eCook Zambia Prototyping Report

September 2019 Final Report

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Executive Summary

This report summarises the findings **from the prototyping carried out in Zambia**, with the aim of informing the development of a battery-supported electric cooking concept, eCook. It is part of a broader programme of work, designed to identify and investigate the opportunities and challenges that await in high impact markets such as Zambia. The evidence shows that today, urban Zambians typically fuel stack between charcoal and electricity. Charcoal is typically used for "long boilers" like beans, however recent advancements in electric cooking appliance technology now offers a much more time and energy efficient alternative to the conventional electric hotplate: the Electric Pressure Cooker (EPC). This appliance is expected to play a key role in the development of future battery-supported cooking systems (eCook), as it is the highly energy intensive "*long boilers*" such as beans or offals that are most likely to create peaks in demand that flatten the battery.

THE MBAULA

- Ubiquitous across urban Zambia today.
- Inefficient, expensive fuel, unhealthy & environmentally destructive
- Popular for "*long boilers*"

THE HOTPLATE

- Aspirational
- Popular for quicker cooking dishes

- Efficient for quick dishes, healthier & less environmentally destructive.
- Still expensive & unpopular for "*long boilers*"

THE ELECTRIC PRESSURE COOKER (EPC)

- Available, but not yet popularised.
- Far more energy efficient, quicker & easier for "*long boilers*"
- Can also cook "*medium boiler/friers*" & "*quick friers*"

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The prototyping carried out in Zambia used experimental *'ethno-engineering'* methodologies to create a kitchen laboratory where current and aspirational Zambian cooking practices and the trade-offs between energy-efficiency and behavioural change could be explored.

Zambian cuisine is made up of a diverse range of dishes, however this can be simplified to facilitate practical system design by categorising them by their energy demand. The three key categories proposed from this study are:

- "**Long Boilers**" – High energy demand, require boiling for more than an hour. High impact opportunity for EPCs.
- "**Medium Boiler/Fryer**" – Medium energy demand, typically 15 mins to 1 hour of boiling and/or frying. Possible to cook on an EPC with moderate energy savings.
- "**Quick Fryers**" – Low energy demand, typically less than 15 mins of frying. Most dishes possible to cook on an EPC, but with limited to no energy savings.

The promising results shown by EPCs in the kitchen laboratory lead to the inclusion of EPCs alongside hotplates in the cooking diaries study.

Values obtained from experimentation in the kitchen laboratory were used to size the demonstration prototype for a typical Zambian day of cooking in a 5-person household:

- A single "*quick fryer*" on a hotplate for breakfast= 0.2kWh
- 2 "*medium boiler/friers*" on a kettle/hotplate or EPC for lunch = 0.5+0.5kwh = 1kWh
- A "*long boiler*" on an EPC with 2 "*medium boiler/friers*" on a kettle/hotplate or EPC for dinner = 0.7+0.5+0.5kwh = 1.7kWh

A concept prototype was assembled from locally available components to supply a total daily energy demand of 2.9kWh. Lithium ion batteries and DC cooking appliances were not available, so an oversized 5.5kWh lead acid battery bank with a 1.5kW inverter/charger had to be substituted. The prototype was capable of charging either from 600W of PV or the grid. The prototype was successfully demonstrated at the eCook Zambia Kick off Meeting and Design Challenge and is now installed at the CEEEZ office. Subsequently, the much more portable and affordable eCookBucket was transported to Zambia, which paired a LiFePO4 battery with a DC rice cooker to create the solar lantern of solar electric cooking.

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1 Introduction

This report presents one part of the detailed in country research carried out to explore the market for eCook in Zambia. In particular, this in country work aims to gain much greater insight into culturally distinct cooking practices and explore how compatible they are with battery-supported electric cooking. The report is rich with detail and is intended to provide decision makers, practitioners and researchers with new knowledge and evidence.

This report presents the key learning points from the design, assembly and testing of a concept prototype to inform the future development of eCook within Zambia. It is one component of a broader study designed to assess the opportunities and challenges that lay ahead for eCook in high impact potential markets, such as Zambia, funded through Innovate UK's Energy Catalyst Round 4 by DfID UK Aid and Gamos Ltd. (https://elstove.com/innovate-reports/). A much deeper analysis of the data collected during this project was supported by the Modern Energy Cooking Services (MECS) programme, which included the writing of this report.

The overall aims of the Innovate project, plus the series of interrelated projects that precede and follow on from it are summarised in in *Appendix A: Problem statement and background to Innovate eCook project* and *Appendix 2: About the Modern Energy Cooking Services (MECS) Programme.*

1.1 Background

1.1.1 Context of the potential landscape change by eCook

The use of biomass and solid fuels for cooking is the everyday experience of nearly 3 billion people. This pervasive use of solid fuels and traditional cookstoves results in high levels of household air pollution with serious health impacts; extensive daily drudgery required to collect fuels, light and tend fires; and environmental degradation. Where households seek to use 'clean' fuels, they are often hindered by lack of access to affordable and reliable electricity and/or LPG. The enduring problem of biomass cooking is discussed further in *Appendix A: Problem statement and background to Innovate eCook project*, which not only describes the scale of the problem, but also how changes in renewable energy technology and energy storage open up new possibilities for addressing it.

1.1.2 Introducing 'eCook'

eCook is a potentially transformative battery-supported electric cooking concept designed to offer access to clean cooking and electricity to poorer HouseHolds (HHs) currently cooking on charcoal or other polluting fuels (Batchelor 2013; Batchelor 2015a; Batchelor 2015b). Enabling affordable electric cooking sourced from renewable energy technologies, could also provide households with sustainable, reliable, modern energy for a variety of other purposes.

A series of initial feasibility studies were funded by DfID UK AID under the PEAKS mechanism (available from https://elstove.com/dfid-uk-aid-reports/). Slade (2015) investigated the technical viability of the proposition, highlighting the need for further work defining the performance of various battery chemistries under high discharge and elevated temperature. Leach & Oduro (2015) constructed an economic model, breaking down PV-eCook into its component parts and tracking key price trends, concluding that by 2020, monthly repayments on PV-eCook were likely to be comparable with the cost of cooking on charcoal. Brown & Sumanik-Leary's (2015), review of behavioural change challenges highlighted two distinct opportunities, which open up very different markets for eCook:

- PV-eCook uses a PV array, charge controller and battery in a comparable configuration to the popular Solar Home System (SHS) and is best matched with rural, off-grid contexts.
- Grid-eCook uses a mains-fed AC charger and battery to create distributed HH storage for unreliable or unbalanced grids and is expected to best meet the needs of people living in urban slums or peri-urban areas at the fringes of the grid (or on a mini-grid) where blackouts are common.

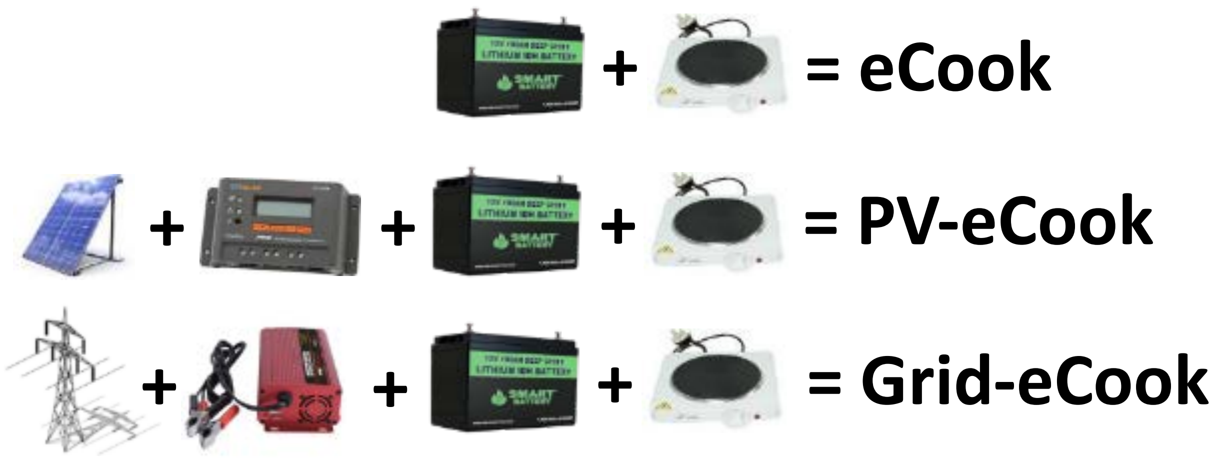

Figure 1: Pictorial definitions of 'eCook' terminology used in this report.

1.1.3 eCook in Zambia

Given the technical and socio-economic feasibility of the systems in the near future, Gamos, Loughborough University and the University of Surrey have sought to identify where to focus initial marketing for eCook. Each country has unique market dynamics that must be understood in order to determine which market segments to target are and how best to reach them. Leary et al. (2018) carried out a global market assessment, which revealed Zambia as the third most viable context for PV-eCook, as 10% of the population already cook on electricity and recent load shedding caused a significant number of these users to revert back to charcoal, rapidly accelerating deforestation.

The accompanying reports from the other activities carried out in Zambia can be found at: https://elstove.com/innovate-reports/.

1.2 Aim

The aim of this study is to design, assemble and test an eCook concept prototype in Zambia.

In particular, the objectives of the study are:

- To design the prototype around the needs and aspirations of Zambian cooks.
- To use the prototype to demonstrate the concept of cooking on battery-supported electricity to key stakeholders.

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2 Methodology

A key variable in the dimensioning of renewable energy systems is the load assessment. In this case, the load is dependent upon the foods to be cooked, the kitchen practices employed and the electrical appliances used. The cooking diaries study carried out as part of the eCook Zambia Market Assessment was designed to explore each of these factors in much greater detail, however, it was only just beginning as the prototyping was being carried out. The opportunity to participate in everyday cooking at Lusaka Backpackers (where the field researcher was staying during the eCook Zambia case study) offered an unexpectedly rich and timely learning opportunity. Although a range of international dishes were prepared by the staff for guests, every lunchtime, the staff would cook Zambian dishes for themselves. The field researcher (Jon Leary) was often accompanied by CEEEZ staff (Nancy Serenje and Francis Mwila) at lunchtime, which lead to fruitful discussions on the implications of that day's experiments.

A mixture of 'ethno-engineering' techniques were employed to explore the compatibility of Zambian cooking practices with a range of electric appliances in a kitchen laboratory setting. 'Ethno-engineering' blends anthropological and engineering approaches to create more holistic and culturally-informed development solutions. Initially, this focussed on simply observing the cooking practices of the staff at Lusaka Backpackers. Evidence was recorded as recipes, tips and reflective notes in a field diary and supplemented by photography. A four-plate cooker with oven and grill, a microwave, a portable double hotplate and a kettle were already available in the hostel kitchen. These appliances were later complimented by several Electric Pressure Cookers (EPCs) purchased during the course of the eCook Zambia Market Assessment. A consignment of plug-in energy meters was received after several weeks for the cooking diaries study, which enabled a more quantitative dimension to the exploration of the trade-offs between energy-efficiency and behaviour change.

Data collection for this activity did not follow a conventional process, so neither does this report. Instead of pages of text, diagrams and tables, it is presented as a photo story, with the post it notes drawing out the key learning points as the story unfolds. The more qualitative results obtained from these initial and more informal experiments are presented here as a complimentary addition to the more quantitative results that will be obtained from the cooking diaries study and presented in a separate report. They are important because, firstly, these informal experiments facilitated the dimensioning of the eCook Zambia prototype; secondly, they allowed the selection of appropriate electric cooking appliances; and thirdly they informed the demonstrations that would be performed to showcase the prototype.

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Figure 2: Experimenting with Lusaka Backpackers staff members in the 'kitchen laboratory' created during the eCook Zambia field research.

3 Results

3.1 Design specification – how do Zambians currently cook?

3.1.1 Which fuels are popular and why?

3.1.1.1 Charcoal & the mbaula

Figure 3: Even where electricity is clearly available, charcoal is still widely used.

THE MBAULA IS SLOW AND INEFFICIENT, BUT ALSO FAMILIAR AND POPULAR. THIS SIMULTANEOUSLY CREATES A BIG OPPORTUNITY AND A BIG CHALLENGE FOR ELECTRIC COOKING IN ZAMBIA.

Figure 4: the mbaula – Zambia's most popular charcoal stove. It's very cheap to make, portable and so widely available that many people are unaware that other charcoal burning stoves even exist. Today, it can be found in most urban Zambian homes, either as the main cooking device or at least as the backup for when the power goes out. However, its thin walls allow heat to escape all around. Small pots simply sit on top of the charcoal, allowing more heat to escape up the sides of the pot, meaning that very little actually makes it into the food.

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Figure 5: Better off households can save money by purchasing a whole sack of charcoal at once.

Figure 6: Poorer households typically buy in smaller amounts, a day at a time, or even a meal at a time.

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SUBSIDISED HYDRO-POWERED ELECTRICITY IN ZAMBIA HAS HISTORICALLY BEEN EXTREMELY CHEAP. AS A RESULT, ALTHOUGH COOKING WITH ELECTRICITY HAS BECOME POPULAR, MOST COOKING APPLIANCES ARE OUTDATED AND HIGHLY INEFFICIENT.

Figure 7: Charcoal is often the only choice for street vendors, who don't have access to an electricity connection where they work.

3.1.1.2 Electricity

Figure 8: A typical electric cooking device for lower income households – a portable single plate hotplate.

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SUPPLYING UP TO 10KW OF POWER FOR A FOUR PLATE COOKER WITH OVEN & GRILL WOULD REQUIRE A BATTERY BANK AS BIG AS THE STOVE ITSELF!

Figure 9: The four-plate stove – the aspirational cooking device for many. Capable of heating four pots, baking and grilling simultaneously. They are typically fitted with 40-60 amp circuit breakers, as they can consume up to 10kW.

3.1.1.3 Fuel stacking

MOST URBAN ZAMBIANS FUEL STACK BETWEEN CHARCOAL AND ELECTRICITY.

Figure 10: In this household, electricity is used for the majority of the cooking and water heating, but every Saturday, they fire up the mbaula to boil beans for week plus the occasional braii.

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There are many reasons why people with a grid connection still chose to use charcoal:

James: "I use charcoal in the mornings for breakfast and lunch because you have to put the stove outside"

Josephine: "Beans are better with charcoal because when you put more charcoal on the stove, it slows the heat down"

Josephine: "I use charcoal for most dishes and electricity only for quick things like eggs"

Gift: "We use electricity to save time, but the best is charcoal. It is best because of the flavour and because it cooks slowly"

COOKING SLOWLY IS A COMMON RATIONALE FOR CHOOSING CHARCOAL, ESPECIALLY FOR LONG BOILING DISHES. HOWEVER, ALMOST ALL ELECTRIC HOTPLATES ALLOW YOU TO CONTROL THE HEAT LEVEL, BUT IN PRACTICE, THEY SEEM TO BE SELDOM USED.

Figure 11: Offal requires boiling for many hours to soften the rubbery tissue.

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Figure 12: At Lusaka Backpackers, the staff can use the electricity for free. At first the electric stove was chosen, however before long, the kitchen began to fill with flies. As the cord for the electric stove was very short, it could not be taken outside, so the mbaula was prepared.

EVEN WHEN ELECTICITY IS AVAILABLE FOR FREE, THERE ARE STILL REASONS WHY PEOPLE CHOOSE TO USE CHARCOAL. HOWEVER, AS WE WILL SEE LATER, THERE IS ANOTHER WAY TO KEEP THE FLIES AWAY WHEN COOKING OFFALS WITH ELECTRICITY.

Figure 13: However, no matches were available, so the electric stove once again became useful. The smoke from the burning charcoal also kept away the flies and four hours later, the offal was deliciously soft and ready to fry with the classic tomato and onion sauce.

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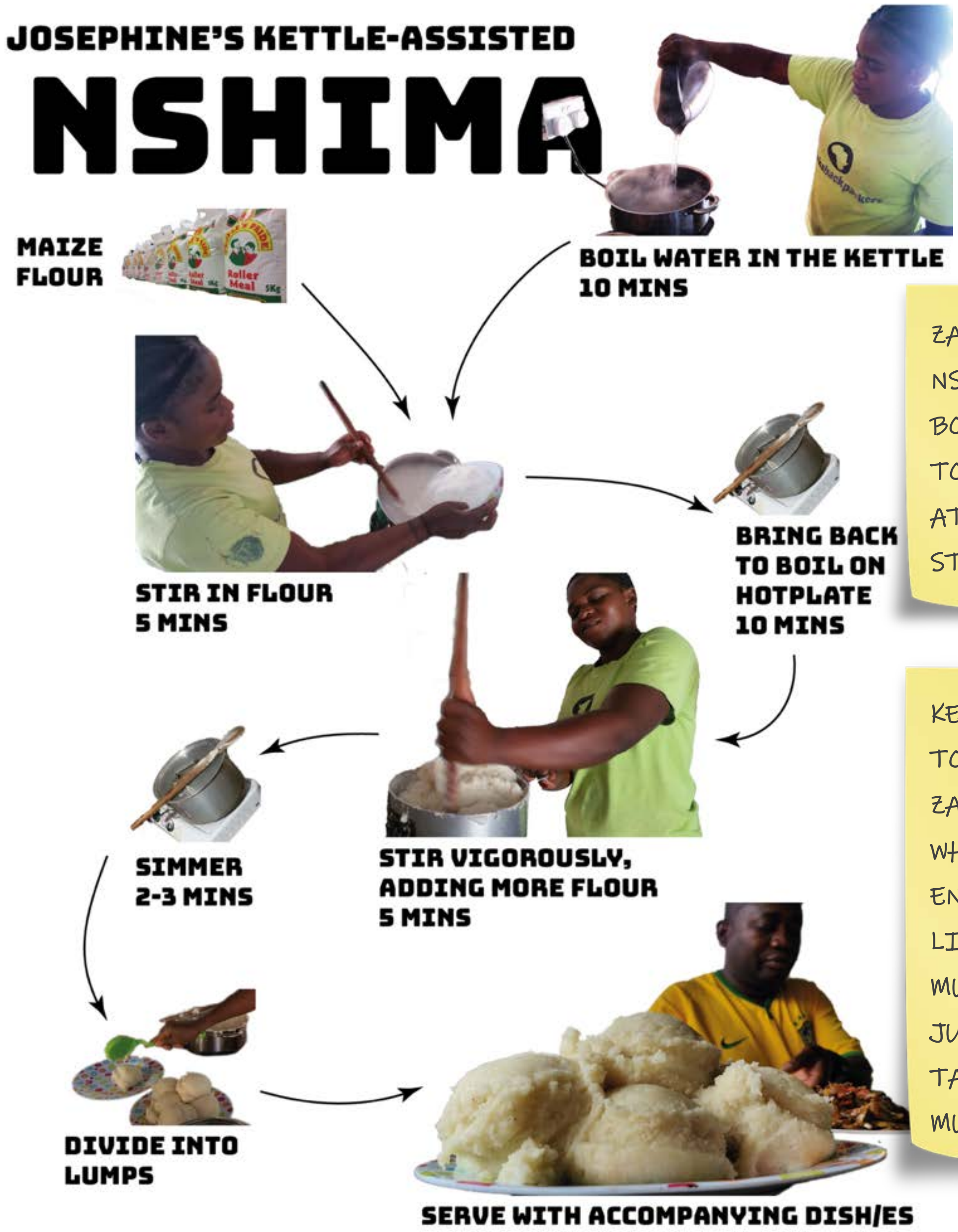
3.1.2 Which foods are popular and how are they prepared?



ZAMBIA'S MAIN STAPLE, NSHIMA, ONLY REQUIRES BOILING, HOWEVER ACCESS TO THE POT IS REQUIRED AT SPECIFIC POINTS FOR STIRRING.

KETTLES ARE OFTEN USED TO SPEED UP COOKING IN ZAMBIA, HOWEVER WHETHER THEY SAVE ENERGY OR NOT WILL LIKELY DEPEND ON HOW MUCH WATER IS BOILED – JUST ENOUGH FOR THE TASK AT HAND OR WAY TOO MUCH.

Figure 14: Nshima is the most popular dish in Zambia and is served with almost every meal.

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3.1.2.1 *Dried foods*

DRYING FOODS TO PRESERVE THEM IS VERY COMMON IN ZAMBIA. COOKING DRIED FOODS USUALLY REQUIRES REHYDRATING THEM. THIS CAN EITHER BE DONE BY SOAKING THEM IN WATER BEFORE COOKING OR BY EXTENDING THE COOKING PROCESS.

Figure 15: Many foods are preserved by drying. a) (far left) bream, b) (mid-left) kapenta, c) (mid-right) caterpillars and d) (far right) beans.

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BEANS

- Boil for several hours until soft enough to squash between your fingers. Drain & set aside.
- Chop half an onion & fry until golden.
- Chop 3 tomatoes & half a green pepper, fry with onion for 10 mins.
- Combine beans & sauce, fry for another 10 mins.

Serve with nshima & accompanying dishes

Figure 16: Beans on the hotplate.

BY CLASSIFYING THE MANY DIFFERENT DISHES THAT MAKE UP ZAMBIAN CUISINE, WE CAN START TO BUILD A DESIGN SPECIFICATION FOR AN ECOOK PROTOTYPE. OBSERVATION OF ZAMBIAN COOKS HAS LED TO THE FOLLOWING 3 CATEGORIES:

- "LONG BOILERS" – HIGH ENERGY DEMAND, REQUIRE BOILING FOR OVER AN HOUR.
- "MEDIUM BOILER/FRYER" – MEDIUM ENERGY DEMAND, TYPICALLY 15 MINS TO 1 HOUR OF BOILING AND/OR FRYING.
- "QUICK FRYERS" – LOW ENERGY DEMAND, TYPICALLY LESS THAN 15 MINS OF FRYING.

EXCEPTIONS: ROASTING (ONLY POSSIBLE IN AN OVEN /GRILL), BAKING (POSSIBLE TO A CERTAIN EXTENT ON SOME E.P.C.S) OR DEEP FRYING (POSSIBLE ON A FEW E.P.C.S).

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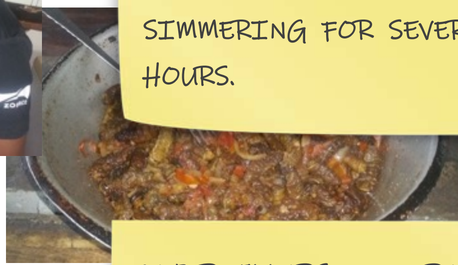
3.1.2.2 *Typical meals – nshima + accompaniments*



BEANS COULD BE CLASSIFIELD AS A "LONG BOILER", AS THEY REQUIRE SIMMERING FOR SEVERAL HOURS.

FRIED CATERPILLARS

- Rehydrate dried caterpillars in boiling water for 10 mins.
- Fry in oil for 15 mins until brown.
- Chop onion and fry with caterpillars for 5 mins until golden.
- Chop garlic and fry for 5 mins.
- Chop tomato and fry for 5 mins until smooth.

CATERPILLARS, RAPE LEAVES & NSHIMA COULD BE CLASSIFIED AS 3 "MEDIUM FRYER/BOILERS".

BLANCHED RAPE LEAVES

- Chop 1 bunch of rape leaves, wash in cold water.
- Boil kettle, blanch.
- Chop half an onion, fry for 5 mins.
- Chop 3 tomatoes, add to pan and fry for 5 mins.
- Add blanched rape to pan, fry for 10 mins.

Serve with nshima

Figure 17: Emmanuel's fried caterpillars, blanched rape leaves & nshima on the hotplate.

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KAPENTA, IMPWA & NSHIMA COULD BE CLASSIFIED AS A "QUICK FRYER" WITH 2 "MEDIUM BOILER/FRIERS".

IMPWA

- Chop impwa into quarters & fry for 10 mins.
- Add tomatoes, chilli, onion & spring onion, continuing to fry for another 10 mins.

KAPENTA

- Dry fry kapenta for 30 seconds.
- Rinse with cold water.
- Fry in oil for 5 mins until crispy.
- Chop half an onion and 3 tomatoes, add to pan.
- Fry together for another 5 mins.

Serve with nshima

Figure 18: Suwilanji's kapenta, impwa, & nshima on the hotplate.

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KAELMBRA, BEEF STEW, RAPE LEAVES & NSHIMA COULD BE CLASSIFIED AS A "QUICK FRIER" WITH 3 "MEDIUM BOILER/FRIERS".

KALEMBRA

- Chop sweet potato leaves, onion & tomato
- Fry for 10 mins

BEEF STEW

- Chop beef into 5cm chunks. Boil for 45 mins.
- Fry for 10 mins in stock.
- Chop 2 tomatoes and half an onion. Add to pot & fry for another 10 mins,

Serve with blanched rape leaves & nshima

Figure 19: Gift's kalembra, rape leaves, beef stew & nshima on the hotplate.

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3.1.2.3 *Jasiel's boiled okra, pork stew, beans & nshima*

BEANS, BOILED OKRA, PORK STEW & NSHIMA COULD BE CLASSIFIED AS A "LONG BOILER" WITH 3 "MEDIUM BOILER/FRIERS".

OKRA

- Boil water in the kettle
- Chop okra & a tomato into 2cm pieces & finely chopped chili
- Por water into saucepan & add a teaspoon of soda
- Add okra & tomato & boil for 15 mins until liquid has reduced

PORK STEW

- Chop joint into 5cm cubes
- Boil for 20 mins
- Reserve stock and shallow fry for 15 mins until fat is golden
- Chop onion & tomato, fry for 10 mins

Serve with beans & nshima

Figure 20: Jasiel's boiled okra, pork stew, beans & nshima.

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3.1.2.4 *Josephine's ifisahi, chicken stew & nshima*

IFISASHI, CHICKEN STEW & NSHIMA COULD BE CLASSIFIED AS 3 A "MEDIUM BOILER/FRIERS".

IFIASHI

- Boil water with the kettle.
- Trim & slice pumpkin leaves.
- Steam in saucepan by adding a little salted water for 10 mins. High heat.
- Dice 2 tomatoes & 1 onion and add to pan. Steam for another 5 mins
- Add pounded groundnuts. Steam for 10 mins until foaming stops then stir.

CHICKEN STEW

- Chop whole chicken into pieces
- Boil for half an hour in salted water. High heat. Reserve stock.
- Fry for 20 mins in oil. High heat. 3 batches. Set aside
- For sauce, chop 2 tomatoes and 1/2 an onion. Shallow fry for 10 mins in leftover oil from frying chicken.
- Recombine with chicken & stock. Reheat on high for 3 mins.

Serve with nshima

Figure 21: Josephine's ifisahi, chicken stew & nshima on the hotplate.

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BOREWORS, RAPE LEAVES & NSHIMA COULD BE CLASSIFIED AS 3 "MEDIUM BOILER/FRIERS".

BOREWORS

- Fry borewors for 30 mins
- Chop 1/2 onion & tomato, fry for 5 mins
- Chop borewors into 5cm chunks, fry in tomato sauce

Serve with ifisashi, fried rape leaves & nshima

Figure 22: Josephine's borewors, rape leaves, ifisashi & nshima.

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3.1.3 Which energy-efficient electric appliances might be compatible with Zambian cuisine?

WHILST IMPORTING DIRECTLY FROM CHINA WAS NOT POSSIBLE WITHIN THE TIMESCALE OF THE PROJECT, CHINA MALL OFFERED A GATEWAY INTO THE LAND OF MASS-PRODUCED CONSUMER GOODS.

Figure 23: Lusaka's China Mall offered an ideal venue to explore the range of electric cooking appliances on offer – some familiar, some new and some better suited to Zambian culture than others.

Figure 24: Pressure cookers are particularly well suited for reducing the boiling time of the "long boilers". By raising the boiling point of water from 100°C to 120°C, they can reduce cooking times by up to half.

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Figure 25: The Electric Pressure Cooker (EPC) is the modern equivalent to the stove-top pressure cooker, integrating a hotplate, automatic control and insulation into a complete cooking solution.

Figure 26: EPCs were also available in other stores with English writing on the buttons.

ELECTRIC PRESSURE COOKERS (E.P.C.S) OFFER THE POTENTIAL FOR BIG ENERGY SAVINGS ON THE BIG ENERGY CONSUMERS, THE "LONG BOILERS", BUT WOULD THE FINISHED PRODUCT BE AS TASTY WOULD THE BEHAVIOURAL CHANGE CHALLENGES OUTWEIGH THE BENEFITS?

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INITIAL TESTS WERE PROMISING, WITH THE FLAVOUR OF THE FINISHED DISHES AS EXPECTED. THE E.P.C.S WERE VERY VERSATILE – WITH THE LID ON, THEY COULD CONDENSE THE LONG BOILING PARTS OF COOKING INTO APPROXIMATELY HALF THE TIME, BUT ALSO BE USED WITH THE LID OFF TO FRY OR BOIL WITH EASY ACCESS TO THE POT FOR STIRRING.

Figure 27: Dried bream stew, dried bean leaf ifisashi & mentesa with pumpkin leaves in the EPC.

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DESPITE WHAT MANY PEOPLE THOUGHT, IT WAS EVEN POSSIBLE TO COOK NSHIMA IN THE E.P.C. IN FACT, CLEANIG THE STICKY LEFTOVERS OFF THE NON-STICK POT AFTERWARDS WAS MUCH EASIER THAN NORMAL. OF COURSE, THE ENERGY SAVINGS WOULD BE MUCH MORE MODEST THAN WITH "LONG BOILERS", AS ACCESS TO THE POT FRO STIRRING IS REQUIRED PERIODICALLY, LIMITING THE USE OF THE PRESSURE COOKING FUNCTION OF THE E.P.C.

Figure 28: Nshima in the EPC.

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Figure 29: Impala is a popular game meat in Zambia and when stewed, it is prepared in a similar way to many other typical meats such as pork and beef. This dish was completely cooked in the EPC, using a total of 0.482kWh:

- *Chop an onion & fry for 5 mins in pressure cooker*
- *Chop impala into 5 cm chunks & add to pan. Fry for 10 mins*
- *Chop 2 cloves garlic, add to pan and fry for 2 mins*
- *Chop 3 tomatoes, add to pan with range biltong spice and chilli powder and fry for 5 mins*
- *Add a cup of water and pressure cooker for 20 mins*

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Figure 30: The EPC can reduce the time for cooking beans by up to half and the energy by up to 80%. However, correctly judging the amount of water and the cooking time is challenging, even for people who have cooked beans many times, as you cannot see (or smell) inside without depressurising. These beans consumed a total of 0.381kWh:

- *Add 3 cups of water and 1.5 cups beans and pressure cook in EPC for 90 mins*
- *Chop an onion, fry for 5 mins in a separate pan on hotplate*
- *Chop a clove of garlic, add to pan and fry for another 2 mins*
- *Chop 3 tomatoes, add to pan with beans spice and fry for 5 mins*
- *Open EPC, add sauce and pressure cook for another 10 mins*

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

Figure 31: The beans and impala were cooked together in two separate EPCs. They were accompanied by nshima cooked on the hotplate/kettle (see Figure 14 for recipe). The sauce for the beans was also prepared on the hotplate, then blended in with the beans on the EPC. The meal served 6 people and the total energy consumption was 1.474kWh:

- Kettle (water for nshima): 0.162kWh
- 2 plate stove (nshima & sauce for beans): 0.449kWh
- Beans (Chinese EPC): 0.381kWh
- Impala (Salton EPC): 0.482kWh

USING A COMBINATION OF EFFICIENT ELECTRIC COOKING APPLINCES AND A PORTABLE HOTPLATE, ONE OF THE MOST ENERGY INTENSIVE ZAMBIAN MEALS, CONSISTING OF 2 "LONG BOILERS' & A "MEDIUM BOILER/FRIER" (DREID BEANS, GAME MEAT & NSHIMA) WAS PREPARED FOR 6 PEOPLE WITH JUST 1.474KWH. USING THE HOPLATE ALONE, THE BEANS WOULD HAVE EASILY EXCEEDED THIS AMOUNT, LET ALONE THE OTHER DISHES.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

Figure 32: Trotters in the EPC - Even a whole trotter can fit inside!

OFFALS OR VARIETY MEATS ARE CONSIDERED DELICACIES BY SOME, BUT IN MANY CULTURES, IT IS THE POORER HOUSEHOLDS WHO TEND TO EAT THESE MEAT PRODUCTS THAT ARE OFTEN LEFT OVER WHEN BUTCHERING AN ANIMAL FOR MORE CONVENTIONAL MEAT. LIKE TROTTERS, MANY REQUIRE BOILING FOR SEVERAL HOURS TO SOFTEN THEIR TOUGHER TISSUES.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

Figure 33: First the offals were boiled alone with the timer set for 45 minutes (which doesn't include the time to get to pressure – approx. 15 mins). This stage used 0.603kWh, but the steam valve was mistakenly left open for the first 20 minutes.

AN UNEXPECTED BENEFIT OF USING AN E.P.C. WAS THAT UNLIKE WITH THE HOTPLATE, WHERE A SWARM OF FLIES WERE ATTRACTED TO THE SMELL OF THE BOILING OFFAL ESCAPING FROM THE POORLY FITTING SAUCEPAN LID, THE E.P.C. IS TOTALLY SEALED UNTIL DEPRESSURISED, ALLOWING COOKING TO TAKE PLACE IN PEACE INSIDE!

Figure 34: Even the tomato and onion sauce can be done in the EPC. After depressurising, chopped tomatoes, onion, garlic and chili were added to the pot and the timer was set to another 10 mins at high pressure. After depressurising again, the dish was too soupy, so the EPC was set to boil with lid off for 15 mins to reduce the sauce. This brought the total to 1.075kWh.

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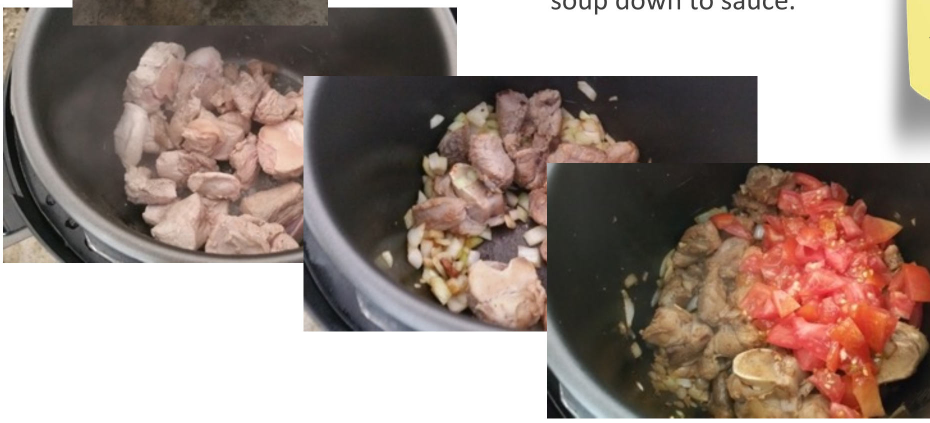
Figure 35: The offals were served with nshima and rumania and the meal was certified as just as tasty as offals cooked on charcoal or a hotplate.

WARTHOG STEW IN THE E.P.C. 0.874kWh

- Trim skin & chop into chunks.
- Fry for 10 mins until browned.
- Chop an onion and fry for 5 mins.
- Chop 2 garlic cloves and fry for 1 min.
- Chop 3 tomatoes and fry for 4 mins.
- Add 200ml water & pressure cook for 30 mins.
- Boil for 15 mins to reduce soup down to sauce.

AT 0.874kWh, WARTHOG STEW ON THE E.P.C. WAS SURPRISINGLY ENERGY INTENSIVE. WHILST THE BULK OF THE COOKING WAS DONE IN THE HALF HOUR OF PRESSURE COOKING, THIS USED RELATIVELY LITTLE ENERGY COMPARED TO THE FRYING AT THE BEGINNING (FOR FLAVOUR) & THE BOILING DOWN AT THE END (AVOIDABLE IF LESS WATER HAD BEEN ADDED).



SERVES 6 WITH CHINESE CABBAGE (blanched, then fried) & NSHIMA (boiled)

Kettle: 0.240kWh

Hotplate: 1.064kWh

Figure 36: Warthog in the EPC.

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3.1.4 Cooking diaries

Figure 37: Training a household participating in the cooking diaries study on using an E.P.C.

THE INITIALLY PROMISING RESULTS SHOWN BY E.P.C.S IN THE KITCHEN LABORATORY LEAD TO THE INCLUSION OF E.P.C.S ALONGSIDE HOTPLATES IN THE COOKING DIARIES STUDY.

20 HOUSEHOLDS WERE ASKED TO RECORD WHAT THEY COOKED, HOW & HOW MUCH ENERGY IT USED FOR 6 WEEKS. INITIALLY ON THE FUELS/APPLIANCES THEY WERE ALREADY USING, THEN AFTER 2 WEEKS, SWITCHING TO 100% ELECTRIC COOKING.

THE RESULTS WILL BE AVAILABLE AT: HTTPS://ELSTOVE.COM/INNOVATE-REPORTS/

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

3.2 Building the prototype

3.2.1 Acquiring components

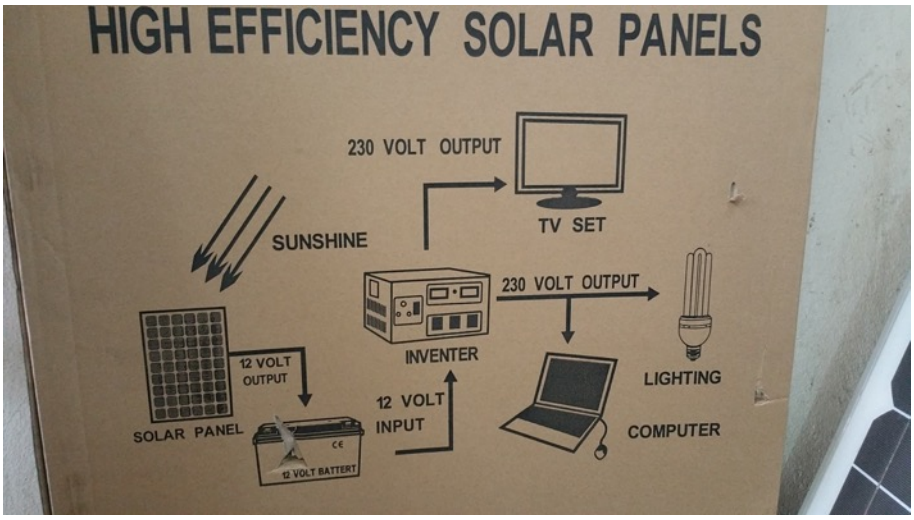


Figure 38: Prices in the local shops on Freedom Way were as little as 1/5 of the reputable solar suppliers, however the quality was questionable.

AS A VERY ROUGH APPROXIMATION TO SIZE THE DEMONSTRATION PROTOTYPE, A TYPICAL ZAMBIAN DAY OF COOKING WAS MODELLED AS:

1. A SINGLE "QUICK FRYER" FOR BREAKFAST
2. 2 "MEDIUM BOILER/FRIERS" FOR LUNCH
3. A "LONG BOILER" WITH 2 "MEDIUM BOILER/FRIERS" FOR DINNER

FROM EXPERIMENTATION IN THE KITCHEN LABORATORY, THE FOLLOWING ENERGY DEMANDS WERE ESTIMATED FOR A 5 PERSON HOUSEHOLD:

- "QUICK FRIER" ON A HOTPLATE = 0.2KWH
- "MEDIUM BOILER/FRIER" ON A KETTLE/HOTPLATE OR E.P.C. = 0.5WH
- "LONG BOILER" ON AN E.P.C. = 0.7KWH

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

Figure 39: Quotes were obtained from 6 reputable solar suppliers in Lusaka, with Suntech coming out on top.

TOTAL DAILY ENERGY DEMAND FOR A SMALL (5 PERSON) ZAMBIAN HOUSEHOLD WAS THEREFORE ESTIMATED AS:

4. BREAKFAST: 0.2KWH
5. LUNCH: 1KWH
6. DINNER: 1.7KWH

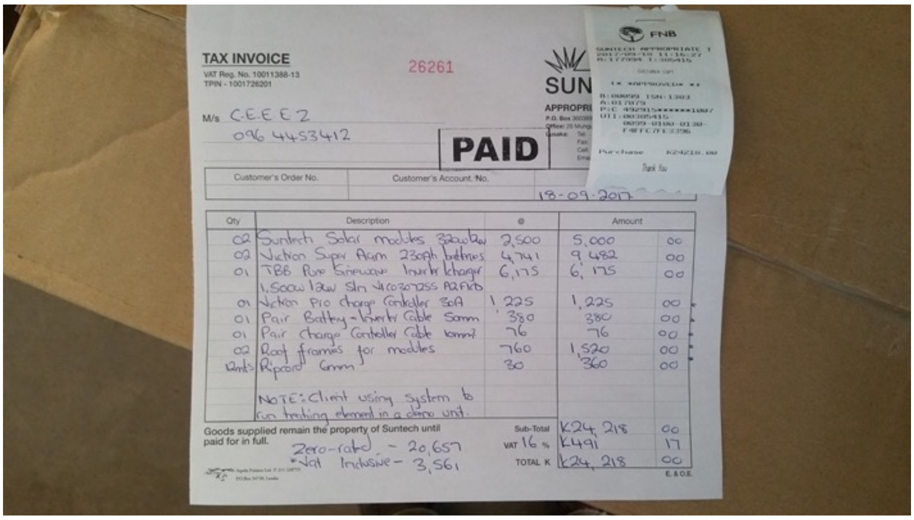
DAILY TOTAL: 2.9KWH

THIS IS SLIGHTLY ABOVE LEACH & ODURO'S (2015) 'LOW COOK' SCENARIO (REPRESENTING SMALL HOUSEHOLDS COOKING EFFICEINTLY) OF 1.4KWH/DAY.

Figure 40: Although a prototype could have been assembled for much less, good quality, reliable equipment was preferred over cost savings, to ensure the demonstrations to key stakeholders went smoothly.

Research@gamos.org | PV-ecook.org

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.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M/s C.E.E.E.Z
096 4453412

PAID

Customer's Order No.	Customer's Account No.	
		18-09-2017

Qty	Description	@	Amount	
02	Suntech Solar modules 320watts	2,500	5,000	00
02	Victron Super Agm 230Ah batteries	4,741	9,482	00
01	TBB Pure Sinewave Inverter charger 1,500w 12w Sln Vic0307255 A2FKB	6,175	6,175	00
01	Victron Pro charge Controller 30A	1,225	1,225	00
01	Pair Battery-Inverter Cable 5omm	380	380	00
01	Pair charge Controller Cable 10mm2	76	76	00
02	Roof frames for modules	760	1,520	00
12mts	Ripcord 6mm	30	360	00
	NOTE: Client using system to run heating element in a demo unit.			
		Sub-Total	K24,218	00
		VAT 16 %	K491	17
		TOTAL K	K24,218	00

Goods supplied remain the property of Suntech until paid for in full.
Zero-rated - 20,657
*Vat Inclusive - 3,561

E.&O.E.

FNB
Purchase K24218.00
Thank You

600W OF P.V. WERE SPECIFIED TO GIVE A DAILY ENERGY YIELD OF 3KWH, BASED UPON AN ASSUMPTION OF 5 SUN HOURS PER DAY.

Figure 41: The final specification for the Zambia eCook prototype was 600W PV, a 5.5kWh 24V lead acid battery bank, a 30A solar charge controller & a 1.5kW inverter/charger. The total purchase cost was 24,000ZWM (2,000USD).

Figure 42: Boxing up the newly purchased components at Suntech.

NO SOLAR SUPPLIERS IN LUSAKA WERE ABLE TO OBTAIN LITHIUM ION BATTERIES OF SUFFIECIENT CAPACITY (>100WH) FOR THE ECOOK PROTOTYPE. A.G.M. LEAD ACID BATTERIES WERE SELECTED AS A SUBSTITUTE & OVERSIZED TO TWICE THE REQUIRED CAPACITY TO PREVENT DAMAGE FROM HIGH C-RATE DEEP DISCHARGES & AVOID BIG VOLTAGE DIPS THAT COULD TRIP THE INVERTER'S LOW VOLTAGE DISCONNECT.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

3.2.2 Assembling & testing components

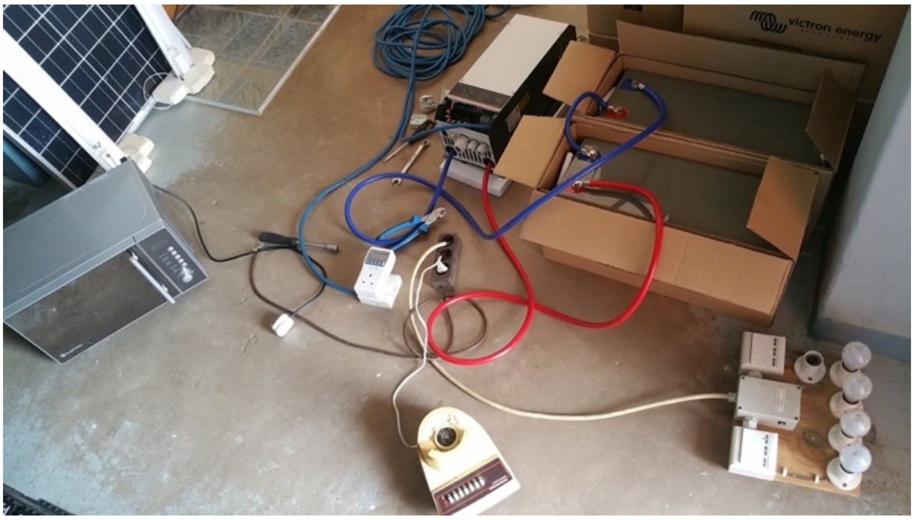


Figure 43: Initial testing with >1kW cooking appliance loads at Suntech.

ONLY A.C. COOKING APPLIANCES WERE AVAILABLE IN LUSAKA, REQUIRING AN INVERTER TO TRANSFORM THE D.C. POWER FROM THE BATTERY INTO A.C. AN INVERTER/CHARGER OFFERED THE ABILIY TO DEMONSTRATE BOTH OFF-GRID (PV-ECOOK) AND WEAK GRID (GRID-ECOOK) FUNCTIONALITY. A GOOD QUALITY 1.5KW INVERTER/CHARGER SHOULD SAFELY ALLOW CONTINUOUS USE (>1HR) OF COOKING APPLIANCES UP TO 1.2KW.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

A HOTPLATE, AN E.P.C., A SMALL KETTLE AND A SLOW COOKER WERE SELECTED AS THE DEMONSTRATION APPLIANCES TO SHOW THE VERSATILITY OF THE ECOOK CONCEPT.

Figure 44: Testing the eCook Zambia prototype by cooking beans on the E.P.C. at the CEEZ office. The oversized battery bank and high-quality pure sinewave inverter were more than capable of handling the relatively small loads from the portable electric cooking appliances.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

3.3 Showcasing the prototype

3.3.1 Kick off meeting

THE STAKEHOLDER WORKSHOP FINAL REPORTS FOR BOTH THE KICK OFF MEETING & THE DESIGN CHALLENGE WILL SOON BE AVAILABLE AT: HTTPS://ELSTOVE.COM/INNOVATE-REPORTS/

Figure 45: The eCook Zambia prototype awaiting the arrival of the participants of the Kick off Meeting at the Radisson Blu Hotel in Lusaka.

Figure 46: Presenting the key findings from the kitchen laboratory.

Figure 47: The eCook Zambia prototype silently cooked beans in the EPC whilst the participants carried out small group discussions on the opportunities and challenges for eCook in Zambia.

THE DEMONSTRATIONS OF COOKING POPCORN AND BEANS SUPPORTED THE FIRST KEY MESSAGE OF THE DAY, THAT COOKING ON BATTERIES WAS POSSIBLE. HOWEVER, THE OVERSIZED SYSTEM UNDERMINED THE SECOND KEY MESSAGE, THAT SOON IT WOULD BE COST EFFECTIVE FOR MANY ZAMBIAN HOUSEHOLDS CURRENTLY COOKING ON CHARCOAL TO ADOPT SUCH A SYSTEM.

Figure 48: Demonstrating cooking popcorn on the eCook prototype before setting beans to boil during the next session.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

3.3.2 Design challenge

Figure 49: Setting up the eCook prototype at the beginning of the day.

Figure 50: Introducing the eCook concept, the prototype and the format for the day.

THE ECOOK ZAMBIA DESIGN CHALLENGE WAS A MUCH MORE PARTICIPATORY EVENT THAN THE KICK OFF MEETING. RATHER THAN SIMPLY OFFERING A DEMONSTRATION OF THE PRINCIPLE OF COOKING ON BATTERY-SUPPORTED ELECTRICITY, THE ROLE OF THE ECOOK ZAMBIA PROTOYPE WAS TO SPARK THE IMAGINATION OF THE PARTICIPANTS. THE EVENT WAS DESIGNED TO CREATE AN OPPORTUNITY FOR ZAMBIAN EVERYDAY COOKS TO WORK DIRECTLY WITH SOLAR/COOKSTOVE/UTILITY ENTREPRENEURS, TO ENABLE THE GENERIC CONCEPT TO EVOLVE AROUND THEIR REAL NEEDS & ASPIRATIONS.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

Figure 51: The eCook Zambia prototype was certainly successful in sparking the imagination of the participants around what might be possible in the future.

3.4 Installing the prototype

Figure 52: Starting the generator during a blackout at the CEEEZ office.

ONE BENEFIT OF THE OVERSIZED NATURE OF THE ECOOK ZAMBIA PROTOTYPE WAS THAT IT WAS CAPABLE OF PROVIDING A BACKUP POWER SUPPLY TO THE C.E.E.E.Z. OFFICE. FREQUENT LOAD SHEDDING WAS ONE OF THE KEY REASONS FOR SELECTING ZAMBIA AS THE FIRST CASE STUDY COUNTRY. ALTHOUGH Z.E.S.C.O. HAD LARGELY ADDRESSED THE PROBLEM BY 2017 WHEN THE ECOOK RESEARCH WAS CARRIED OUT, UNPLANNED BLACKOUTS WERE STILL A FREQUENT OCCURANCE.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the ME

Figure 53: Installing the mounting frame for the PV on the roof of the CEEEZ office.

Figure 54: Bolting the PV onto the mounting frames.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

Figure 55: The installation completed just in time for sunset!

Figure 56: Admiring the fine handiwork.

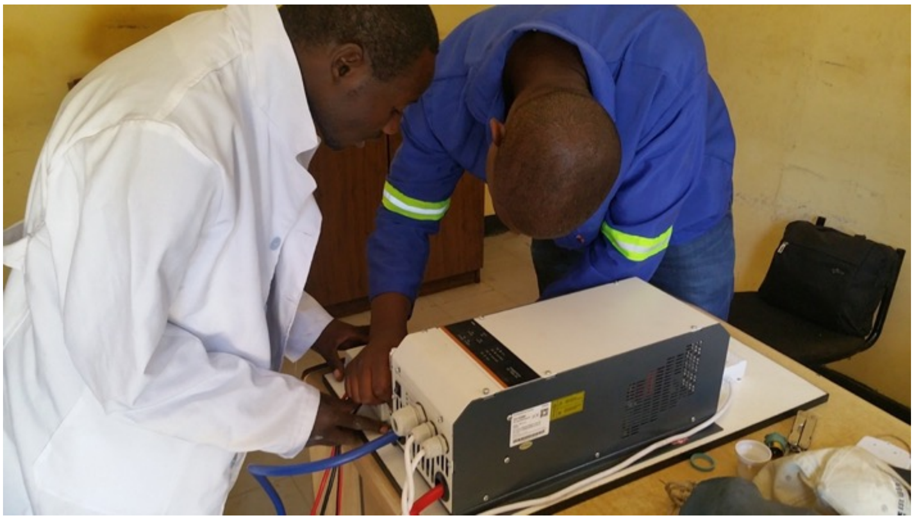
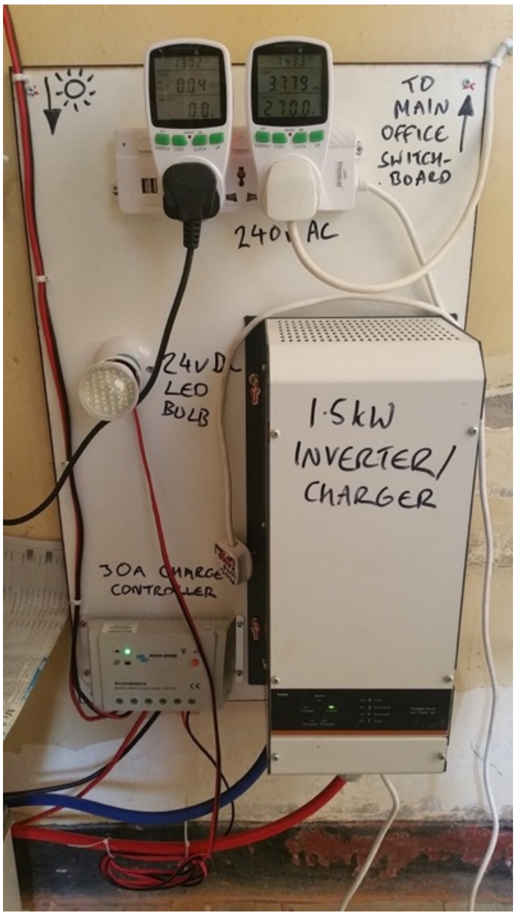


Figure 57: Preparing a mounting board for the power electronics.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

Figure 58: Adding a new changeover switch alongside the existing grid/generator switch.



THE ECOOK ZAMBIA PROTOTYPE ENABLED CEEEZ A PERMANENT INSTALLATION TO DEMONSTRATE THE ECOOK CONCEPT TO STAKEHOLDERS WHO MAY VISIT THE CEEEZ OFFICE IN THE COMING YEARS. HOWEVER, IT WAS HEAVY, BULKY & BOLTED TO THE BUILDING, SO IMPRACTICAL TO DEMONSTRATE ELSEWHERE. IT ALSO GAVE THE IMPRESSION OF ECOOK AS A BULKY, COMPLICATED & EXPENSIVE TECHNOLOGY.

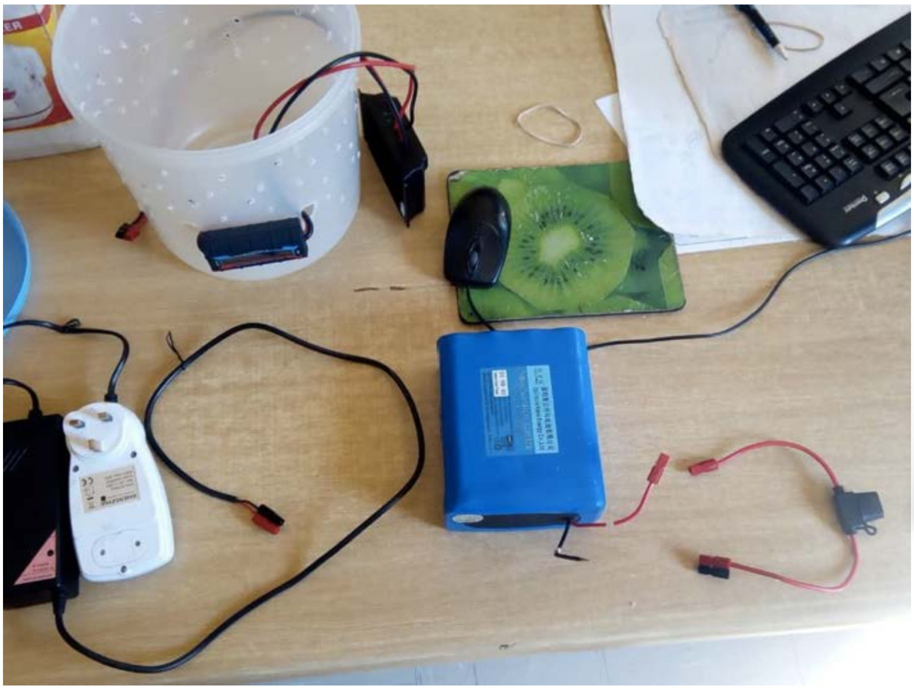
Figure 59: The final installation allowed CEEEZ to switch almost seamlessly between solar, generator & ZESCO grid power supplies. The batteries could charge from solar during the day and on cloudy days with high energy demand, they could be topped up from the grid.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

3.5 The bonus prototype

THE ECOOKBUCKET BONUS PROTOTYPE WAS THE POLAR OPPOSITE TO THE MAIN ECOOK ZAMBIA PROTOTYPE. IT WAS LIGHTWEIGHT, SIMPLE, CHEAP & PORTABLE. IT WAS THE SOLAR LANTERN OF THE SOLAR ELECTRIC COOKING WORLD.

Figure 60: The simple eCookBucket was merely an actual bucket paired with a DC rice cooker obtained as a sample from a Chinese factory. Together, they created a very crude DC battery-integrated cooking appliance.



THE ECOOKBUCKET PAIRED A LIFEPO4 BATTERY PACK WITH A DC COOKING APPLIANCE - BOTH OF WHICH WERE OBTAINED OVERSEAS DURING THE SUBSEQUENT COUNTRY CASE STUDIES.

Figure 61: The key internal components of the eCookBucket: a 240Wh LiFePO4 battery, a DC watt-hour meter, a solar charge controller, a fuse and an AC charger.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

Figure 62: Cooking lunch at the office with the eCookBucket.

4 Conclusion

The prototyping carried out in Zambia showed that in 2017, many of the basic components required to build a cost-effective and technically optimised eCook system were still not available. In particular, higher capacity lithium ion batteries and DC cooking appliances were simply not available. However, a broad range of AC electric cooking appliances were available on the market. Extensive testing was carried out in a kitchen laboratory, which revealed the Electric Pressure Cooker (EPC) as a prime candidate for future eCook products, as it can significantly reduce the energy demand for the biggest energy consumers: "long boiling" dishes. The eCook Zambia prototype was successful in demonstrating the concept of battery-supported cooking to key stakeholders and the bonus eCookBucket prototype was able to show a simpler, more affordable and more portable embodiment of the eCook concept.

The findings from this prototyping will be combined with those from the other activities that have been carried under the eCook Zambia Market Assessment. Together they will build a more complete picture of the opportunities and challenges that await this emerging concept. Further outputs will be available from https://elstove.com/innovate-reports/.

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5 Appendix

5.1 Appendix A: Problem statement and background to Innovate eCook project

5.1.1 Beyond business as usual

The use of biomass and solid fuels for cooking is the everyday experience of nearly 3 Billion people. This pervasive use of solid fuels—including wood, coal, straw, and dung—and traditional cookstoves results in high levels of household air pollution, extensive daily drudgery required to collect fuels, and serious health impacts. 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. Indoor biomass cooking smoke also 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 recommended levels of 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.

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), World Bank (2014), note that the use of biomass for cooking is likely to continue to dominate through to 2030.

> "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)

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,) It notes that without major new interventions, over 180 million households globally will gain access to, at least, minimally improved[1] 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

[1] 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" (ibid)

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

improvement to health. Against this backdrop, there is a need for a different approach aimed at accelerating the uptake of truly 'clean' cooking.

Even though improved cooking solutions are expected to reach an increasing proportion of the poor, the absolute numbers of people without access to even 'cleaner' energy, let alone 'clean' energy, will increase due to population growth. The new Sustainable Development Goal 7 calls for the world to "ensure access to affordable, reliable, sustainable and modern energy for all". Modern energy (electricity or LPG) would indeed be 'clean' energy for cooking, with virtually no kitchen emissions (other than those from the pot). However, in the past, modern energy has tended to mean access to electricity (mainly light) and cooking was often left off the agenda for sustainable energy for all.

Even in relation to electricity access, key papers emphasise the need for a step change in investment finance, a change from 'business as usual'. IEG World Bank Group (2015) note 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 (IEG World Bank Group 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 to really address global electricity access targets would be about $37 billion per year, including erasing generation deficits and 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 year for their electricity sectors from public and private sources" (ibid). The document calls for the Bank Group's energy practice to adopt a new and transformative strategy to help country clients orchestrate a national, sustained, sector-level engagement for universal access.

In the following paragraphs, we explore how increasing access to electricity could include the use of solar electric cooking systems, meeting the needs of both supplying electricity and clean cooking to a number of households in developing countries with sufficient income.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

5.1.2 Building on previous research

Gamos first noted the trends in PV and battery prices in May 2013. We asked ourselves the question, is it now cost effective to cook with solar photovoltaics? The answer in 2013 was 'no', but the trends suggested that by 2020 the answer would be yes. We published a concept note and started to present the idea to industry and government. Considerable interest was shown but uncertainty about the cost model held back significant support. Gamos has since used its own funds to undertake many of the activities, as well as IP protection (a defensive patent application has been made for the battery/cooker combination) with the intention is to make all learning and technology developed in this project open access, and awareness raising amongst the electrification and clean cooking communities (e.g. creation of the infographic shown in Figure 63 to communicate the concept quickly to busy research and policy actors).

Gamos has made a number of strategic alliances, in particular with the University of Surrey (the Centre for Environmental Strategy) and Loughborough University Department of Geography and seat of the Low Carbon Energy for Development Network). In October 2015, DFID commissioned these actors to explore assumptions surrounding solar electric cooking[2] (Batchelor 2015b; Brown & Sumanik-Leary 2015; Leach & Oduro 2015; Slade 2015). The commission arose from discussions between consortium members, DFID, and a number of other entities with an interest in technological options for cleaner cooking e.g. Shell Foundation and the Global Alliance for Clean Cookstoves.

Drawing on evidence from the literature, the papers show that the concept is technically feasible and could increase household access to a clean and reliable modern source of energy. Using a bespoke economic model, the Leach and Oduro paper also confirm that by 2020 a solar based cooking system could be comparable in terms of monthly repayments to the most common alternative fuels, charcoal and LPG. Drawing on published and grey literatures, many variables were considered (e.g. cooking energy needs, technology performance, component costs). There is uncertainty in many of the parameter values, including in the assumptions about future cost reductions for PV and batteries, but the cost ranges for the solar system and for the alternatives overlap considerably. The model includes both a conservative 5% discount rate representing government and donor involvement, and a 25% discount rate representing a private sector led initiative with a viable return. In both cases, the solar system shows cost effectiveness in 2020.

[2] The project has been commissioned through the PEAKS framework agreement held by DAI Europe Ltd.

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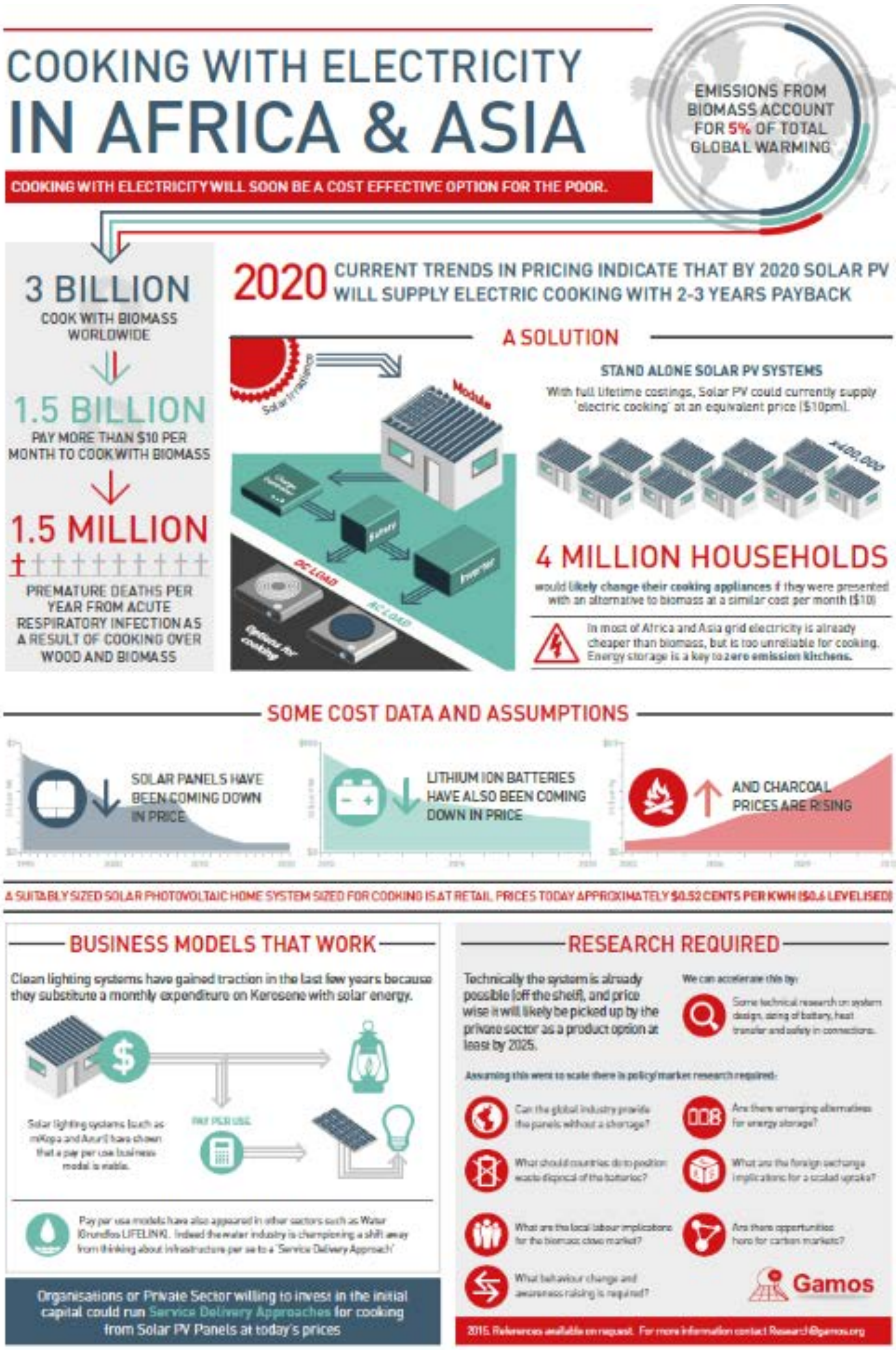

Figure 63 Infographic summarising the concept in order to lobby research and policy actors.

The Brown and Sumanik-Leary paper in the series examines the lessons learned from four transitions – the uptake of electric cooking in South Africa, the roll out of Improved Cookstoves (ICS), the use of LPG and the uptake of Solar Home Systems (SHS). They present many behavioural concerns, none of which preclude the proposition as such, but all of which suggest that any action to create a scaled use of solar electric cooking would need in depth market analysis; products that are modular and paired

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with locally appropriate appliances; the creation of new, or upgrading of existing, service networks; consumer awareness raising; and room for participatory development of the products and associated equipment.

A synthesis paper summarising the above concludes by emphasising that the proposition is not a single product – it is a new genre of action and is potentially transformative. Whether solar energy is utilised within household systems or as part of a mini, micro or nano grid, linking descending solar PV and battery costs with the role of cooking in African households (and the Global South more broadly) creates a significant potential contribution to SDG7. Cooking is a major expenditure of 500 million households. It is a major consumer of time and health. Where households pay for their fuelwood and charcoal (approximately 300 Million) 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 "consumer expenditure" is of an order of magnitude more than current investment in modern energy in Africa and to harness it might fulfil the calls for a step change in investment in electrical infrastructure.

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5.1.3 Summary of related projects

A series of inter-related projects have led to and will follow on from the research presented in this report:

- Gamos Ltd.'s early conceptual work on eCook (Batchelor 2013).
    - The key **CONCEPT NOTE** can be found here.
    - An early infographic and a 2018 infographic can be found here.
- Initial technical, economic and behavioural feasibility studies on eCook commissioned by DfID (UK Aid) through the CEIL-PEAKS Evidence on Demand service and implemented by Gamos Ltd., Loughborough University and University of Surrey.
    - The key **FINAL REPORTS** can be found here.
- Conceptual development, stakeholder engagement & prototyping in Kenya & Bangladesh during the "*Low cost energy-efficient products for the bottom of the pyramid*" project from the USES programme funded by DfID (UK Aid), EPSRC & DECC (now part of BEIS) & implemented by University of Sussex, Gamos Ltd., ACTS (Kenya), ITT & UIU (Bangladesh).
    - The key **PRELIMINARY RESULTS** (Q1 2019) can be found here.
- A series of global & local market assessments in Myanmar, Zambia and Tanzania under the "*eCook - a transformational household solar battery-electric cooker for poverty alleviation*" project funded by DfID (UK Aid) & Gamos Ltd. through Innovate UK's Energy Catalyst Round 4, implemented by Loughborough University, University of Surrey, Gamos Ltd., REAM (Myanmar), CEEEZ (Zambia) & TaTEDO (Tanzania).
    - The key **PRELIMINARY RESULTS** (Q1 2019) can be found here.
- At time of publication (Q3 2019), a new DfID (UK Aid) funded research programme '*Modern Energy Cooking Services*' (MECS) lead by Prof. Ed Brown at Loughborough University is underway and will take forward these ideas & collaborations.

This data and material have been funded by UK Aid from the UK government; however, the views expressed do not necessarily reflect the UK government's official policies.

5.2 Appendix 2: About the Modern Energy Cooking Services (MECS) Programme.

Sparking a cooking revolution: catalysing Africa's transition to clean electric/gas cooking.

www.mecs.org.uk | mecs@lboro.ac.uk

Modern Energy Cooking Services (MECS) is a five-year research and innovation programme funded by UK Aid (DFID). MECS hopes to leverage investment in renewable energies (both grid and off-grid) to address the clean cooking challenge by integrating modern energy cooking services into the planning for access to affordable, reliable and sustainable electricity.

Existing strategies are struggling to solve the problem of unsustainable, unhealthy but enduring cooking practices which place a particular burden on women. After decades of investments in improving biomass cooking, focused largely on increasing the efficiency of biomass use in domestic stoves, the technologies developed are said to have had limited impact on development outcomes. The Modern Energy Cooking Services (MECS) programme aims to break out of this "business-as-usual" cycle by investigating how to rapidly accelerate a transition from biomass to genuinely 'clean' cooking (i.e. with electricity or gas).

Worldwide, nearly three billion people rely on traditional solid fuels (such as wood or coal) and technologies for cooking and heating[3]. This has severe implications for health, gender relations, economic livelihoods, environmental quality and global and local climates. According to the World Health Organization (WHO), household air pollution from cooking with traditional solid fuels causes to 3.8 million premature deaths every year – more than HIV, malaria and tuberculosis combined[4]. Women and children are disproportionally affected by health impacts, and bear much of the burden of collecting firewood or other traditional fuels.

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[3] http://www.who.int/indoorair/health_impacts/he_database/en/

[4] https://www.who.int/en/news-room/fact-sheets/detail/household-air-pollution-and-health https://www.who.int/gho/hiv/epidemic_status/deaths_text/en/, https://www.who.int/en/news-room/fact-sheets/detail/malaria, https://www.who.int/en/news-room/fact-sheets/detail/tuberculosis

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

Greenhouse gas emissions from non-renewable wood fuels alone total a gigaton of CO_2e per year (1.9-2.3% of global emissions)[5]. The short-lived climate pollutant black carbon, which results from incomplete combustion, is estimated to contribute the equivalent of 25 to 50 percent of carbon dioxide warming globally – residential solid fuel burning accounts for up to 25 percent of global black carbon emissions[6]. Up to 34% of woodfuel harvested is unsustainable, contributing to climate change and local forest degradation. In addition, approximately 275 million people live in woodfuel depletion 'hotspots' – concentrated in South Asia and East Africa – where most demand is unsustainable[7].

Africa's cities are growing – another Nigeria will be added to the continent's total urban population by 2025[8] which is set to double in size over the next 25 years, reaching 1 billion people by 2040. Within urban and peri-urban locations, much of Sub Saharan Africa continues to use purchased traditional biomass and kerosene for their cooking. Liquid Petroleum Gas (LPG) has achieved some penetration within urban conurbations, however, the supply chain is often weak resulting in strategies of fuel stacking with traditional fuels. Even where electricity is used for lighting and other amenities, it is rarely used for cooking (with the exception of South Africa). The same is true for parts of Asia and Latin America. Global commitments to rapidly increasing access to reliable and quality modern energy need to much more explicitly include cooking services or else household and localized pollution will continue to significantly erode the well-being of communities.

Where traditional biomass fuels are used, either collected in rural areas or purchased in peri urban and urban conurbations, they are a significant economic burden on households either in the form of time or expenditure. The McKinsey Global Institute outlines that much of women's unpaid work hours are spent on fuel collection and cooking[9]. The report shows that if the global gender gap embodied in such activities were to be closed, as much as $28 trillion, or 26 percent, could be added to the global

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[5] Nature Climate Change 5, 266–272 (2015) doi:10.1038/nclimate2491

[6] http://cleancookstoves.org/impact-areas/environment/

[7] Nature Climate Change 5, 266–272 (2015) doi:10.1038/nclimate2491

[8] https://openknowledge.worldbank.org/handle/10986/25896

[9] McKinsey Global Institute. *The Power of Parity: How Advancing Women's Equality can add $12 Trillion to Global Growth*; McKinsey Global Institute: New York, NY, USA, 2015.

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

annual GDP in 2025. Access to modern energy services for cooking could redress some of this imbalance by releasing women's time into the labour market.

To address this global issue and increase access to clean cooking services on a large scale, investment needs are estimated to be at least US$4.4 billion annually[10]. Despite some improvements in recent years, this cross-cutting sector continues to struggle to reach scale and remains the least likely SE4All target to be achieved by 2030[11], hindering the achievement of the UN's Sustainable Development Goal (SDG) 7 on access to affordable, reliable, sustainable and modern energy for all.

Against this backdrop, MECS draws on the UK's world-leading universities and innovators with the aim of sparking a revolution in this sector. A key driver is the cost trajectories that show that cooking with (clean, renewable) electricity has the potential to reach a price point of affordability with associated reliability and sustainability within a few years, which will open completely new possibilities and markets. Beyond the technologies, by engaging with the World Bank (ESMAP), MECS will also identify and generate evidence on other drivers for transition including understanding and optimisation of multi-fuel use (fuel stacking); cooking demand and behaviour change; and establishing the evidence base to support policy enabling environments that can underpin a pathway to scale and support well understood markets and enterprises.

The five year programme combines creating a stronger evidence base for transitions to modern energy cooking services in DFID priority countries with socio-economic technological innovations that will drive the transition forward. It is managed as an integrated whole, however the programme is contracted via two complementary workstream arrangements as follows:

- An Accountable Grant with Loughborough University (LU) as leader of the UK University Partnership.

[10] The SE4ALL Global Tracking Report shows that the investment needed for universal access to modern cooking (not including heating) by 2030 is about $4.4 billion annually. In 2012 investment was in cooking was just $0.1 billion. Progress toward Sustainable Energy: Global Tracking Report 2015, World Bank.

[11] The 2017 SE4All Global Tracking Framework Report laments that, "Relative to electricity, only a small handful of countries are showing encouraging progress on access to clean cooking, most notably Indonesia, as well as Peru and Vietnam."

This research is funded by DfID/UK Aid and Gamos through the Innovate UK Energy Catalyst and the MECS programme.

- An amendment to the existing Administrative Arrangement underlying DFID's contribution to the ESMAP Trust Fund managed by the World Bank.

The intended outcome of MECS is a market-ready range of innovations (technology and business models) which lead to improved choice of affordable and reliable modern energy cooking services for consumers. Figure 64 shows how the key components of the programme fit together. We will seek to have the MECS principles adopted in the SDG 7.1 global tracking framework and hope that participating countries will incorporate modern energy cooking services in energy policies and planning.

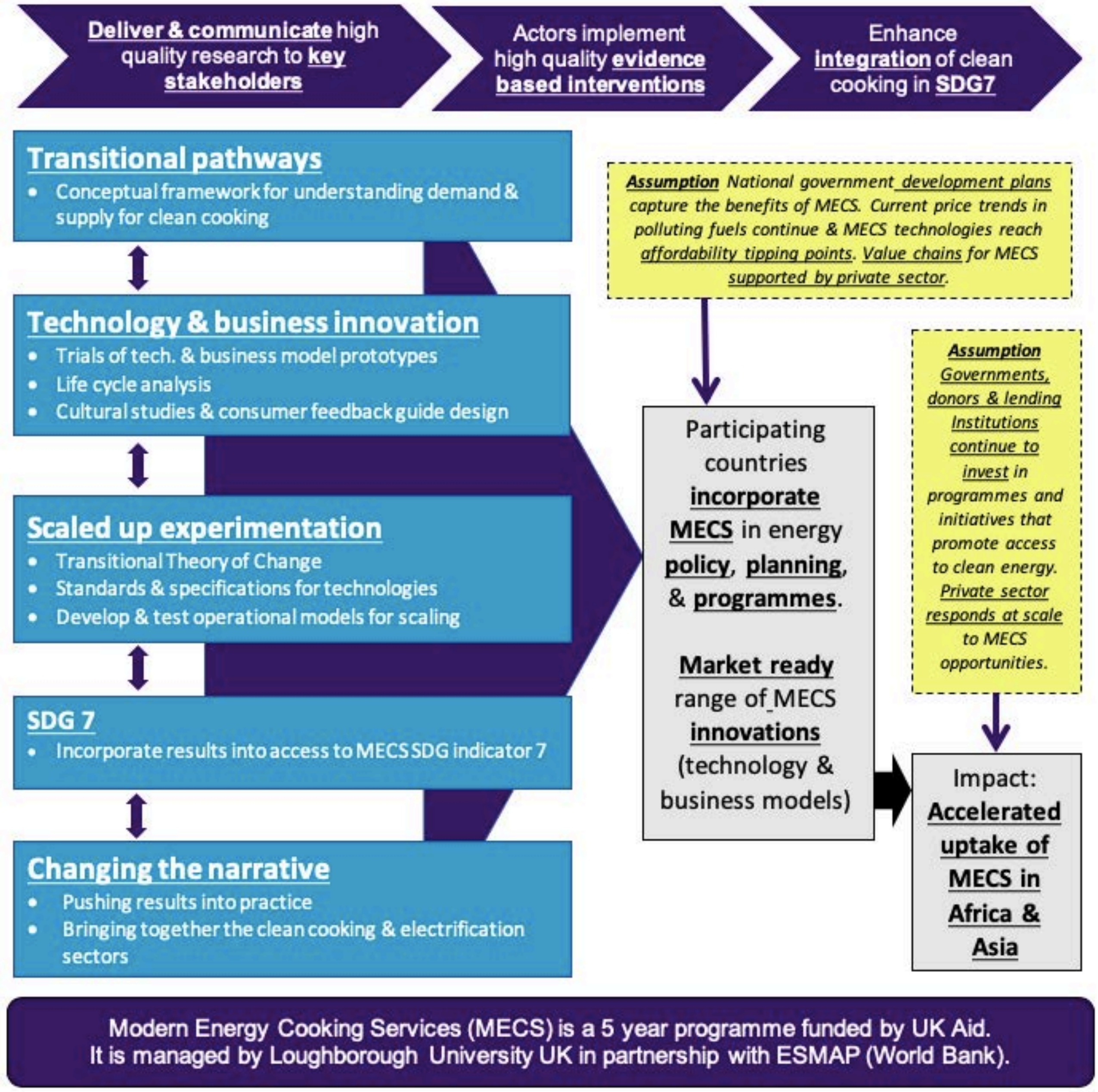

Figure 64: Overview of the MECS programme.

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