject might influence another:




- Field research into cooking patterns - identifying the actual energy used with different cooking appliances (and the opportunities to reduce consumption).
- Fuel price data – more specific data with key assumptions noted to enable inter comparison of data between regions
- Markets for PV-battery electric cooking – further work to estimate the size of the potential markets
- Consolidation of the evidence from the deployment of solar PV for other purposes – detailing realistic costs for deployment
- A programme of experimentation that focuses on the full characterisation of the behaviour of LiFePO4 battery packs (those current and those shortly to be introduced) and, for meaningful comparisons relative to an existing alternative battery pack approach, of VRLA battery packs
- System design - further detail will be needed on the system configuration, including wiring and control schemes.
- Investment scenarios – research into the typical cost base for existing investment types, including grid extension and its distribution networks and micro- and nano-grid investments and concepts.
- Thinking beyond the household – research into
    - Larger systems for community services, e.g. schools, and small businesses. If distributed free of charge as a marketing strategy to these places, they could also provide a way of raising awareness of eCook.
    - Portable systems for nomadic and semi-nomadic people.

- Specialist systems designed for rapid deployment in disaster relief scenarios.
- Theft - This potentially significant issue will require further exploration
- Marketing strategies - explore a range of different female-led marketing techniques

In addition to the recommendations documented by the other papers, some broader 'global' research is also required. This includes:

- Strategies for waste disposal of systems,
- The possible role of carbon finance mechanisms, and
- Possible shortages of key elements used in battery manufacture (causing temporary price rises).

There are also 'National' research questions which are only lightly touched on by the authors. For instance, PV-eCook and B-eCook could assist with grid load management, enabling grids to make more effective use of existing modern energy resources; this should be researched further. It is possible that direct engagement with utilities could create an interest and investment in taking the idea further.

Finally, a communication strategy is required to engage with various interested communities. Like any policy influencing strategy, there needs to be a mixture of actions (Batchelor 2012). These reports provide a basis for discussion, however DFID could consider various ways of engaging policy actors:

- **Convening**:- DFID could use its convening power to create a new space specifically for discussion on modern energy and cooking. Since this is currently not being discussed, and such discussion as there is tends to be siloed into those engaged with ICS and those engaged with Solar, a new networking space to facilitate crossover between the two would be useful.
- **Networking**:- The project team and DFID RED could actively use their networks to discuss the idea. A Delphic survey method such as that used for the DFID funded research 'Gender Energy and Poverty' could be employed.
- **Social and mainstream media**:- DFID could ensure that the idea is profiled on their .gov webpages and suitable social media used to stimulate interest.
- **Create a challenge fund**:- DFID could work with existing initiatives such as Innovate UK, Mission Innovation, Breakthrough Energy Coalition, and LCEDN to call for researchers to investigate the idea further, or to respond to the research challenges noted above.

## 11.2 Conclusion – the propositions contribution to Sustainable Development Goal 7

It is important to realise that the proposition is not a single product – it is a new genre of action, and is potentially transformative. The proposition is about strategically considering whether the current expenditure on biomass can be converted to modern energy. This synthesis paper started by linking the proposition to the Sustainable Energy Development Goal 7 – modern energy. The world has invested in Improved Cookstoves for more than 4 decades and has had some success. The recent focused strategy of the Global Alliance for Clean Cookstoves has affected millions of lives. However even GACC acknowledges that population increases may outrun their roll out of improved stoves, and that many improved stoves do not lead to significant health benefits. The emerging call is for a transformation to modern energy with its zero kitchen emissions. Some commentators believe that with a stable electric infrastructure, cooking with electricity would become the norm. While evidence from South Africa seems to confirm this most of Africa is many years (perhaps decades) away from having stable, reliable grids that could fulfil the peak loads that electric cooking would create.   Even so, the World Bank calls for a step change in investment to get near to this stable energy infrastructure by 2030.

Whether solar energy is utilised within household systems or as part of mini, micro or nano grids, linking falling solar and battery costs with cooking in African households (and Asia) creates the  potential to make a significant contribution to SDG7.  Cooking is a major expenditure for 500 million households.  It is a major consumer of time and health.   Where households pay for their fuelwood and charcoal   this is a significant cash expense.  Solar electric cooking holds the potential to turn this (fuelwood and charcoal) cash into investment in modern energy.  This new genre of technology could harness “consumer expenditure” of an order of magnitude more than current investment in modern energy.

However, the challenge of biomass cooking is not just about household economics; it is about health, as kitchen based respiratory infections in Africa cause millions of deaths every year; it is about the environment, both locally with population pressures causing growth of charcoal production and destroying landscapes, and globally with a contribution to climate change emissions; it is about quality of life.  **A significant programme of research and activity on Solar Electric Cooking could change the lives of millions.**

The proposition directly addresses the challenge of SDG7, and offers the potential for a step change in investment in modern energy.  It is an innovation that challenges the business as usual approach of governments, donors, private sector, and consumers in Africa, and if taken forward at a measured pace could transform levels of access to modern energy.  It addresses the energy trilemma of energy security, energy equity, and environmental sustainability.  As such, the conclusion is clearly that the proposition merits further research, as well as discussion and dialogue among interested stakeholders and associated networks.

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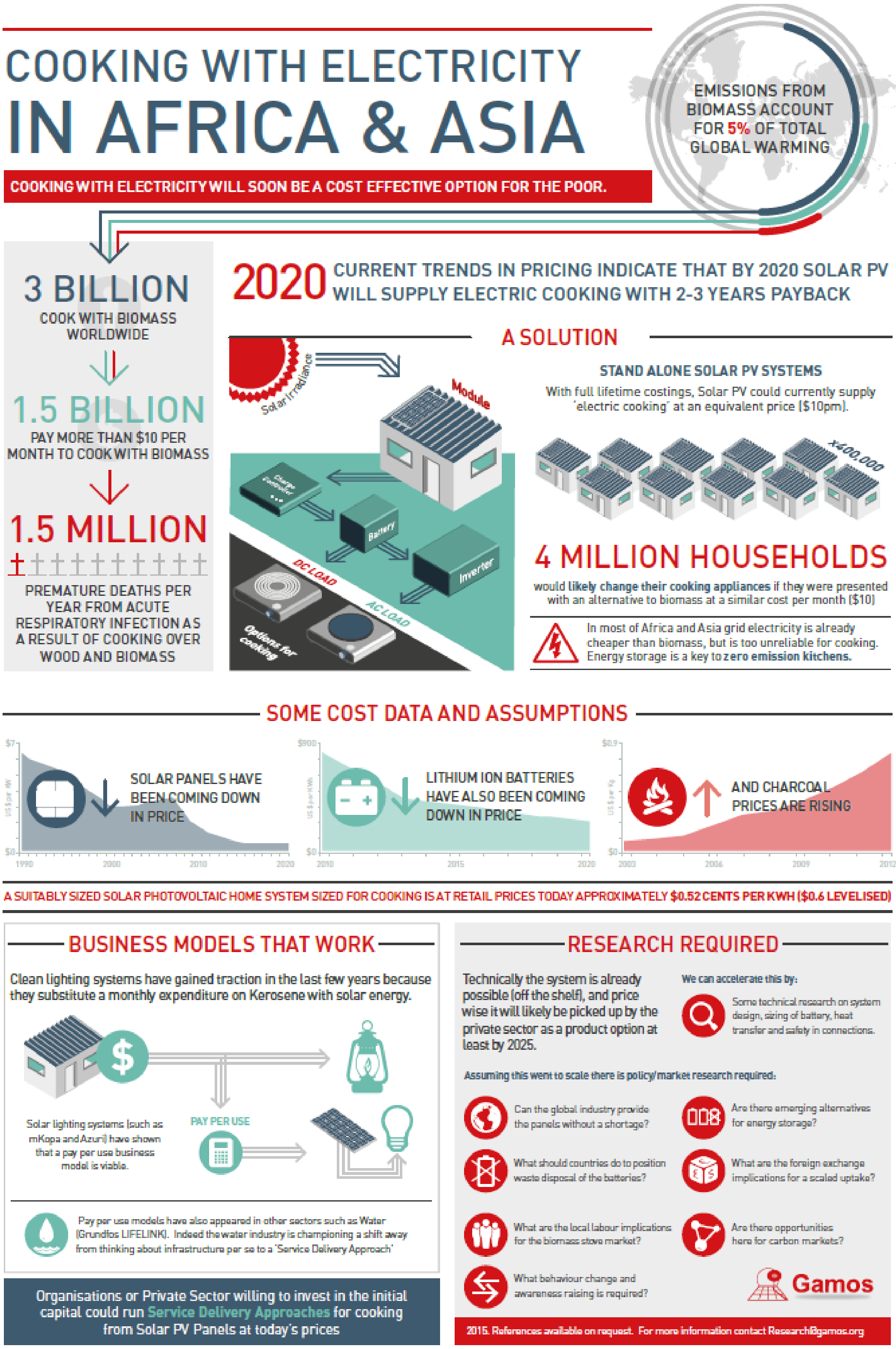
## Annex 1 Infographic



**Annex 2 Terms of Reference**

## Key Assumptions and Concepts on Potential for Solar Electric Cooking

**Objectives**
The purpose of these Terms of Reference is to assess some of the key assumptions around the potential for solar electric cooking as an option for poor households.

A research consortium led by Loughborough University and including University of Surrey (Dept. of Chemistry) and Gamos Ltd has been in discussion with DFID and a number of entities with an interest in technology options for cleaner cooking (e.g. Shell Foundation and Global Alliance for Clean Cooking). Specifically, their interest relates to the concept that combination of battery with cooking hob 'opens up' new opportunities for the resource poor to transition to a modern zero (kitchen) emission fuel. The concept is highlighted in the information note attached as annex 1.

These various discussions have highlighted a number of aspects of the approach where further analysis, information and expert and academic opinion is needed to strengthen confidence in the technical and financial feasibility of the option going forward.

This terms of reference addresses questions around pricing, battery durability and what aspects of behaviour change might need deeper consideration around solar electric cooking.

The aim of the assignment is to provide papers which can complement and strengthen proposals for further work in this area that might be funded by DFID or other entities with an interest. It is anticipated that the information could also be shared more widely across the sector to stimulate further debate and thinking.

**The specific objectives are to:**

- Ensure that decisions by research funders, including DFID, are made on the basis of viable assumptions and a rigorous understanding of the technical demands and capabilities of the technology, particularly the battery storage system.
- Using up-to-date data, information and analysis to give a good sense of what the likely stabilised price of a basic unit (with storage) could be in 5, 10 or 15 years time with some commentary on the sensitivities to different variable.
- Capture the behavioural change challenges that should be understood and investigated through longer term research that may affect the outworking of the concept.
- Use the above information to reassess and update earlier ideas, concepts and approaches with a view to the possibility of developing an appropriate longer term research programme.

**Specific key areas/questions to be covered include:**

**Research question 1:-** Given the trends in pricing in Solar Photovoltaic panels, lithium Ion batteries and charcoal/wood pricing in Africa, will there be a point when a suitably appropriate use of solar panels combined with battery, hot plate; control panels; with/without inverter could create a cost effective Solar Electric Cooking system which would substitute for charcoal (and wood) consumption for the same lifetime expenditure?

**Research question 2:-** Given the technological development in Batteries, and their current stated use, what would be the anticipated lifetime of a lithium Ion PO4 battery (suitably sized for research question 1) operating in 'harsh' conditions (excessive heat and dust) and discharging for between 40 mins and three hours a day.

**Research question 3**:- What are the possible intra and inter household dynamics among African households (including the very poor) that may affect the uptake of a Solar Electric Cooking system as described in research question 1. DFID has funded the Global Alliance on Clean Cooking to undertake research on behavioural change through its Evidence Base to catalyse a global market for Clean Cookstoves and Fuels (EBCC) Programme and more recently on a market transformation component of the Sustainable Energy for Girls and Women programme. In framing the issues around solar electric cooking, both of these programmes may provide useful insights on approach and learning.

It is envisaged that each research question will addressed by a separate standalone paper.

A synthesis report will be produced that captures the implications of the findings in the three papers on development of the concept going forward.

**Annex 3 Recommendations for further research**

All the individual papers make recommendations for further research. The sum of the data generated by the three papers shows that it is VERY likely that Solar Electric Cooking will be viable from a price point of view by 2020 or soon after. It therefore seems reasonable that a consortium of interested actors be encouraged to research the strengths, weaknesses and unknowns that may impact the lives of the poor should this proposition go to scale.

The following are the list of areas the authors highlighted:-

**Cooking patterns**

The literature is relatively sparse on evidence about eating and cooking patterns, and how these translate into the energy requirements. Further work could be done on lab tests for appliance efficiencies, surveys and observations of practices and field testing of energy consumption in use.

Of particular importance is to improve the understanding of the daily variation in cooking practices. For the present study we assumed that the same meal type is cooked every day. In practice of course some days will see more cooking undertaken, either to feed more people, or to cook tougher meat or pulses requiring longer simmering.

**Fuel prices**

The fuel price evidence base is patchy, with different cost bases and hence uncertainty about inter comparison of data between regions. Much of the data are reported on a nominal cost basis, with nothing said about the inflation rates in those periods, thus rendering headline figures of rapid fuel price growth unhelpful. Furthermore, more careful attention is needed to how subsidy and other market distortions are handled in reported prices.

**Market for PV-battery electric cooking**

A global market assessment to identify actual places that most closely resemble the ideal context described above should be undertaken. In each of the places identified with high potential, a more detailed local market assessment can determine in what form eCook should be delivered in order to achieve maximum impact for the poorest members of society. If the results of the local market assessment are favourable, a participatory process should ensue, whereby local people can determine how eCook can best evolve to meet their needs, engaging local leaders, particularly women, as champions. The potential for local manufacture should be given thorough consideration in each place, as supply chains, manufacturing capacities and enabling policies vary greatly.

**Solar PV**

For the next stage in this work, effort should be made to gather evidence from the deployment of solar PV for other purposes, seeking to understand the costs of real systems, their performance in use, and to confirm lifetimes. In addition, the supply chain for PV in developing countries is evolving, and will be an important reference point for developing similar chains for an electric cooker. There is a range of experience for smaller systems (e.g. for solar lighting and solar home systems) as well as a growing body of experience with much larger systems. It is however likely that there will be limited evidence for PV units in the 0.4 to 1 kW range.

Regarding solar insolation: there are numerous resources available to help map insolation levels. It is uncertain if there is an existing tool that can map the average daily insolation according to month or season, as needed for system sizing. However it is certain that such data can be extracted from existing tools, and with some effort could be developed into national and regional maps, as part of a market assessment.

**Batteries**
Given the significance of batteries to this concept, further research into the technical design and into battery prospects is essential. In particular, attention should be given to translating existing data to be relevant for this size of stationary power system, and the developing country application.

Regarding the technical research question of batteries working in 'harsh' conditions Slade recommends:

- A programme of experimentation that focuses on the full characterisation of the behaviour of LiFePO4 battery packs (those current and those shortly to be introduced) and, for meaningful comparisons relative to an existing alternative battery pack approach, of VRLA battery packs, both with duty cycles appropriate to higher power delivery at elevated temperature, as would be required in solar electric cooking in, for instance, sub-Saharan Africa. This would be concerned both with individual cells and, most importantly, complete battery packs of the differing battery approaches.
- A life-cycle-based techno-economic-ecological comparison of different energy storage options
- Maintain a watching brief on future battery technology developments
- Develop an interface between a prospective solar electric cooking development programme and UK-based battery pack manufacturers
- Consider the potential for extending cycle life and useable electrical energy storage performance by incorporation of supercapacitor components when seeking persistent high electrical power outputs

**Balance of system**
As part of a more detailed system study, fuller analysis is needed of the operating cycles implied for controllers and inverter. A design study of the options for such components for a specific PV-battery-stove would be valuable.

Evidence should also be sought from field studies on the lifetimes and durability of the balance of system components, for example as part of solar home systems.

**System design**
For the next stage of this work, further detail will be needed on the system configuration, including wiring and control schemes.

There is no substitute for empirical data and as a result, field trials in locations identified above are the logical next step. eCook should be trialled in a significant number of households, collecting valuable data on actual energy consumption, consumer satisfaction and suggestions for further design modifications to both the generic and local variant of the concept. The dynamics of fuel stacking should be given particular attention, as understanding the degree to which any eCook device is able to replace pre-existing stoves will determine to what degree the benefits can be obtained. Further consideration should also be given to the user experience in cooking, to feed into industrial design of the system: the size, location of components and general ergonomics.

**Financing**
A detailed study will be required of possible models of deployment, including past experience in other sectors (e.g. mobile communications, solar lanterns, solar home systems). However, given the significantly larger scale of the investment likely to be needed, further primary research is warranted, speaking to donors and commercial institutions about

their appetite for the levels of risk involved. Similarly, whilst there is an existing body of evidence about householders' propensity to adopt new technology and to accept credit or other service models, further research focused on the type of system proposed here will be needed. As discussed in section 6.2 it seems most appropriate to regard e-Cook as infrastructure investment for access to modern energy. Further research is thus warranted into the grounds for this proposition, and then into the typical cost base for existing investment types, including grid extension and its distribution networks and micro- and nano-grid investments and concepts.

Brown and Leary phrase this as Utility business models and leasing of high value products by poor households. This paper has focussed on the micro-credit and fee-for-service business models commonly employed by SHS initiatives, however as discussed earlier in this section, the higher cost of eCook systems (and therefore much longer investment horizon) suggests that a utility model may be more appropriate. Further research is needed into both the generic aspects of utility models and their compatibility with the eCook concept, as well as context-specific research into locally appropriate variants, the latter of which will most likely be conducted as part of a series of local market assessments. In addition to this, studying the financial mechanisms that have allowed poor households to gain access to other high value items such as motorbikes or biogas digesters would also be beneficial.

**Thinking beyond the household**
A number of additional market segments have been identified during the course of this research that could generate additional demand for eCook. Further research is needed to investigate each of the following options:

- Larger systems for community services, e.g. schools, and small businesses. If distributed free of charge as a marketing strategy to these places, they could also provide a way of raising awareness of eCook.
- Portable systems for nomadic and semi-nomadic people.
- Specialist systems designed for rapid deployment in disaster relief scenarios.

**Marketing strategies**
Some of the focus in the preceding discussion has been upon the development of participatory female focused marketing strategies and training programmes. There is a need for further work to be done on the successes and challenges faced by existing examples of such initiatives in the solar and ICS contexts, as well as the degree to which they have been accepted and/or challenged by men. During the early stages of market development, it will be important to explore a range of different female-led marketing techniques, measure uptake and explore the experiences of the entrepreneurs and their male partners/family members using a range of qualitative research techniques.

**Alliances and policy actor networks**
Thinking more broadly, developing strong relationships with the Global Alliance for Clean Cookstoves (GACC), the World Health Organisation (WHO) and other international organisations concerned with clean cooking, as well as local stakeholders in each new context, will also be important. Finally, investigating the dynamics of the 2% of South Africans already reportedly cooking on solar electric systems (e.g. system design, target market segments, end-user feedback, drivers of uptake) could provide valuable further learning opportunities for eCook.

**Theft**
One further research question which arose whilst conducting the research for this paper was the degree to which the increasing number of PV panels on household roofs required for the PV-eCook concept might result in increased incidences of theft. This is a potentially

significant issue and will require further exploration into both the incidence of panel theft in existing SHS and solar mini-/micro-/nano-grid programmes in a range of different contexts, as well as careful observational research during eCook pilot programmes.