



WHITEPAPER

BATTERY SUPPORTED ECOOKING TECHNOLOGIES WITH A DISCUSSION ON BATTERY SWAP MODELS



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The paper was initiated and conceived by Damilola Ogunbiyi, the CEO and Special Representative of the UN Secretary-General (UN SRSG) for Sustainable Energy for All, and Co-Chair of UN-Energy. An early draft was generated by Emmanuella Buerki Nelson, with guidance from Grace Busingye, Caroline Ochieng, and Mikael Melin at SEforALL.

Dr Simon Batchelor OBE, Research Director at MECS, who had been working on a similar concept, took up the mantle and revised the structure and narrative, taking the white paper to completion.

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An early draft of the paper was used by MECS in the launch of a "Standalone or rooftop solar systems inclusive of e-cooking" (STARSS) accelerator fund, and a number of projects that utilise these ideas and will generate evidence and data on the feasibility of this approach are being implemented during 2025/2026.

ABBREVIATIONS & TERMS

BMS	Battery Management System
BSS	Battery Swapping Station
C-rate	Charge/Discharge Rate (battery performance measure)
CAPEX	Capital Expenditure
DoD	Depth of Discharge (battery usage metric)
eCooking	Electric cooking
EPR	Extended Producer Responsibility
EV	Electric Vehicle
FinTech	Financial Technology
GIS	Geographic Information System
LFP	Lithium Iron Phosphate (battery chemistry)
NDC	Nationally Determined Contribution (under the Paris Agreement)
OPEX	Operating Expenditure
PAYGO	Pay-As-You-Go (financing model)
PV	Photovoltaic (solar power systems)
RBF	Results-Based Financing
ROI	Return on Investment
SDG	Sustainable Development Goal
SHS	Solar Home System
TOU	Time of Use (tariff)
UX	User Experience

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1 EXECUTIVE SUMMARY

Battery-enabled eCooking has strong potential to expand the use of energy-efficient appliances in settings with limited or unreliable electricity supply. This includes: (i) areas where the grid is weak — unreliable, low-power, or with incomplete and poor-quality wiring; (ii) grids and mini-grids that offer incentives to reduce peak demand; and (iii) locations without any grid connection.

In weak-grid contexts, a battery can draw a low current to trickle-charge during available supply periods, then discharge high power for short durations to operate eCooking appliances. Where time-of-use incentives exist, batteries may be charged during off-peak hours and discharged during peak times to support cooking needs. In off-grid areas, batteries paired with renewable generation — such as solar PV panels, micro-hydro systems, or small wind turbines — can provide reliable household or institutional power for eCooking.

For each of these scenarios, it is essential to understand the battery's charging and discharging regime, size it appropriately, and ensure the overall system is reliable, cost-effective, and sustainable. This requires assessing key technical parameters — including depth of discharge, C-rating, charging profile, cycle life-

time (which depends on these factors), as well as cost and maintenance requirements.

The paper examines these considerations in the context of powering energy-efficient eCooking appliances. It also highlights the decreasing cost of batteries, driven by economies of scale and manufacturing learning curves, and presents examples of relevant battery chemistries and their potential applications. Selected case studies illustrate how batteries are being deployed to support eCooking solutions.

However, three factors have driven interest in a Battery Swapping Model (BSM), in which users lease rather than own the battery. These factors are: a) the operational and sustainability challenges of managing a battery effectively for more than ten years; b) the continued requirement for significant upfront capital, despite the ongoing decline in battery prices; and c) growing experience and innovation within the electric vehicle sector.

Under the BSM concept, batteries are charged, maintained, and managed by a dedicated agency — comparable to a service station — often referred to as a Battery Swapping Station (BSS). Consumers rent or lease charged

batteries for eCooking, exchanging them as needed. This model may be particularly effective in areas with lower-tier or constrained electricity access (Scenarios i and ii above) and could also enable eCooking in locations where national or mini-grids are not yet established (Scenario iii).

Battery swapping has become a limited but expanding component of the e-mobility landscape, particularly among motorcycles and cars that 'refuel' not by charging their in-built batteries but by exchanging them for fully charged units — a practice increasingly common in motorcycle taxi services. The advantages of this approach over conventional recharging include reduced waiting times for consumers and the ability of centralised battery management systems to extend battery lifetimes through controlled charging rates and the replacement of degraded cells. Although battery swapping for e-mobility remains at an early stage, notable examples include NIO in China and Mobile Power in Kenya.

The paper examines the key parameters of a Battery Swapping Model (BSM) for eCooking. It analyses relevant battery chemistries, highlighting critical variables such as charge rate (C-rating), which influences the recharging regime, and energy density, which determines the physical weight of the battery. It also reviews existing examples and pilot initiatives, and proposes three potential configurations suitable for low- and middle-income countries, outlining their market potential and principal parameters. Finally, the paper presents use-case scenarios aligned with Scenarios (i), (ii), and (iii) described above.

In examining the potential for battery swapping to support eCooking, we conclude that the number of viable markets may be limited. The Earth is often described as existing within a “Goldilocks Zone” — where conditions are neither too hot nor too cold, allowing water to flow and life to thrive. Similarly, a “Goldilocks Zone” appears to exist for battery swapping in eCooking: where the battery is large enough to meet cooking energy needs but not too heavy to transport, and where the distance to the Battery Swapping Station (BSS) is neither so short as to favour direct grid connection nor so far as to make daily exchange impractical.

The Goldilocks Zone is most likely to occur in informal urban and peri-urban settlements, in humanitarian or displacement settings, and at the edges of mini-grids. In more remote rural off-grid areas, the viability of battery swapping will depend on population density and the willingness or ability of users to undertake daily travel. This may be particularly constrained not only by spatial factors but also by social and cultural norms — for instance, whether women are enabled or permitted within their households to travel daily to collect batteries.

In some borderline Goldilocks contexts, Battery Swapping Stations (BSS) could explore options for daily delivery of charged batteries, either directly to consumers or through local agents closer to the final point of use.

The paper concludes that the battery swapping concept warrants further exploration through targeted trials and pilot initiatives to better understand the relative importance of the parameters that determine its financial and operational viability.

2 THE WHITE PAPER LOGIC



The following summarizes the logic of the Battery swapping White Paper. It is a concise sequencing of assumptions which at each step can be challenged or contribute to the logic that a Battery Swapping Model for eCooking should be explored further.

-
- ① **Some households have low tier access to electricity, or no access.**

 - ② **Energy Storage in the form of a chemical battery, can deliver an eCooking experience.**
 - To do this, a battery would have to experience a 'regular' (possibly daily) cycle of charging and discharging.
 - Batteries have characteristics and their use is constrained by their capacity and the required depth of discharge.
 - Batteries also should have reasonable C rates of charging and discharging.

 - ③ **Those with low tier access to electricity or no access could own batteries and create conditions to regularly charge them and use them discharging for eCooking.**
 - The prices of batteries have dropped significantly in the last ten years due to learning and manufacturing gains, and are likely to continue to become more affordable, with better performance.
 - Renewable energy generation at a household level (e.g. Solar Home Systems) could do a daily charging cycle, but:
 - There would be significant upfront cost for the entire system, which would likely require access to credit to install the system;
 - Sizing the battery to cover seasons and cloudy days would increase the cost of the system.
 - Those with access to a weak and unreliable grid could charge the battery when they have electricity access, and discharge it for cooking;
 - Some connections in Asia are limited to 300W, which is not enough for cooking;
 - Some connections on mini-grids are limited to 5 amps which is not enough for cooking;
 - Those who access electricity illegally or from their landlord often have poor wiring, and drawing high power through it would create brown outs.

An alternative to owning a battery-based eCooking system is to lease, rent, or hire charged batteries. This approach mirrors the daily collection or refilling of fuels such as ethanol or LPG, though it may also present comparable considerations around cost, risk, and safety.

This model forms the basis for establishing a Battery Swapping Station (BSS). There is limited experience of battery swapping in electric vehicles.

- Battery swapping in vehicles has the advantage of a short swap time, which is potentially more convenient than fast charging of batteries.
- Fast charging of electric vehicles depends on a strong electrical infrastructure. Developed economies have such infrastructure and continue to upgrade it, so the emerging norm for charging a vehicle is either at home or at a public charge point.
- Battery swapping has been and is being explored for cars, but it requires substantial station infrastructure to handle the heavy batteries (often robotic swapping).
- Battery swapping has been and is being explored for e-cycles, and is showing some value for taxis and localised motor vehicle networks.

4 Battery swapping for eCooking has a different profile from a station that swaps for eCycles.

- Demand would become regular – households living near the station would likely swap batteries regularly (possibly daily).
- The physical size of a 1.5 kWh battery (sufficient for one day of eCooking) means that households must be able to carry it easily to their homes.
- A larger multi-day battery might be feasible for users who have their own vehicle (bicycle, motorcycle, etc.).
- A variant of the battery-swapping station could include daily delivery of charged batteries to people's homes along regular routes.

5 A battery-swapping station could potentially ensure that batteries are:

- Better maintained by professional technicians;
- Charged at the correct rate;
- Disposed of safely at end of life, improving e-waste management.

6 A battery-swapping station could also potentially:

- Access investment finance for upfront capital costs through a clear business model (in contrast to households taking individual loans to purchase batteries on credit);
- Digitally monitor battery use, and access results-based finance and carbon finance by digitally verifying battery use against a baseline of biomass consumption. A station could therefore form the basis for a carbon-finance project.

7 Implementing the concept of battery swapping could depend on:

- 'Goldilocks conditions', where people lack access to higher-tier electricity but live in sufficient proximity to make a daily journey feasible.
- A socio-economic context that allows households to access finance for regular payments to a swap station, but not enough to upgrade their electricity tier.
- A socio-cultural context in which daily collection of a battery is acceptable. (In some societies, women may not be permitted to leave the home regularly, while men may be unwilling to collect the cooking fuel.)

8 A battery-swapping station could also serve as a community hub supporting daily interaction and relationships.

- A venue for complementary service businesses that use the shared energy infrastructure (for example, hairdressing).

9 A site for productive uses of energy that add value to goods or services (for example, grain milling or sewing).

- A location where eCooking in bulk prepares meals — either sit-down or takeaway — or for pre-cooking food to be reheated at home.



3 INTRODUCTION

eCooking technologies have proven to be a viable substitute for conventional and traditional biomass-based cooking methods, offering:

- beneficial outcomes such as an emission-free kitchen environment,
- a reduction in environmental damage (when compared with the use of solid biomass as fuel), and
- a release of time for the cook (and for fuel collection where relevant).

They also provide:

- an opportunity to leverage investment in electricity access,
- a means to strengthen demand and improve returns on such investments for both grid and off-grid systems,
- a way to enhance the use of renewable energy technologies, and
- cost effectiveness in many contexts through the use of energy-efficient appliances.

Electricity access is often characterised as being below ideal levels due to: a) fluctuating voltages; b) excessive peak demand requiring active management; and c) transmission and distribution losses that result in low voltage and unreliable supply, limiting what consumers can use their access for.

Incorporating energy storage into eCooking technologies can add an important layer of resilience, helping to overcome these limitations and ensuring a continuous cooking experience, independent of the grid infrastructure. Battery storage solutions are likely to become pivotal in overcoming the challenges associated with unreliable and weak grids. By efficiently storing surplus energy during periods of grid availability, or harnessing renewable sources such as solar energy, batteries can provide a reliable energy supply for meal preparation. The scalability and modularity of battery systems allow for customisation, ensuring an appropriately tailored power supply for a range of eCooking appliances. Furthermore, batteries can act as a buffer, stabilising voltage fluctuations and protecting appliances from potential damage caused by power irregularities.

The rapid growth of electric vehicles and the broader momentum towards a net zero economy have contributed to a significant decline in the cost of energy storage and battery technologies over the past decade. While the use of batteries to enable a seamless and reliable eCooking experience has been discussed for many years, only recently have falling battery prices made such systems cost effective, even for the lowest wealth quintiles. In anticipation of further cost reductions, several studies have explored how eCooking can be effectively combined with energy storage.

This paper draws together insights from eCooking and battery research, integrating them with recent learning from the eMobility sector. Its purpose is to inspire greater application of energy storage to address grid unreliability, and to promote wider adoption of eCooking systems linked to renewable energy technologies. In particular, the paper focuses on battery swapping as a potential mechanism for implementation.

Battery-enabled eCooking has strong potential to support the use of energy-efficient eCooking appliances in three contexts:

- i. areas where the grid is weak — unreliable, low-power, or with incomplete and poor-quality wiring;
- ii. grids and mini-grids that offer incentives to mitigate peak demand; and
- iii. locations without grid access.

In weak-grid areas, a battery can draw low current to trickle-charge during supply periods and then discharge high power for short durations to operate eCooking appliances. Where time-of-use incentives exist, batteries can be charged during off-peak periods and discharged during peak times to support cooking needs. In off-grid settings, batteries combined with renewable generation — such as solar PV panels, micro-hydro systems, or small wind turbines — can provide household or institutional energy systems that support eCooking.

For each of these scenarios, it is essential to understand the battery's charging and discharging regime, size it appropriately, and ensure that the system remains reliable, cost-effective, and sustainable. This includes assessing the delivery modalities of the battery — its required depth of discharge, C-rating, charging profile, cycle lifetime (which depends on these factors), cost, and maintenance requirements. The paper discusses these elements in relation to powering energy-efficient eCooking appliances. It also notes that battery costs are decreasing due to manufacturing scale and learning effects, and provides examples of relevant chemistries and their potential applications.

However, the same advancements in battery technology that could enable independent eCooking can also be undermined by poor-quality or poorly timed charging. On weak national grids, without a well-defined charging strategy, the full potential of battery storage may go unrealised, further exacerbating peak demand pressures. Efficient use of batteries for eCooking could help overcome unreliable and unstable electricity supply, yet load shedding and power interruptions can leave users unable to recharge depleted batteries after cooking sessions, disrupting their ability to rely consistently on eCooking. Similarly, where batteries are charged directly from renewable sources

such as solar panels, cloudy conditions or undersized systems may leave users without sufficient stored energy when needed for cooking.

Despite the substantial decline in battery prices over the past decade, the upfront cost of an appropriately sized battery remains significant, particularly for poorer households — those most likely to experience lower-quality electricity access.

To address these challenges, the concept of a Battery Swapping Station (BSS) is proposed as a potential solution to streamline the charging process and ensure efficient use of battery storage capacity. These stations would allow users to exchange depleted batteries for fully charged ones, ensuring a reliable and uninterrupted cooking experience. A key feature of this model is that ownership of the batteries would rest with the BSS, which would lease them to users under a service agreement involving regular payments and exchanges — thereby overcoming the burden of upfront costs.

Implementing such a system could not only resolve many of the barriers associated with individual charging but also accelerate the adoption of eCooking technologies. The aim is to provide users with a simple, reliable means of maintaining continuous power for energy-efficient electric cookers. This approach could promote sustained use of eCooking and reduce the risk of households reverting to traditional biomass cookstoves. Such a shift would represent a significant step towards cleaner, more resilient, and energy-efficient cooking solutions aligned with broader sustainable development objectives.

3.1 Objective

The **objective** of this paper is to:

- outline the current landscape of using batteries to support eCooking;
- briefly discuss the strengths and weaknesses of various energy storing systems, associated technologies and the use scenarios;
- present the concept of a battery swapping station (BSS), a business model specifically tailored for eCooking technology; and
- consider under what conditions and contexts the BSS might be viable

This discussion is aimed at enhancing efficiency, reliability, and seamless integration of electric cookers into diverse energy ecosystems.

3.2 Target Readers

This white paper is intended to provide a high-level overview of the opportunities for integrating batteries with eCooking, aimed primarily at decision-makers. It outlines a range of possible approaches and implementation strategies that could support the expansion of eCooking. The ideas presented here will require further development and detailed design before implementation.

The paper also introduces the concept and potential benefits of a Battery Swapping Model (BSM) for consideration by project developers. It serves as an outline for developers and implementers in designing and executing battery-swapping programmes, and may also offer strategic insights for eCooking technology manufacturers and policymakers seeking to integrate battery-swapping solutions into wider energy strategies.



Photo credit: TaTEDO-SESO

4 UNDERSTANDING BASIC BATTERY CHEMISTRIES AND TERMINOLOGY



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

②

"Batteries have specific performance characteristics, and their use is constrained by both their storage capacity and the required depth of discharge. They must also be capable of charging and discharging at appropriate rates to ensure efficient and reliable operation." From the logic model for the paper

Understandably, as we move towards a net zero, decarbonised world, there is a rapidly expanding body of work on energy storage. In this section, we touch briefly on some battery chemistries and clarify the terminology commonly used when discussing eCooking.

Batteries are said to have a capacity, but how that capacity can be utilised in real-world applications is influenced by three key characteristics. These three characteristics help define batteries and their performance:

Energy density – this is the amount of energy a battery can store relative to its weight. For eMobility, this is particularly important as it determines the range of the vehicle — lighter, more energy-dense batteries can travel further (assuming similar engineering and power conversion conditions).

Depth of Discharge (DOD) – within a battery's total energy storage, only a portion is 'useful'. Below a certain depth of discharge, the voltage drops to an unusable level, and the internal structure of the battery may begin to degrade.

Rate of charging and discharge (C-rate) – this is represented by the letter C. A 1C battery can safely charge and discharge its full capacity in one hour. Batteries can operate above or below their nominal C-rate depending on the current drawn, but exceeding the recommended rate can

damage the battery's internal resistance. (For example, 2C indicates total discharge in 30 minutes, while C/2 means total discharge in two hours is the recommended maximum.)

These factors mean that choosing the right battery for a specific purpose involves more than simply looking at its stated energy capacity. For instance, a 12V 500Wh battery rated at C/5 would be damaged if connected to a 1kW cooking device — it would require a battery rated at 2C. Significant internal resistance can prevent a battery from delivering high C-rates.

When using a battery, there are three additional important terms to consider:

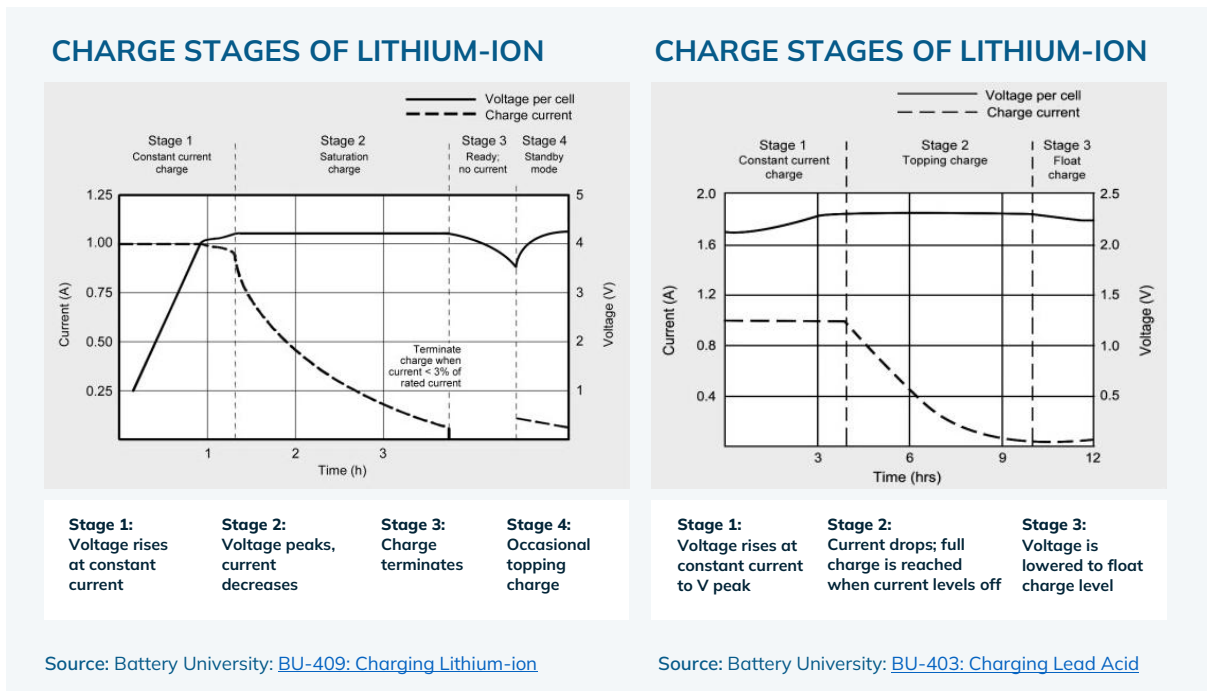
- **State of Charge (SOC) (%)** – the percentage of energy currently stored in the battery compared with its maximum capacity.
- **Depth of Discharge (DOD) (%)** – the inverse of SOC; the proportion of energy discharged as a percentage of the maximum. An 80% DOD is considered a deep discharge, and, as discussed later, some batteries do not tolerate frequent deep discharges and degrade over time.
- **Terminal Voltage (V)** – the voltage measured across the battery terminals when a load is applied. The nominal voltage is specified at the time of sale, but the actual voltage can exceed this by a few percent when fully charged and will drop as the battery discharges.

There are other characteristics to consider, but these are the principal ones when selecting a battery. Many of these factors are interdependent — for example, the lifetime of a battery, expressed in the number of cycles, depends on both the Depth of Discharge (DOD) and the C-rate.

4.1 Chemistries

Until the turn of the century, lead-acid batteries were the dominant form of storage, accounting for about 50% of all batteries in 1999. They have a relatively low energy density and were therefore not well suited to the development of electric vehicles. Lead-acid batteries are good at supplying surge currents and were widely used as starter batteries in vehicles. However, with a relatively low cycle life (around 500 to 1,000 cycles) and a need for regular maintenance, including desulphation, they remained mainly in power systems until the last decade. They were also heavy and not easily portable, with the added risk of acid spills, although later gel and glass mat versions were sealed, easier to handle, and described as maintenance free. Lead-acid batteries are recyclable and show a characteristic pattern of voltage change during discharge, particularly when compared with lithium-ion batteries, which are discussed below.

FIGURE 1 A charge diagram for a typical lithium battery¹ compared to Lead Acid.²



In the last two decades, lithium-based batteries have come to the foreground, with the IEA reporting that lithium now holds over 90% of the global market share. We have mentioned lead acid because professionals and informed lay people working in the solar (or DIY solar) sector have extensive experience with it and sometimes project the characteristics of lead acid onto lithium-based batteries. The characteristics of lithium-ion batteries represent a significant improvement over lead acid, and lithium-ion has now become the norm.

However, the term “lithium-ion” can be confusing to non-specialists. It refers to around twelve different chemistries and configurations, all of which use lithium ions to conduct electricity. Most handheld electronics use lithium with a polymer gel as the electrolyte; these cells are grouped together to operate as a coherent battery. Such polymer-based batteries can catch fire or even explode if the cells lose their integrity through fire or mechanical damage, creating the impression among consumers that they are inherently dangerous.

In most vehicles, lithium is combined with manganese oxide, sometimes designated as NMC. These have less potential to catch fire or explode but still present a mild risk. For this reason, for example, Tesla houses its batteries in titanium casings to prevent puncture when driving over rough roads. (Such housings currently make recycling or reuse of the battery cells difficult and cost-ineffective.) Lithium is also combined with iron phosphate (LFP), which is widely used in the home solar market and suitable for domestic DIY installations.

As of 2022, lithium nickel manganese cobalt oxide (NMC) is the dominant battery chemistry, holding about 60% of the market, followed by lithium iron phosphate (LFP) with just under 30%. While other configurations exist, the last chemistry particularly relevant to eCooking is lithium titanate (LTO), which has roughly three times the cycle life of LFP and can be discharged to a greater depth.

One of the key challenges for consumers is identifying the actual chemistry used when a battery is marketed simply as “lithium-ion.” Lithium-ion batteries all have higher energy density than chemistries such as lead acid, but some are safer than others. All lithium batteries perform poorly if left discharged for long periods and can fail if the depth of discharge falls below a certain point. Maintenance through careful and timely recharging is therefore important. Overcharging or charging too quickly can cause heat build-up and, in the case of lithium polymer gels, may result in cell breakdown and catastrophic fire. Although rapid discharge rarely generates heat, it can still damage the internal structure of a battery.

Batteries have internal resistance, which limits the energy they can deliver. For instance, it would be of no use to attempt to power a 400W eCooker with a 20Wh lithium motorcycle battery.

The concept of a battery-swapping station helps mitigate some of the uncertainties surrounding the use of lithium batteries by managing the charging cycle and ensuring consistent maintenance.

BOX 1 The advent of Sodium

Side Note – the advent of Sodium

There is considerable ongoing work on commercialising sodium-ion batteries. Similar in many respects to lithium-based batteries, sodium is far more abundant on Earth, meaning a shift to sodium could support large-scale battery production globally.

Sodium–water batteries have existed for some time and were once used on submarines — “salt water” batteries that could be recharged by flushing the substrate into the ocean and replacing it with seawater. These saltwater batteries have lower energy density and higher internal resistance, making it difficult for them to deliver discharge rates above 1C.

However, because they rely less on scarce and geopolitically sensitive minerals, sodium-based chemistries offer a more abundant and potentially safer alternative. While their energy density is currently lower than lithium-ion, ongoing research and development may yield viable eCooking applications within the next decade.

Sodium-ion batteries have internal resistance comparable to lithium iron phosphate and can deliver relatively high C-rates. Although emerging sodium-ion technologies may eventually outperform lithium-ion, they are unlikely to become commercially cost-effective for another ten years. Active research is underway to accelerate the deployment of sodium batteries in low- and middle-income settings^{3,4}.

4.2 Sizing the battery for eCooking



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

②

Energy Storage in the form of a chemical battery, can deliver an eCooking experience.

To do this, a battery would have to experience a ‘regular’ (possibly daily) cycle of charging and discharging.

The amount of energy required to cook several meals a day depends on the cooking culture and the equipment used. A typical East African single meal cooked with an Electric Pressure Cooker (EPC) for five people can be prepared using less than 0.5 kWh. This suggests that the total energy demand for cooking multiple meals using an EPC is likely to be lower compared to less efficient traditional methods or other electric cooking appliances used for the same purpose. The EPC is one of the most efficient appliances, with energy-saving features such as effective heat transfer to the pot, automated control of power input, insulation, and pressure cooking. If induction stoves are used, they only deliver effective heat transfer to the pot and rely on human behaviour for control of power input, rarely using insulation. This can result in much higher energy consumption for the same meal. Other cultures may use less energy, for instance rice-based cultures with quick fry foods can use less than the “long bean-based cook” of Africa, but they also cook a greater variety of meals, which can result in a variety of dishes and the use of more energy.

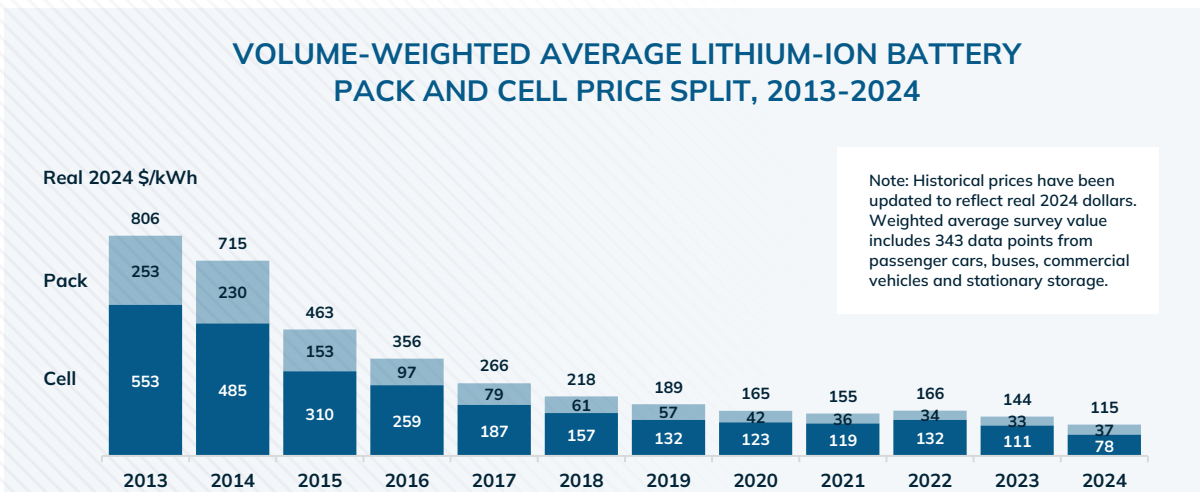
And of course, households may choose to eat one, two or three meals a day. For the exercise of battery sizing, let us assume 1.5 kWh per day can cover most household demand for cooking with energy-efficient measures in place.

4.3 Basic costs

In the introduction we noted that the costs of energy storage have come down dramatically over the last two decades, driven mainly, though not exclusively, by the growth of eMobility. Figure XX shows the fall in price for lithium batteries since 2013. The 95 percent reduction in price since 2000 helps explain why lithium-ion now accounts for around 90 percent of the market.

FIGURE 2 Cost reductions in lithium-ion batteries driven by learning-curve effects (2014–2024)⁵

Source: BloombergNEF



The figure shows that the decline in battery prices appears to be slowing, almost levelling out. This may be due to the recent turbulence in the global economy, including the impacts of COVID-19 and the war in Ukraine, as well as surging prices for key raw materials. The downward trend may, however, resume in the coming years as the learning curve continues, driven by advances in manufacturing efficiency and technological innovation, both of which are evolving rapidly.

The blue box briefly discusses the target price of batteries that could make a solar home system cost-effective for eCooking. Although current battery prices are around half of Batchelor's original 2013 projection, the box places these prices in the context of household fuel expenditure in different markets. There are also emerging cost-effective propositions where rooftop solar installations are combined with batteries to maximise returns on investment, although this remains a complex and evolving market.

BOX 2 Solar Home Systems and eCooking

Solar Home Systems and eCooking

Batchelor 2015^{6,7} suggested that if a complete solar home system could provide 1.5 kWh of storage and be retailed at around USD 800, it could enable eCooking to be cost effective. He assumed that a 1.5 kWh battery would cost about USD 350 ex-factory by 2020, with PV panels at around 40 US cents per peak watt, allowing for only minimal additional system and customer acquisition costs. He also noted that, according to the World Bank, half of the households using polluting fuels spent more than USD 20 per month, and that such expenditure could service an USD 800 loan. Spreading this upfront cost over five years at 5 percent credit interest would make repayment feasible, given the expected 30-year lifetime of the solar PV panels. The long-life battery would require replacement after about ten years, but by then would likely cost only a fraction of its original price.

As stated in the main text, the current costs of batteries and PV panels are now well below Batchelor's projections. However, the flaw in his argument lies in the type of market this technology targets. The market for standalone solar home systems exists mainly where there is no grid, and households in such areas are typically farmers or pastoralists with seasonal incomes. They often operate largely outside the cash economy and rely on biomass that is readily available at little or no financial cost. Although collecting wood requires labour and thus has an opportunity cost, it is still perceived as free. Such households, therefore, do not fall within the half of the global population paying more than USD 20 per month for fuel. They are also remote, which increases customer acquisition costs.

While the total system cost of a standalone solar home system is now below USD 500 and continues to decline, even this reduced price struggles to compete with the perceived "free" availability of firewood. This is particularly true in contexts where women are responsible for collecting the wood while men control household finances. There are many benefits to shifting cooking towards clean, solar PV-based energy, but these advantages may not be sufficient to convince households to take on even a small amount of credit debt.

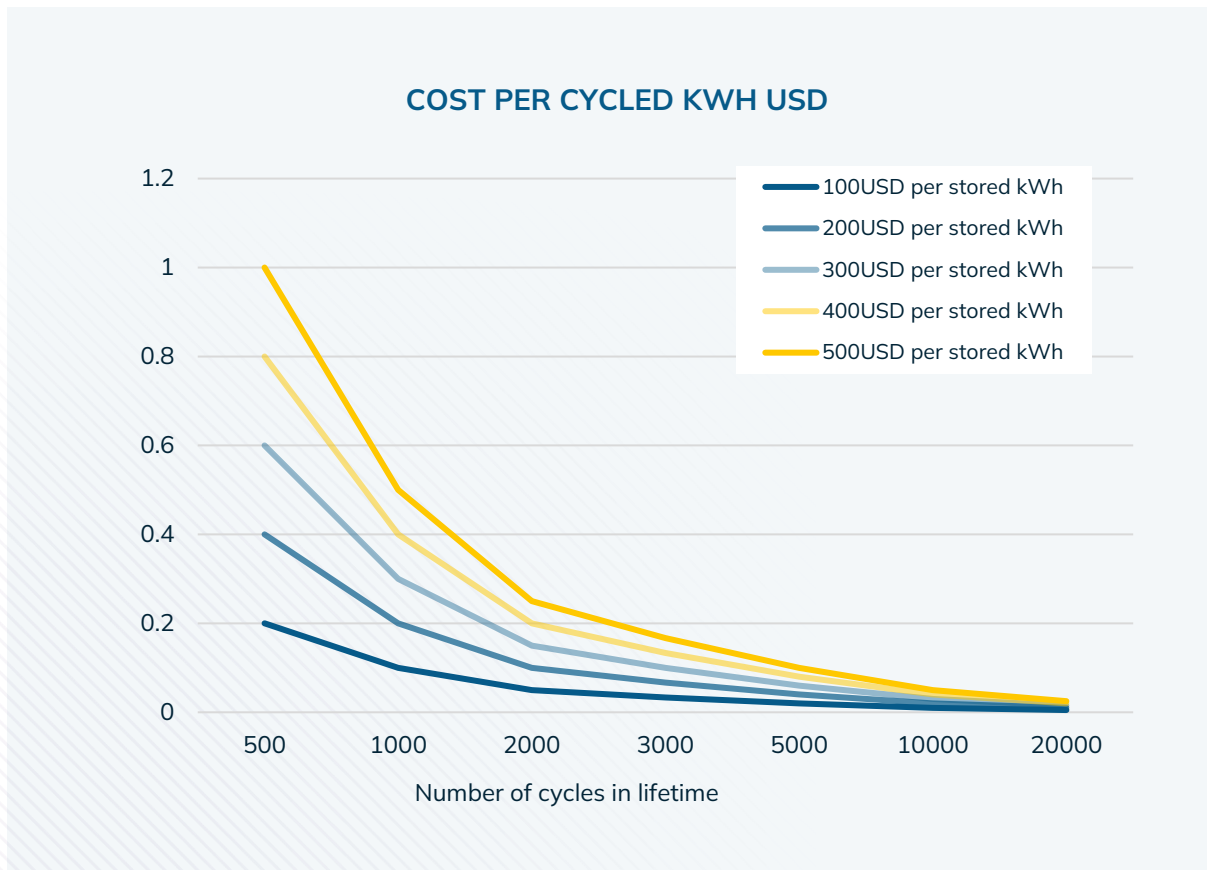
4.3.1 The battery cost per cycled kWh depends on number of cycles

So, if we take a snapshot in 2024, what might this mean for eCooking? A 12V or 24V LFP 1.5 kWh battery would be capable of delivering several meals per day. Such a battery is currently priced at around USD 200 ex-factory in China and about USD 400 at retail in Europe. Assuming 3,000 cycles, this suggests a cost per cycle of between 6 and 13 cents.

This cost per cycle becomes relevant when the battery is charged from the electricity grid, whether reliable or unreliable. In that case, an additional 6 to 13 cents should be added to the effective cost per unit of energy used per cycle. Essentially, each time the battery is discharged and recharged using grid power, this cost is incurred. If the battery is part of a solar home system, then the cost per kWh unit becomes the total lifetime cost of the system — with the battery as one component — divided by the total energy delivered over its life.

The cost per cycle also depends on how the battery is used. If batteries are discharged to only 60 percent depth of discharge (DoD), the number of effective cycles increases compared to regular use at 80 percent DoD. The typical 3,000 cycles can be more than doubled to around 7,000. Lithium titanate, while more expensive than lithium iron phosphate, is reported to deliver around 10,000 cycles at 80 percent DoD and possibly up to 20,000 at 60 percent. This means that although the initial cost is higher, the more expensive battery results in a lower cost per effective cycle — effectively a lower daily cost for eCooking.

FIGURE 3 Battery cost cycle depending on number of cycles (which depends on depth of discharge)
Source: Authors



4.4 Recent developments in battery enabled eCooking



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

③

Those with low tier access to electricity or no access could own batteries and create conditions to regularly charge them and use them discharging for eCooking.

The prices of batteries have dropped significantly in the last ten years due to learning and manufacturing gains, and are likely to continue to become more affordable, with better performance.

4.4.1 Experience to date of battery enabled eCooking

Early prototypes: The UK private sector company Gamos Ltd foresaw the potential of battery-enhanced eCooking for low- and middle-income countries as early as 2012. The company developed an open-source design and piloted a prototype that incorporated a 1.4 kWh LFP battery built into the appliance, based on the assumption that consumers would prefer an integrated device similar to eMobility products such as e-scooters. However, although some energy-efficiency measures were included, the design required further iteration before it could become a commercially viable model⁸.

In 2018 at the start of the Modern Energy Cooking Service Programme the CREST research team chose a different approach which was to make a battery-based generator capable of delivering power to ecooking devices⁹. The project experienced significant delays, and the 120 prototypes were finally placed with households in Kenya, Uganda, and Tanzania in 2022. Each trial included 20 direct current (DC) versions with DC appliances and 20 alternating current (AC) versions with AC appliances. Despite market surveys indicating consumer preference, the design team initially limited the DC units to a maximum output of 300 W. As the field team later observed, this power level did not provide a satisfactory eCooking experience. The systems were subsequently upgraded to 500 W, and the team collaborated with eWant in China to develop a 450 W DC electric pressure cooker, which is now commercially available and used in Malawi (see below). The AC version used the same batteries and was designed to deliver 1 kW, and the DC version was later modified to match this output.

The two-year trials concluded in late 2023, and the project reported high satisfaction among participants, largely because the units were able to overcome local grid power shortages.

SONG: The SONG project was an early exploration of battery swapping¹⁰. Sited in Kenya, the community were able to bring depleted batteries to a charging station and swap them for charged ones. The research project faced several challenges, including the fact that the batteries were of a new design and did not perform as expected, leading the team to revert to lead-acid gel batteries. The community valued the experiment and continue to speak positively about their experience; however, the main lessons from the research centred on the inability of the community committee and charging-station managers to record basic data and maintain clear accounts. While this could be mitigated through training, it was considered a significant barrier to replication, even if the technical issues were resolved.

Pesitho: The Danish company Pesitho produced a bespoke cooking pot integrated with a battery¹¹. The design includes insulation to improve energy efficiency, but the device is limited to use with its own specialised pot. Early field trials were conducted with refugees in Uganda, and the product is now well regarded among international agencies. It contains a 0.5 kWh battery, making it suitable mainly for preparing one meal per day.

Ongoing trials and research have shown that the system can have a relatively short lifetime if it is not supported by a suitable local repair and maintenance scheme. Minor breakages can disable the entire unit but can be repaired easily if a trained technician is available.

Kachione: A relatively small NGO in Malawi (Kachione) worked alongside a US based organization (Solar4Africa) to develop a locally made eCooker connected in a solar home system to Lithium Titanate Batteries¹². The locally made eCookers had a limited lifetime, suffering from corrosion on the heating element. Working with MECS, the eWant DC electric pressure cooker was improved and introduced in Malawi, and as of 2024 more than 200 systems are operating daily. The programme has three notable features:

- i. It uses lithium titanate batteries. The individual cells are assembled into battery packs by trained local technicians using an open-source battery management system. This makes the batteries cheaper than importing complete units from China.
- ii. Social mobilisation has been a key component of the programme. Women-led solar shops sell and rent a wide range of solar equipment, including eCookers. Solar pumping systems have improved agricultural yields and attracted men to the technology, while the addition of an eCooker to a pumping system has proved appealing to women.
- iii. The use of DC appliances imported from China has been shown to be highly cost effective when procured in bulk, and the devices have demonstrated a very low failure rate.

EGenerators: While the CREST team (above) were developing their bespoke battery-based “generator,” similar ideas were emerging elsewhere. From 2020 onwards, a new generation of generators appeared for use in the off-grid camping markets of developed economies. As growing discomfort with the noise of petrol and diesel generators spread across European and American campsites, a new market developed for “battery generators” equipped with inverters for AC outlets, USB-C ports, and DC outputs.¹³

There are now many such products on the market, and prices have fallen dramatically over the past three years as the sector has matured. In 2021, a 1.5 kWh, 3 kW continuous-output generator cost around USD 1,800; by 2024, the same unit costs about USD 800. Specific programmes are also emerging that aim to replace small petrol and diesel backup generators — for example, those used for general electricity supply in small businesses — with clean battery-based eGenerator alternatives in countries such as Nigeria.¹⁴

While there may be other trials around the world, in Kenya the company Biolite has been exploring whether such a commercially available eGenerator coupled with eCooking devices might have a place in the Kenyan market¹⁵. Having gained significant experience in large-scale battery deployments for national and mini-grids, AgreatE has entered the camping eGenerator market. The company has recognised the potential of these generators for eCooking and plans to explore deployment in Cameroon and Mozambique¹⁶.

SunCulture: As the case of Kachione highlights the coupling of solar-based eCooking with solar-powered irrigation pumps, it is worth noting that SunCulture has also explored whether eCookers could complement their growing sales of solar pumps¹⁷. This initiative was potentially very innovative, as SunCulture's Internet of Things (IoT) monitoring system could have provided verified usage data for carbon finance payments. However, their batteries operate at 32 V, and while the eWant DC cooker is rated safe up to 30 V, trials showed that it could not function safely at the higher voltage. Given the company's focus on expanding its core business, the eCooking component was set aside to avoid diverting attention from its main product line. SunCulture has since leveraged millions in carbon finance and working capital to scale its water pumping operations.

Mobile Power: Operating across seven African countries, Mobile Power is one of the leading innovators in battery-swapping models for motorcycles. The company has established a clear pay-per-swap business model, and its MOPO hubs are prominently featured on its website.¹⁸ While the site does not suggest battery swapping for eCooking, they are currently undertaking trials in Kenya with the Ewant DC EPC.

Tangram Energy LTD (Nigeria): Working in Nigeria, this group has added a cabinet with an induction stove and substantial batteries to provide a modern cooking solution. The batteries are delivered and swapped¹⁹ regularly, giving consumers a consistent and reliable cooking experience.

These cases not only document the progress made over the past decade in the uptake of battery-driven eCooking, but also highlight several key lessons for future planning of a battery-swapping business model:

- Private sector delivery of battery-enabled appliances should be based on a clearly defined, market-driven product, while remaining open to expanding the product range in terms of both battery size and appliance use.
- Tailor the delivery model to the socioeconomic market segment. The Kachione mobilisation of women's groups demonstrates how social capital can serve as a strong driver for customer acquisition.
- The organisation and management of batteries depend on reliable data collection and sound accounting practices.
- Consider the lifetime of the battery and explore alternative commercial chemistries. Depth of discharge will affect lifetime, so financial models should take a conservative approach to assumed lifecycles. Higher upfront costs for batteries with longer lifetimes, as seen in the Kachione project using lithium titanate, may prove more cost-effective over time.
- There is likely to be a market for both appliances with integrated battery storage and those that can be connected to lower-power battery generators, whether AC or DC.

4.5 Charging dynamics



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

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Renewable energy generation at a household level (e.g. Solar Home Systems), could do a daily charging cycle but:

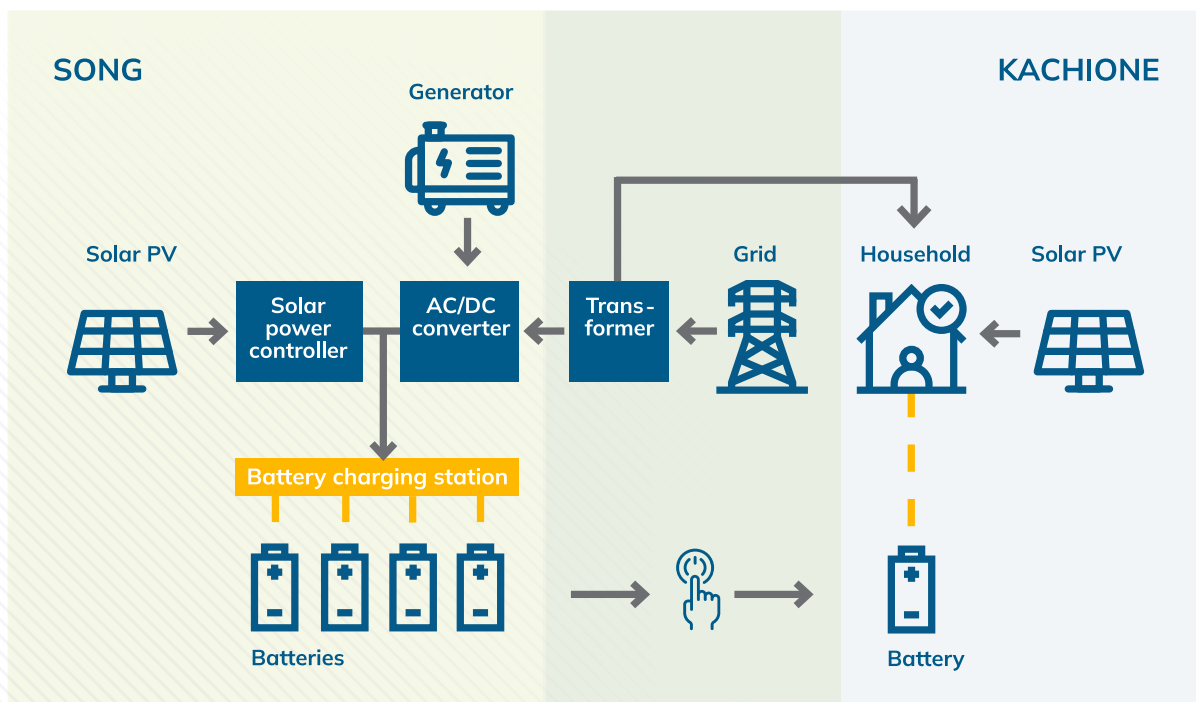
- there would be significant upfront cost for the whole system, which would likely require access to credit to install the system; and
- sizing the battery to cover seasons and cloudy days would increase the cost of the system.

Those with access to a weak and unreliable grid, could charge the battery when they have electricity and discharge it for cooking:

- Some electricity connections in Asia are limited to 300 W, which is not sufficient for cooking.
- Certain connections on mini-grids are limited to 5 amps, which is also inadequate for cooking.
- Households accessing electricity illegally or through a landlord often have poor-quality wiring, and drawing high power through it can cause brownouts.

Before discussing the idea of a battery-swapping station or model, it is useful to first consider the dynamics of charging a battery. Many of the projects cited above rely on solar photovoltaic panels for charging, such as SONG, which uses a community charging station, and Kachione, where individual households charge their own batteries. Mobile Power, by contrast, uses grid electricity supplemented by backup generators.

FIGURE 4 General Profile for battery enhanced energy delivery Source: Authors



Solar photovoltaic (PV) panels provide charging during daylight hours and depend on the availability of sunlight. The use of solar PV for charging devices and powering enterprise appliances for productive use has been widely researched, with a steadily growing body of work exploring its optimal application. Figure XX summarises a generic profile for battery-enhanced energy delivery.

In the context of eCooking, solar PV presents a potential challenge when providing energy for three meals a day. The evening meal and breakfast are typically prepared when the sun is setting or rising, meaning the battery must supply power independently. As a result, the battery must have sufficient capacity to cover two to three meals per day. Midday meals, by contrast, may be supported directly by power from the PV panels, depending on weather conditions.

4.5.1 How long does it take to charge a battery?

If we accept that a 1.5 kWh battery can meet most, if not all, of a family's eCooking needs in low- and middle-income countries, the next question is how such a battery can be charged. Any LFP battery of a specific voltage can be charged using a lithium charger rated for the same voltage. The charger detects when the battery is fully charged and switches off automatically. Chargers are available with different current ratings, allowing for both fast and trickle charging. However, it remains the responsibility of the user to ensure that the charger is correctly matched to the battery in both voltage and current.

For solar home systems, slow charging during the day is acceptable and forms the basis of most home system designs. As discussed earlier, most batteries should not be charged at rates above 1C. For a 1.5 kWh battery, this would require 1.5 kW (peak) of solar panels. A common error made by planners is to assume that, in order for a battery to power a 1 kW kitchen appliance, the system needs a 1.5 kWh battery (to run it for an hour at 70 percent depth of discharge) and therefore a solar PV array of over 1 kW.

In practice, under good sunshine conditions, a 600 W panel can charge a 1.5 kWh battery (starting at 80 percent depth of discharge) in about three hours. This implies that a 300 W panel could achieve a full charge in around six hours, which is a reasonable expectation on a sunny day. The challenge, however, is how to plan for cloudy conditions. Should the system be designed with an oversized battery — often the most expensive component — or with oversized PV panels? Given the dramatic reduction in PV panel prices, it currently makes more sense to oversize the panels to cope with cloudy days. Of course, a prolonged rainy season still presents problems, but in such cases, households may choose to fuel stack with LPG or revert temporarily to biomass.

It is also worth noting that the overall performance of a solar home system depends not only on solar irradiance for the area and season but also on how the panels are installed — whether they are shaded by trees at certain times of day, whether the angle of the panels is optimal, and whether they are kept clean. Dust and heat both reduce the efficiency of a solar PV array.

The PV-based eCooking target is generally to have a fully charged battery by the time the evening meal needs to be prepared. In Malawi, the Kachione programme encourages customers to cook

during the day while also charging the battery, and sizes systems accordingly. This ensures that the battery can provide enough energy for the evening meal and, if possible, for breakfast as well.

We will not discuss cooking cultures in detail here, but it is worth noting that many breakfasts are relatively light, often consisting of tea, reheated food, or porridge. The energy requirement for breakfast is therefore typically much lower than for the evening meal. There are also socio-cultural “workarounds” to consider in discussions with consumers. For instance, some may be open to pre-cooking or batch-cooking the evening meal at midday so it can be reheated later, although for many households this would not align with the expectations of the household decision-maker.

For mini-grids, many of which are based on solar PV, similar challenges to those faced by solar home systems apply. They may, however, have slightly greater flexibility in managing a larger battery array and could cater for cloudy days through backup generators, often powered by fossil fuels.

For weak grids, trickle-charging a single battery or an array of batteries can often be achieved without the need for wiring or transformer upgrades. This approach also allows for the use of off-peak electricity. The battery can then be used for cooking even when grid power is unavailable at that particular time.

We mentioned earlier the possibility of **a rooftop system** that primarily feeds its solar PV-generated energy into the grid but can be enhanced through the addition of energy storage. This approach is becoming increasingly common in developed economies, where there is now a strong market for sizeable batteries that capture excess midday generation and release it during the evening. These batteries typically have storage capacities of between 5 and 11 kWh and are designed to meet the evening energy needs of households in developed economies.

India now has a rooftop solar programme and is considering including battery storage to promote eCooking. The batteries in such systems are charged from the solar PV array, but sizing is less critical than in a stand-alone home system, since they can also draw power from the grid on cloudy days or during periods of unusually high evening demand. The charging rate of these batteries is typically spread over five to six hours, similar to that of a stand-alone system

4.5.2 Is it safe to turn up the charging?

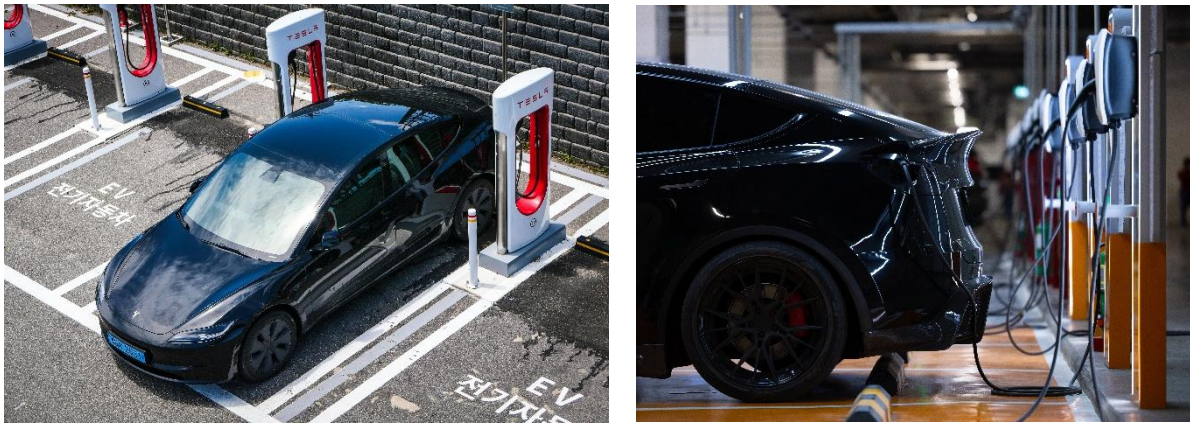
Fast charging or overcharging without proper electronic controls can cause batteries to overheat. A common current problem is that low-quality electric scooters are being used by families as toys and are charged without adequate control systems, leading in some cases to fires and explosions.

There has historically been a similar issue with laptop computers. Until recently, each brand had its own charger, and if one was lost, it could not easily be replaced with another brand’s charger, as different models charged at different rates. This situation has improved with the introduction of standardised USB charging for laptops, tablets, and phones. The mobile phone industry also went through a period when multiple chargers were in use, but this has now largely been resolved, particularly with the widespread adoption of USB-C.

For electric vehicles, the charge rate varies considerably and is constantly evolving²⁰. National infrastructures in developed economies are being overhauled to accommodate fast charging for electric vehicles²¹.

Currently, there is little standardisation between batteries and chargers in the eMobility sector. The rise of fast charging for electric vehicles has led companies such as Tesla to create their own charging infrastructure, and while most cars can be charged at home, debate continues over plug types and charging rates. Many public chargers can now deliver around 11 kWh of energy in one hour, allowing a car at 80 percent depth of discharge to be recharged in about 15 minutes — roughly the time it takes for the driver to have a coffee. Achieving this requires sophisticated battery balancing and high-quality electronics to monitor cell balance, temperature, and state of charge. The same batteries can also be charged at home through a standard 13-amp plug at a rate of around 2 kW.

FIGURE 5 Fast charging stations



Implications for a Battery Swap Station: Assuming a lithium-ion battery suitable for cooking weighs around 20 kg and has an energy density of 100 Wh/kg, its total capacity would be about 2 kWh. If such a battery were charged at a swap station using a 1 kW charging system, the charging time would be roughly two hours. In this case, a depleted battery could be fully recharged in about two hours at the swap station — a charging rate of 0.5C, which is well within the specification of most batteries. It is important to note, however, that faster charging generates heat, so both the swap station and the battery design would require robust thermal management systems to ensure safety and maintain battery longevity.

4.5.3 Shape and Form – standardization?

The ‘a’ rating system on mainstream non rechargeable batteries was essential to their uptake²². Most people know that their devices require a “double AA” battery or similar. By standardising the battery’s shape, size, and voltage, the same type of battery can be used across multiple devices.²³.

As smaller batteries have become rechargeable, their interchangeability and the ubiquity of their shape and form have helped drive sales and adoption. There are now initiatives to standardise larger batteries, such as those used for gardening and woodworking equipment. At present, larger

battery packs suitable for eCooking are available in various sizes, with terminals that, much like the early solar home systems, can be connected either directly to appliances or to inverters.

4.6 Life cycle and maintenance of a battery

While PV panels are designed to last 25 years or more, LFP batteries are typically rated for around 3,000 cycles. With daily charging and discharging, this translates to an expected lifetime of roughly seven years. Households using stand-alone systems will therefore need to plan for eventual battery replacement. Given the ongoing reduction in production costs, it is possible that in seven years the same capacity battery could cost less than half of today's price. Nevertheless, this replacement remains a system cost that must be accounted for.

It is also worth noting that the lifetime of appliances is not yet fully established. In developed economies, electric pressure cookers typically last between 10 and 20 years, although early evidence suggests that in harsher environments their average lifespan may be closer to four years.

It is worth noting that e-waste is a growing concern, and the safe disposal of electronic equipment requires robust infrastructure, responsible recycling practices, and consumer awareness. This is particularly important in the case of batteries. At present, the recycling of lithium batteries is a specialist activity and remains relatively costly. However, as global supplies of lithium and cobalt are finite and their prices are expected to rise, the cost-recovery dynamics for recycling lithium batteries are likely to improve — both through higher material values and advances that reduce recycling costs.

Over-discharging is also a concern. Over-discharge occurs when an LFP battery is completely drained but continues to discharge under residual voltage. This leads to the formation of copper dendrites, which increase internal resistance, reduce capacity, and shorten battery lifespan. To prevent over-discharge, it is essential to use protective mechanisms such as Battery Management Systems (BMS), Protection Circuit Modules (PCM), or Printed Circuit Boards (PCB). Avoiding complete discharge also plays a key role in preventing this type of damage.

Recovering an over-discharged LFP battery is possible to a limited extent by using a parallel charging board to connect it to a standard 3.2 V LFP battery. However, this method is only viable if the battery voltage remains around 3 V after over-discharge. Batteries with significantly lower voltages are typically beyond recovery due to irreversible damage to the active battery material.”²⁴.



5 BATTERY SWAPPING



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

An alternative approach to owning a battery based eCooking system would be to lease, rent or hire charged batteries.

This is the basis for a battery swapping station.

5.1 eMobility concepts and early lessons



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

③

There is limited experience of battery swapping in electric vehicles.

Battery swapping in vehicles offers the advantage of a short swap time, making it potentially more convenient than fast charging.

Fast charging for electric vehicles depends on strong electrical infrastructure. Developed economies generally have such infrastructure and continue to upgrade it, so the emerging norm for vehicle charging is either at home or at public charge points.

Battery swapping has been, and continues to be, explored for cars, though it requires substantial station infrastructure to handle the heavy batteries, often through robotic systems.

Battery swapping is also being explored for e-cycles and has shown particular value for taxis and other localised motor vehicle networks.

Given the above, one enhancement to the idea of battery-supported eCooking would be the introduction of battery swapping. Battery swapping could:

- Help manage battery charging to ensure timely availability for eCooking.
- Enable the use of larger solar PV arrays or grid electricity to balance and optimise power generation across multiple batteries, improving overall efficiency and maximising energy use and storage.

- Where grid electricity is used for charging, allow the swapping station to charge batteries during off-peak hours and help smooth out short power outages.
- Manage battery failures effectively and ensure safe disposal at the end of life.
- Distribute the lifetime cost of the battery charging system across multiple batteries, managed and accounted for by an enterprise, rather than leaving individual households to bear the full cost of ownership.
- Address the sourcing and sustainability challenges of critical minerals. Centralising battery ownership and management can extend battery lifespans through optimised maintenance and enable more efficient end-of-life recycling and material recovery. This improved utilisation and circularity could reduce the need for newly mined materials compared with individual ownership models.
- Provide a convenient collection point for used batteries and eCooking devices at the end of their life, creating an opportunity to collaborate with manufacturers on extended producer responsibility initiatives. Perhaps surprisingly, the idea of battery swapping dates back not to this century (the 21st), but to the previous one. It is a largely forgotten fact that in the very early days of motor vehicles, during their period of “niche innovation,” electricity rivalled petroleum as a power source. As shown in Figure 1 (REF), by 1912 all taxis in New York were battery driven. They would return to the depot and swap out their batteries before heading out again on duty. One of the most innovative electricity companies of the time, the Hartford Electric Light Company, partnered with the General Vehicle Company (GeVeCo), one of the first firms to offer electric trucks²⁵. HELC offered swappable charged batteries and explored several innovative business models, including payment per mile and monthly subscription fees. Reportedly, the company’s electric trucks covered more than six million miles before the scheme was eventually retired. Interestingly, HELC was also among the first companies to innovate and develop electric kitchen cookers, selling around 20,000 units in the Hartford area.

FIGURE 6 Old photo of an early electric vehicle swapping station. Source: [Wikimedia Commons](#)



Electrobat - one of the world's first all-electric cars, was popular in Manhattan, New York in the late 19th century²⁶.

There were other electric vehicle innovations up until around 1920, but the chemical batteries of that era were heavy and had very limited range — suitable for short services such as town taxis, but not for longer journeys. The dominance of fossil fuels in vehicles largely emerged from the need for a range of a hundred miles or more to provide a practical alternative to the horse¹. Electric vehicles themselves remained niche until recently, and the idea of swappable batteries has only been explored in a few specialist cases.

Over the past two decades, electric vehicles have advanced rapidly and are now well on their way to becoming mainstream, with several swappable battery business models emerging, particularly for smaller two- and three-wheeled vehicles. Renault trialled battery swapping around 2011 in Israel, with ambitious plans for a “Better Place” network, but the company behind the scheme filed for bankruptcy in 2013.²⁷

Some of the reasons for the failure of early battery-swapping initiatives included the high infrastructure costs of building and maintaining a widespread network of automated stations, limited EV adoption and standardisation across manufacturers, consumer preferences shifting towards conventional charging, and the inability to establish a sustainable business model.

Tesla announced in 2012 that it would trial battery swapping the following year, but its expanding Supercharger network quickly overtook such plans. Currently, Nio is the only known car manufacturer offering battery swapping at scale, with more than 3,000 swap stations in operation, each capable of completing a swap in about five minutes.²⁸ Other emerging companies, such as Ample, are also working to establish themselves within the battery-swapping ecosystem. An early lesson from one of the Chinese pioneers of city-based swapping was that repeated loading and unloading caused wear on the connectors, and in one instance, a battery caught fire, damaging the project’s reputation.

For smaller vehicles such as scooters, companies like Gogoro operate in Taiwan, where there are now more than 11,000 swap stations in place²⁹. Similar initiatives for small vehicles are also emerging in Africa, including those led by Mobile Power. We will explore this further below.

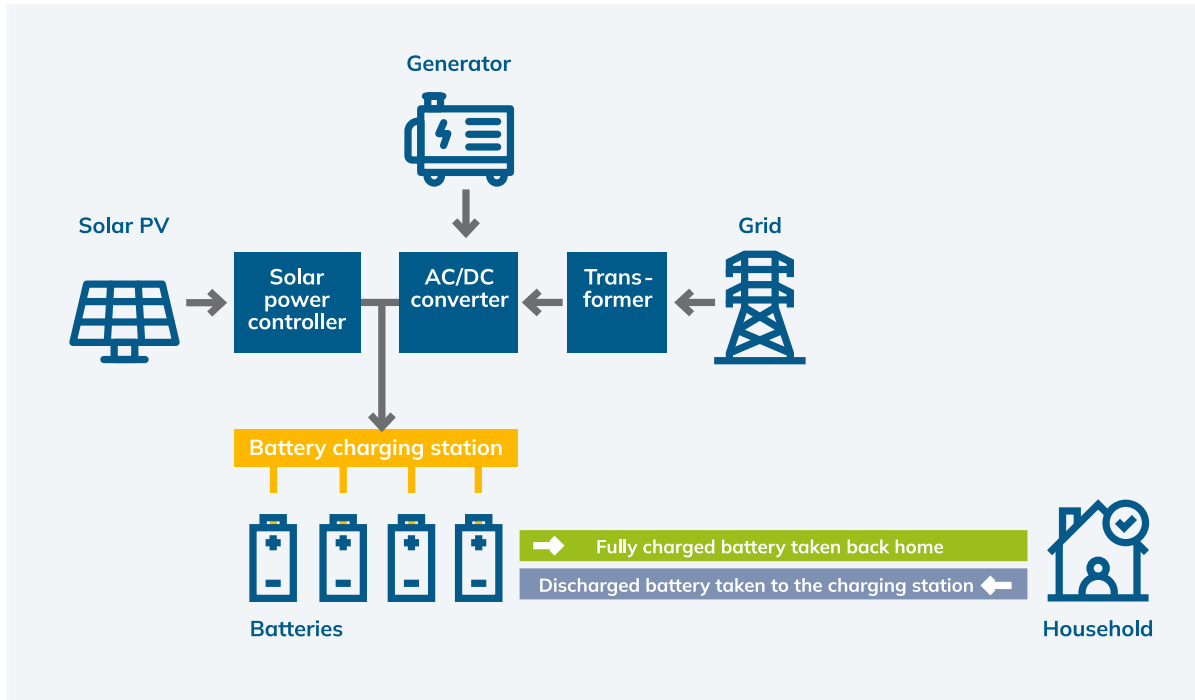
The idea of battery swapping is attractive for vehicles because it eliminates the wait associated with recharging. However, with the expansion of supercharging networks in developed economies and the convenience of home charging, the added value of battery swapping in these markets is, if anything, diminishing. As we will see below, there are advantages in long-term battery management associated with swap schemes, as well as opportunities in countries that lack the infrastructure required for widespread supercharging networks.

Finally, in terms of community or domestic use, there has been very limited exploration of battery swapping. As described earlier, the SONG research in 2012 in Nakuru, Kenya, introduced a central charging station where households could bring their spent batteries to exchange for charged ones.

¹ The Museum also noted that petrol cars surpassed electric vehicles in popularity after the invention of the electric starter motor. Before then, drivers disliked petrol cars because they had to be cranked by hand — once that inconvenience was removed, petrol vehicles quickly outsold electric ones.

The idea proved attractive to the community, but the pilot faced challenges due to the use of a novel and untested battery configuration that suffered a high failure rate. The location of the charging station also proved critical: people preferred to replace their batteries as part of their trip to the market, but the station was situated slightly away from the market—just far enough to discourage regular use.

FIGURE 7 Battery swap model (SEforALL 2024)



Creating a Battery Swap Model for eCooking



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

④

Battery swapping for eCooking has a different profile from a station that swaps for eCycles.

- Demand would become regular - Households living near the station would likely swap 'regularly' (possibly daily).
- The physical size of a 1.5kWh battery (one day of eCooking) suggests that households have to be able to carry it easily to their home.
- A larger multi day battery might be possible for people who have their own vehicle (bicycle, motorcycle, etc).
- There may be a variant of the battery swapping station that delivers the battery to peoples home by regular route.

So, how might these emerging lessons from eMobility inform a Battery Swapping Model for eCooking? With battery swapping designed for eCooking technologies, the user would obtain a

fully charged battery—possibly every day—by exchanging a discharged one at the swapping station. The user would likely not own a specific battery, since it is exchanged frequently. More plausibly, the user would have a subscription, lease-hire, or rental arrangement with the swapping station. This infrastructure can lower upfront investment for the user. The counterpoint is that it requires significant investment by the station developer, and for the model to be sustainable it must be profitable; all capital and operating costs still need to be covered within the lease or service fee. It does not necessarily make energy storage cheaper overall, but it can be more attractive than household ownership if it helps overcome the upfront cost barrier.

Frequency of the swap – Daily collection?

How might a swap station for eCooking differ from one for electric vehicles? One key difference is localisation. While electric cars may require swaps anywhere along a journey, eCooking users would typically enrol with the nearest station to their home. In the longer term, several stations may emerge within reach of households—similar to how LPG cylinders are sold by multiple agents—but there will generally need to be at least one swap station within easy reach of the household.

There will also be a regularity to demand that is not present in eMobility. Vehicles travel and require swaps unpredictably, benefiting from near-instant recharging. By contrast, eCooking follows a regular, predictable pattern. With a few exceptions, to meet daily cooking needs the battery must either last several days or, if sized for roughly one day, be swapped daily (see below on battery weight).

Therefore, unlike eMobility stations that face variable demand from a wide catchment, a battery swap station for eCooking is likely to serve a relatively limited clientele living nearby, with regular, forecastable demand.

An exception arises where battery-enabled eCooking is part of a fuel stack, reducing the expected daily consumption of about 1.5 kWh. This is the case for users of the Pesitho Ecoca cooker, where a 0.5 kWh battery can support one meal or contribute to several meals.

Is the idea analogous to LPG cylinders?

A larger battery providing several days of cooking could be heavy. Households do refill 12–14 kg LPG cylinders and, with the cylinder weight, the total is roughly 25 kg. A 25 kg LFP battery would be on the order of 6 kWh and, assuming 1.5 kWh per day, would last about three days. A 14 kg LPG cylinder typically lasts a household about a month but is often delivered by motorbike rather than carried from the shop. Recently, 3 kg LPG cylinders have become more common. These are easier to carry and allow lower-income households to purchase smaller quantities that match their cash flow. A 3 kg LPG cylinder should last a household around five days. An LFP battery weighing 3 kg would store approximately 0.21–0.6 kWh and would last less than one day.

5.2 Parameters for the battery swapping?

We have identified three key parameters for a Battery Swapping Station that, together, could form differentiated scenarios or the beginnings of a typology:

1. **The source of electricity** – This may come from the grid, stand-alone renewable energy systems (such as solar PV), or a hybrid of both. Within this category, further distinctions can be made — for instance, between a connection to the national grid and one that is part of a mini-grid. There may also be implications if the stand-alone source is hydro rather than solar, since hydro systems can charge batteries continuously. Finally, there may be differences if the station is located in an area with a weak grid that restricts power draw.
2. **The spread of the clientele** – As discussed earlier, existing battery swap stations have primarily served the eMobility sector, where users are dispersed across a wide area. By definition, these users have transport to reach a swap point and may choose whichever station is most convenient when their battery runs low. This creates the need for multiple stations and careful management to ensure a surplus of charged batteries that can meet unpredictable demand.
3. **The daily turnover of batteries** – In eMobility, recharging patterns are highly variable. Users such as motorcycle taxi operators visit on an irregular basis depending on how much they have worked, which, combined with a large user base, requires careful station management. In contrast, for eCooking the frequency of battery swaps is likely to be more predictable. Households cooking daily meals will generally have consistent demand, with exceptions such as hosting visitors or dining out. A village-level swap station could therefore serve a regular clientele with predictable needs, potentially eliminating the need for an app or formal appointment system.

5.3 Target Markets

There are three drivers that could create a battery swapping market:

5.3.1 Lack of upfront finance

While households connected to even a weak grid could trickle-charge a battery, owning one may be difficult due to the high upfront cost. Renting a battery, therefore, presents a viable alternative, allowing for gradual expenditure throughout the year. In a typical urban, peri-urban, or market-town setting with a weak grid or poor wiring, there may be a potential customer base among households unable to access credit to purchase their own battery, as well as among those without grid connections, such as residents of informal settlements. The ability to rent a battery for a day to cook could thus be a strong value proposition.

Considering that an energy-efficient eCooking appliance costs around USD 50–80, and a suitable battery costs approximately USD 200–300, one can imagine situations where a household has access to credit for the appliance but not for the battery. In this case, the option to rent a battery would likely be very attractive. It would remove the need for upfront finance and could be structured as a daily rental arrangement to match household income patterns. The lease agreement could also include the appliance itself.

5.3.2 The lack of land tenure and ownership

In informal settlements, infrastructure is often lacking because there is an implied link between access to energy and land ownership. Electricity connections are typically provided to those who hold legal rights to their homes, while withheld from those who have settled informally. This often leads to chaotic wiring systems at the edges of settlements, with landlords sometimes extending connections from their own houses to shacks rented to tenants. Survey data suggests that landlords frequently prohibit tenants from cooking with electricity, as the connections are often unmetered and paid for at a fixed monthly rate. In many cases, the wiring is also too weak to sustain the high, regular power draw required for cooking.

In such situations, a battery-swapping model could operate effectively at the edge of the informal settlement, connected to the national grid.

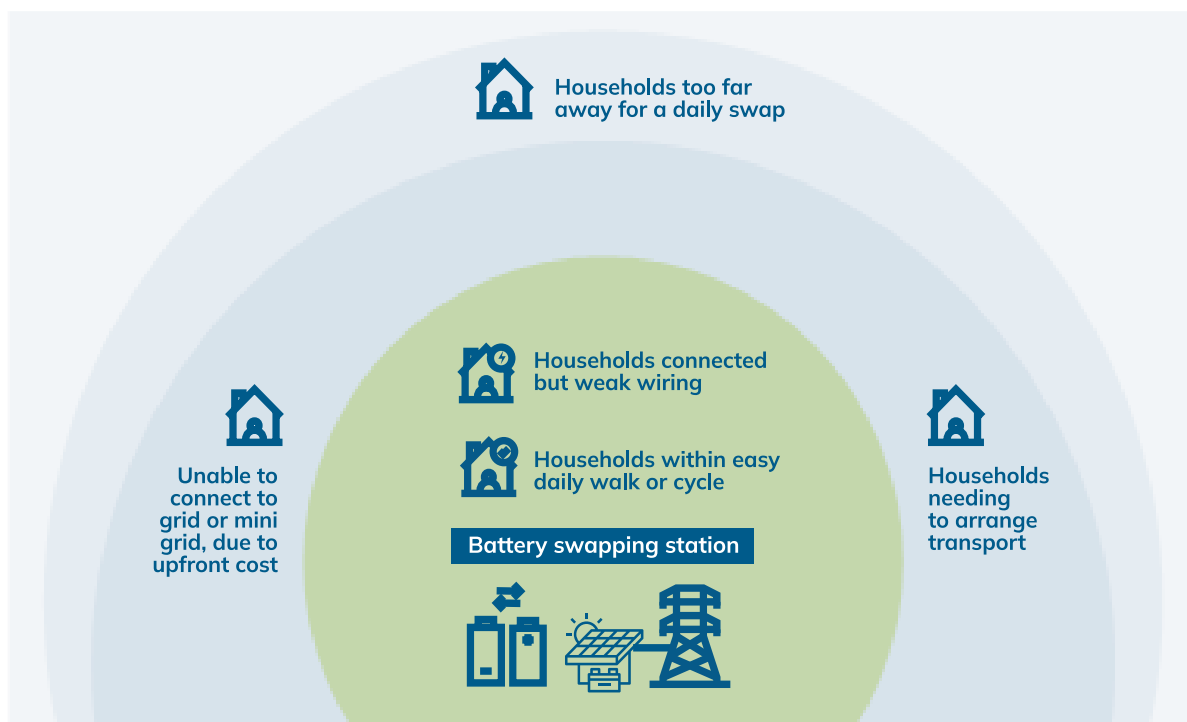
Similarly, humanitarian and displacement settings—such as refugee camps and informal settlements—present a unique opportunity for the deployment of battery-swapping models. These communities often face severe energy poverty, lack formal grid access, and rely on costly or polluting fuels such as firewood or kerosene. The centralized nature of many camps, combined with their dependence on institutional support, aligns well with the operational model of a Battery Swapping Station (BSS). Humanitarian agencies could subsidise or operate BSS infrastructure as part of clean cooking, protection, or livelihood programmes.

Additionally, BSS deployment could help reduce the risks of gender-based violence associated with firewood collection, while also creating economic opportunities—for example, through women-led swap points or maintenance hubs. By leveraging donor finance, results-based funding, and carbon credits, BSS offers a clean, scalable, and context-appropriate solution for energy access in humanitarian contexts.

5.3.3 The lack of energy access infrastructure.

One potential application of eCooking lies in villages or informal settlements where grid electricity either does not reach every household or is entirely unavailable. In such cases, developers could install solar PV-powered charging stations or integrate eCooking charging facilities within existing mini-grids. Alternatively, as seen in some parts of Asia, constrained or weak grids may be installed, limiting power availability to around 300 W per household.

When discussing battery swapping, many of those consulted envisioned scattered rural households where neither the grid nor mini-grids have yet been extended. While this is a possible scenario, the availability of credit must still be considered—if credit is accessible, households might instead invest in their own batteries through solar home systems. The key constraint for a battery-swapping model in such areas appears to be the travel distance required for daily exchange. Almost by definition, the reason the grid has not reached these households is their remoteness. For a swapping system to function effectively, there is a maximum distance beyond which users will be unwilling or unable to travel each day. Even with larger batteries lasting several days—such as a three-day battery—this model still seems unlikely to be practical in highly dispersed rural contexts.

FIGURE 8 Battery swapping for cooking - dependent on distance and strength of electricity access.

5.4 A delivery model?

The above scenario assumes that customers will want easy access to the swap station. They are likely to make a journey to the station every day, so most would prefer a location within easy walking or cycling distance. It can be assumed that households requiring motorbike, truck, bus, or taxi transport are unlikely to subscribe, as the expense and inconvenience of a daily trip would likely be discouraging.

An alternative model for developers to consider is delivery. There is now experience with Pay-as-You-Go (PAYG) LPG systems that connect to a server signalling when a cylinder is nearly empty, prompting automatic delivery and exchange at the household. Because LPG cylinders last for nearly a month, this process does not require daily operation, and a delay of a day or two makes little difference to the consumer. By contrast, a battery-swapping delivery model would likely be far more sensitive to precise timing.

It is conceivable that a battery swap station could operate a delivery service, using a truck or other vehicle to distribute fully charged batteries to households each day. A planned route could maximise efficiency and minimise travel costs. While this would create an additional cost for the developer, it could be incorporated into the lease or service charge.

Such a system would likely be more convenient for consumers than having to arrange their own transport, and could help attract households who wish to participate in battery swapping but live slightly beyond walking distance from the main station.

The batteries in a battery swap station?



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

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A battery swap station could potentially ensure that batteries are:

- better maintained by professional technicians;
- being charged at the right rate; and
- disposed of safely at their end of life (better eWaste management).

As discussed above, there are multiple trials of eCooking with battery support, but no single dominant system has yet emerged. Given that a battery swap model is still largely untested, there is currently no standardisation across different brands or even within the same brand for battery-supported eCooking systems. If a Battery Swapping Station (BSS) aims to serve more than one type of eCooking battery, battery heterogeneity must be carefully considered during both the construction and operational stages.

The shape and form of the battery will have direct implications for the business model. For example, if standard LFP batteries with exposed terminals are used, will the BSS allow users to recharge them at home or through a neighbour? How will the BSS prevent overcharging at home, which could result in battery damage or reduced lifespan? As seen in the Mobile Power example, designing a BSS-specific battery shape and connector can encourage proper use by making at-home charging visibly difficult, thus discouraging tampering.

A lesson from France in the 1980s showed that connectors can wear out quickly from constant connecting and disconnecting. This suggests that bespoke-designed batteries and connectors may help address both durability and safety concerns. However, if BSSs are to evolve into service stations that accommodate different types of eCooking batteries—similar to petrol stations handling different vehicle types—battery heterogeneity will pose a considerable technical and operational challenge.

For owners and operators of Battery Swapping Stations, understanding the diversity of batteries in use among customers will be critical. Gathering data on battery types, capacities, voltages, physical sizes, and associated eCooking technologies and usage patterns should therefore be an essential first step.

There is also the issue of preventing over-discharge. Most mobile phones, for example, switch off before their batteries are completely depleted—a function managed by the Battery Management System (BMS) and the Printed Circuit Board (PCB). A fully discharged lithium battery can be difficult to restart and develops higher internal resistance, reducing its overall performance. This is prevented in phones by maintaining a small residual charge. The question for battery swapping systems is whether similar protection mechanisms can be integrated into swappable batteries used across varied appliances.

5.5 Power Sources of a battery swap station

In developing a Battery Swapping Station (BSS) for eCooking, three distinct power source configurations could be considered. These configurations play a pivotal role in determining the station's energy supply dynamics, directly influencing its efficiency and overall functionality. The three options are: Grid, Off-grid Renewables (such as photovoltaic, wind, or hybrid systems incorporating fuel generators), and Hybrid (a combination of grid and self-generation).

Grid

In this configuration, the BSS is connected directly to the national grid and draws its power from it. The charging infrastructure is fully integrated with the grid, providing a generally reliable and stable electricity supply. This seamless connection enables efficient and dependable battery charging. However, the reliance on the grid can also present challenges—particularly where grid stability is poor or tariffs are high—potentially increasing operational costs and affecting consistency of service³⁰ (Ahmad et al., 2020).

Developers of a Battery Swapping Station (BSS) should liaise with the utility provider to ensure that the local transformer can handle what may, in a scaled-up station, become a significant and continuous energy demand. Given that most trickle charging for lithium iron phosphate (LFP) batteries operates at between 3 and 5 amps for a 24V battery, ten batteries charging simultaneously would draw approximately 720 to 1,200 watts—well within the capacity of a standard 13-amp circuit. (It is worth noting that charging a 1.5kWh battery at 3 amps would take around 20 hours.)

However, at greater scale, such as a station with 100 batteries charging concurrently—even at low current—the power draw would rise to between 7.2kW and 12kW. This would exceed the capacity of a single 13-amp or even a single 30-amp circuit, making it advisable to consider a three-phase connection to manage the load safely and efficiently.

This also raises an important consideration regarding the applicable electricity tariff. A BSS operating as a commercial entity may not qualify for domestic rates, and discussions with the utility would be required to confirm whether the station would be billed under a commercial or industrial tariff structure.

Off-grid renewable energy

Given the substantial electricity consumption associated with a Battery Swapping Station (BSS), renewable energy sources—particularly solar photovoltaic (PV) systems—could provide an effective and sustainable power supply option. For many battery-swapping users, daytime charging aligns well with solar generation periods, making PV a potentially efficient and synergistic solution for combining energy production and battery recharging.

However, several challenges arise with this configuration.

Higher current ‘trickle’ charging

While a grid-connected BSS can operate overnight, providing each 24V battery with up to 20 hours of charging (for example, 1.5kWh at 3 amps), a solar-based system only benefits from around six effective hours of daylight. This means that a single battery must either remain at the station for more than one day or be charged at a higher rate—say 10 amps (around 250W). A 10-amp charge represents a rate of 0.167C, which is well within the safe operating range for most batteries rated up to 1C. However, this approach requires the solar PV array to be sized appropriately to deliver higher current outputs.

Sizing of the panels

The capacity of a solar-powered BSS can be scaled modularly in line with customer growth and demand. For example, a station with capacity for ten batteries charging simultaneously at 10 amps would require approximately 2.5kW of installed solar panels. While this might be manageable at a small scale, expansion to 100 batteries would represent a substantial increase in investment and space requirements.

Variability of solar energy

Fluctuations in solar generation due to weather conditions, combined with uncertainties in swapping demand, make system sizing more complex than the previous estimates suggest. Developers could choose to oversize the PV array to accommodate cloudy days, or alternatively, accept occasional service interruptions—though this could risk customers reverting temporarily to traditional cooking fuels.

There are, however, other renewable energy sources that can complement or substitute for solar photovoltaics. While solar PV remains the most convenient and cost-effective technology for off-grid systems, wind and hydro power can also play important roles in certain contexts.³¹ Wind generation, though less commonly deployed for off-grid mini-grids or home systems, has the advantage of producing electricity at night. The economics of supplementing daytime solar with nighttime wind generation could therefore be worth exploring. Similarly, in areas with access to small-scale hydro resources—such as in parts of Nepal—hydropower offers a cost-effective and continuous energy source. In such cases, integrating battery swapping into the system could enhance utilisation, with hydro ensuring consistent trickle charging throughout the night.

Off-grid renewable generation could also be supported by the strategic use of generators. Many mini-grids already rely on diesel or other fossil fuel generators to compensate for cloudy days or peaks in demand. Instead of oversizing PV systems to account for prolonged periods of low irradiance, a BSS could employ a similar backup strategy. While generator-based charging is generally more expensive per kWh and dependent on fossil fuels, it may serve as a practical short-term measure to maintain service continuity when renewable output is insufficient.

Hybrid BSS

A hybrid-powered Battery Swapping Station (BSS), using a combination of different energy sources for battery charging, could help overcome many of the challenges described above. Such a configuration might integrate grid electricity with renewable sources—most commonly solar PV—to improve the sustainability, reliability, and efficiency of operations ^{32 33}.

By combining grid power with renewables, hybrid BSSs can strike a balance between cost-effectiveness and performance. This approach minimises operational costs by prioritising the use of clean energy when available, while the grid connection provides backup during periods of low renewable generation, ensuring a consistent and dependable charging service for users.

5.5.1 Chargers

In developing a Battery Swapping Station (BSS) for eCooking technologies, chargers are a critical component—acting as the linchpin for efficient battery exchange and reliable replenishment. They play an essential role in ensuring the continuous and effective operation of the station.

Trickle chargers provide a low, constant current over an extended period to maintain battery charge. They are commonly used in vehicles, motorcycles, boats, and other equipment—such as electric cookers—during periods of inactivity.

Higher-ampereage ‘fast chargers’ deliver a much higher current, enabling significantly shorter charging times. These chargers are typically used for electric vehicles and other high-capacity battery systems, including those designed for electric cooking, where rapid turnaround and high energy throughput are essential. [Click or tap here to enter text.](#)

Implicit in a Battery Swapping business model is that the batteries are owned by the charging station and loaned to users. This distinguishes a Battery Swapping Station (BSS) from a battery charging station, where users typically own their batteries and bring them in for recharging—similar to refuelling at a petrol station.

Fast charging for electric vehicles now takes around 15 to 30 minutes, with drivers usually waiting during the process. In some contexts, however, a battery charging station located near a market—where users could leave their batteries to charge while attending to other activities—might be an attractive alternative model.

Note: Smart chargers were already well established with lead-acid batteries. Over time, such batteries could develop sulphur deposits that reduced performance, and desulphation was achieved by pulsing the charging current. This type of maintenance is not relevant for modern lithium-based chemistries. All lithium chargers are designed to prevent overcharging and manage current intelligently; therefore, in practice, all contemporary chargers can be considered “smart.”

5.6 Digital monitoring



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

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A battery swap station could potentially:

- Access investment finance for upfront capital costs through a clear business model, in contrast to a household taking a loan from a bank to purchase a battery on credit.
- Digitally monitor and track battery usage.
- Access Results-Based Finance and carbon finance by digitally verifying battery use against a baseline of biomass consumption. A station could also serve as the source of a carbon finance project.

There has been significant progress in recent years in the remote digital monitoring of equipment. This technology has already been applied to eCooking, as it enables access to carbon finance—a topic that will be explored briefly below. Within the context of a Battery Swapping Station (BSS), remote monitoring offers several additional advantages.

Tracking and managing the flow of batteries in and out the BSS.

One key benefit is the ability to track and manage the flow of batteries in and out of the station. Digital data on each battery's history can help monitor performance and lifetime, ensure only fully charged batteries are issued to users, and support maintenance planning. These functions can be implemented through proximity-based mechanisms such as QR codes.

MECS has previously commissioned research on tracking methods for the timely replacement of gas cylinders, where the use of QR codes proved effective in monitoring cylinder circulation and ensuring proper distribution³⁴.

However, there would also be value in tracking the physical location of each battery. Batteries represent relatively high-value assets, and in informal settlements there is a risk that they could be stolen or sold outside the intended service area. Incorporating geo-location capabilities could therefore be a worthwhile measure for Battery Swapping Station (BSS) operators to protect their assets and ensure proper management of the battery fleet.

Monitoring the State of Charge (SOC) of a battery can be done during charging, but it may also be valuable to track it while the battery is in use. Users will require a visual display to check the SOC and determine when to return the battery. If this information were also uploaded digitally to a cloud platform, the BSS could automatically prompt users to return their batteries or, in the case of a delivery-based service, dispatch a replacement directly to the user's location. This approach mirrors recent innovations in Pay-As-You-Go (PAYGO) LPG distribution models³⁵.

Remote monitoring use of the battery

Remote monitoring of eCooking appliances has enabled suppliers to verify actual usage and claim carbon credits for the transition from biomass to electric cooking, as discussed later. Remote monitoring can also support battery management by ensuring that batteries are not being bypassed or overused.

Any form of remote monitoring will incur data transmission costs. These can be easily justified when the data is used to verify carbon finance, but if carbon finance is not involved, the BSS developer will need to assess whether such monitoring is necessary. In cases where the BSS serves a small, well-defined community with limited geographical spread, remote monitoring may not be essential, and each battery can instead be health-checked upon return.

An alternative approach is to download usage data directly when the battery is returned. This could be achieved through localised data transfer methods such as Bluetooth, avoiding the need for ongoing GSM connectivity and monthly data charges.

Mobile Money

A BSS could operate on a cash basis, but experience from Pay-As-You-Go (PAYGO) systems suggests that integrating mobile money payments improves transparency, tracking, and revenue collection.

Disarming the equipment – remote cut off

One common feature of PAYGO systems is the ability to remotely disable equipment if the user fails to make payments. This has been particularly valuable for solar home systems located far from suppliers, where physically pursuing payment would be costly. Although there are few verified reports of such systems being actively disabled, the feature remains a useful deterrent.

For Battery Swapping Stations, however, where operations are localised and batteries are bespoke and cannot be charged at home, the ability to remotely disarm a battery may not be necessary and would add little value to the business model.

5.7 Carbon Finance

The year 2024 was a turbulent one for carbon finance and the clean cooking sector. A series of journalistic and academic investigations raised concerns about the overclaiming of carbon credits from cookstove projects. One of the main issues identified was that credits were often issued based on stove sales rather than on verified usage. This loss of confidence in the market led to a decline in carbon credit purchases and a significant drop in prices.

Amid this uncertainty, digital remote monitoring has emerged as a game changer. By enabling the verification of actual use, it provides a level of transparency and accountability previously missing from many projects. Because eCooking systems are inherently measurable, integrating digital monitoring reassures carbon buyers that their purchases correspond to real, verifiable emission reductions—allowing such projects to command premium prices.^{36 37 38}

The carbon market is also expected to advance as Article 6 of the Paris Agreement begins to take shape in practical terms. While most carbon trading to date has taken place in the voluntary market, Article 6.2 establishes a framework for government-to-government transactions, and Article 6.4 will ultimately create an international trading platform. As the world moves further towards a decarbonised economy, these mechanisms present strong opportunities to support the transition away from biomass-based cooking, which is estimated to account for around 2% of global greenhouse gas emissions^{39 40}.

A Battery Swapping Station (BSS) could enable users to transition from biomass-based cooking—particularly charcoal use in informal urban settlements—to eCooking. If the emissions reductions achieved through this shift can be demonstrated to be additional, the system would be eligible for carbon credits. These ongoing credits, potentially generated over the lifetime of the batteries (ten years or more), could be leveraged to secure working capital for the BSS developer, or alternatively, a portion of the value could be passed on to users as an incentive.

5.8 Battery Swap Station Design Features?

The main advantage of a Battery Swapping Station (BSS) over a charging station is the near-instantaneous exchange, eliminating the need to wait for a battery to recharge. In a BSS designed for eMobility, as the state of charge (SOC) of a vehicle battery decreases, the owner can use an app to locate the nearest BSS and initiate a swap request. Upon arrival, the depleted battery is handed over and replaced with a fully charged one, a process that typically takes only a few minutes.

For eCooking, the model would likely involve a regular group of customers who require daily battery swaps. Whether this takes the form of walk-in exchanges or bookings made through an app would depend on the local context.

Once a battery is returned to the BSS, it is recharged—either through trickle or fast charging—depending on the station’s setup and available power source.

From the perspective of the Battery Swapping Station (BSS), there are three primary operational tasks: managing swap requests from users, overseeing the charging of returned batteries, and handling payments.

5.8.1 Handling Swapping Request – customer experience

It is important that households have confidence that their batteries can be swapped whenever needed. Effective management of swapping requests between the BSS and the consumer should ensure an experience that is efficient, reliable, and satisfactory. When a customer wishes to exchange a depleted battery for a fully charged one, the request could be submitted through three main methods.⁴¹

- **Walk-in request:** A user arrives at the BSS without a pre-set appointment to swap their battery. There may or may not be a fully charged battery available, so the user takes their chances. If this is the norm, the BSS should plan to maintain a surplus of fully charged batteries to ensure consistent service.
- **Reserve (daily schedule):** The user schedules a daily appointment with the BSS to swap their battery at a specific time. Key details such as battery model, collection or delivery time, and expected state of charge (SOC) are recorded during the reservation. If this approach is standard, the BSS should ensure the reserved battery is fully charged and ready.
- **Advance request:** To optimise the swapping process and improve service quality, the BSS could encourage users to submit appointment requests in advance. These requests would include expected arrival time and battery type, allowing the BSS to plan charging and swapping schedules efficiently. Incentive mechanisms could be used to promote timely booking. The BSS could also develop a simple mobile app to manage user requests and scheduling.

If the BSS is part of a programme supplying eCooking services to households, battery swaps may occur on a daily basis. The regularity of this routine could make a complex pre-booking system unnecessary, as users may simply confirm their next visit informally—“See you tomorrow”—when collecting their charged battery.

While no data yet exists on swapping stations for eCooking, it can be hypothesised that there would be regular peak swapping hours. Since batteries are used for cooking, the three main meal times—breakfast, lunch, and dinner—suggest that peak swap periods are likely to occur in the intervals between these times.

5.8.2 Enhancing and expanding User Accessibility and Convenience

As the concept of Battery Swapping Stations (BSS) matures, some features developed for eMobility stations could potentially be adapted for eCooking users. A key distinction between eMobility and eCooking lies in battery transportation and access to swap or charging stations. In eMobility, users generally have a built-in means of reaching the station unless their vehicle is fully discharged, in which case the battery remains within the vehicle or is managed at the station. In contrast, eCooking users must carry or transport batteries between their homes and the BSS, or depend on delivery services. This introduces risks such as battery damage, loss, or theft during transit.

Table 1 presents ideas that are currently being explored for eMobility, and comments on their relevance to eCooking.

TABLE 1 Learning from battery swapping in eMobility

Suggested enhancement for eMobility	Relevance to eCooking
Mobile Application Integration: Develop a user-friendly mobile application that enables users to locate the nearest battery swap station, reserve a battery, and manage their subscription services. This app can also provide notifications on battery readiness, promotional offers, and reminders for battery swaps.	Most eCooking users will likely have access to only one Battery Swapping Station (BSS) within easy reach of their homestead. By definition, these users are likely to fall within the lower wealth quintiles, as they typically lack reliable electricity at home. Consequently, many may not have regular access to a smartphone. In some households, gender dynamics may further limit phone access, with the woman—usually the primary cook—less likely to control or use the household phone. Given that visits to the BSS are likely to follow a regular pattern, advanced planning and digital notifications, while useful, may have limited practical value in such contexts.
Customer Loyalty Programs: Introduce loyalty programs that reward frequent users with discounts, priority service, or free swaps after a certain number of exchanges. This would incentivize continued use of the battery swap service and enhance customer retention.	Again, eCooking customer are likely to be loyal to their nearest station. One could imagine a discount system where long-term regular use prompts a discount. This may counter reverting to fuel stacking when the trip to swap the battery is inconvenient.
Educational Initiatives: Conduct workshops and training sessions to educate potential users about the benefits of electric, particularly eCooking, technologies and the battery swap model, focusing on cost savings, environmental impact, and health benefits.	
Local Partnerships: Partner with local businesses, such as grocery stores or community centers, to establish mini swap stations that provide convenience for users. These partnerships can expand the network reach and provide added value to the community.	This could have some relevance, where an eCooking orientated swap station does regular deliveries to agents on the edges of its reach. That could effectively extend the reach to more outlying households. While we have discussed a delivery model, this is a hybrid model – the swap station arranges regular delivery of charged batteries and collection of discharged batteries to an agent who extends their reach.
Modular Swap Stations: Design modular battery swap stations that can be easily scaled up or down based on demand. This flexibility allows for efficient capital expenditure and the ability to respond to changing market needs.	There are examples of containerized solar PV generators (for schools and institutions) and charging stations for public use (e.g. ⁴²). One could imagine a containerized BSS, the size of the container being varied depending on the eCooking demand.

5.9 Ensuring Safety and Compliance

All of the swap stations will need to ensure they adhere to best practice in terms of safety and compliance, and ensure their consumers are safe in their battery use.

Safety of the swap station: As discussed in passing above, the combined charging of multiple batteries could sum up to a considerable draw on the local electrical grid. If drawing from the national grid, then it will be worth having discussion with the utility as to whether this will put any noticeable strain on the local transformers. If drawing from a mini-grid, there may need to be negotiations with the mini-grid developer and management. Exceeding the recommended maximum power draw from a transformer can cause burn outs.

Safety of battery handling: DC currents can be more harmful to humans than AC currents. The charge flows through the body causing burnt skin, and if passing through critical organs could cause even death. It will be important if any type of fast charging using a higher than normal current, that staff are equipped and trained to connect and disconnect the batteries safely.

Business certification: A BSS is a new form and shape of a business. The nearest precedence might be a petrol station, which has their own set of safety and compliance rules. The station may need to work with local authorities and international safety organizations to obtain certification for a BSS as a registered business or social enterprise.

Safety in accessing the swap station: There could be a near constant traffic of consumers swapping their batteries. It is likely that the swap station could share the space as a swap station for electric vehicles, and we have discussed above using the swap station as a hub for markets and businesses. It is likely that the swap station will be next to the road, to allow for all these activities, and therefore siting and situation may become important.

Emergency Response Plan: Battery overcharging can result in a breakdown in the battery, overheating and in some rare cases actual explosion. If the batteries are of high quality, and the charge rate does not exceed 1C, the likelihood of overheating problems is negligible. However, as best practice, it would be good to develop and integrate a robust emergency response plan that includes fire suppression systems and spill containment strategies to deal with any potential battery failures or accidents.

Consumer safety: As discussed earlier, one of the challenges is preventing users who lease batteries from a swap station from recharging them at home or through unauthorized grid connections. It was suggested that instead of using generic terminals common to most batteries, a bespoke connector design should be adopted—one that makes unauthorized charging difficult. Consumer safety is also a key concern if users are able to charge batteries themselves. They may use or construct improvised chargers that exceed the recommended 1C charge rate, leading to potential overheating, or charge at incorrect voltages, causing cell imbalance and possible failure of the battery management system.

5.10 Enhancing Battery Lifecycle Management:

Battery Refurbishment Program: The swap station could establish a program to refurbish batteries that are nearing the end of their optimal lifespan for eCooking. These repurposed batteries could then be used for less demanding applications such as lighting or powering low-load devices, thereby extending their usefulness and supporting sustainability.

Recycling Partnerships: Establish partnerships with recycling firms specialized in handling batteries to ensure environmentally responsible disposal of batteries that can no longer be refurbished or repurposed.

Starting the BSS with second life batteries: There is strong potential for the BSS itself to serve as a mechanism for battery recycling. In eMobility applications, batteries are required to deliver high power performance as specified, and a performance loss of around 20% often triggers their retirement from vehicles. However, such batteries still retain sufficient capacity to meet the lower power demands of eCooking. A BSS could therefore operate using second-life batteries repurposed from the eMobility sector.

5.11 Charging time

The time required to charge a battery depends on several factors, including its chemistry, capacity, and the specifications of the charger. In a battery swap station, the focus is on providing users with a rapid exchange of depleted batteries for fully charged ones. Charging therefore takes place at the station, where maintaining a steady pool of charged batteries is essential.

While users do not directly experience the charging process, the turnaround time for recharging batteries remains critical. Fast charging is particularly important to ensure a consistent and reliable supply of fully charged batteries for continuous operation.

5.12 Business registration

Should a BSS operate as a community initiative, social enterprise, or a private sector venture—profit or non-profit? Given its role as a public service, it may naturally lend itself to community-driven action or a social enterprise model. However, it is worth noting that most cooking and transport fuels are currently supplied through private enterprises.

Utilities often occupy a middle ground between public service and private enterprise, typically under strict regulation. The tariff charged to a BSS could depend on whether the utility or regulator classifies its work as a commercial activity or a social good, and whether it is seen as adding to or offsetting domestic consumption. Although utilities may not easily adjust tariffs for such a purpose, it would still be worth exploring the possibility.



6 PLANNING FOR THE SOCIO-CULTURAL DYNAMICS OF A SWAP STATION FOR ECOOKING



BATTERY SWAPPING MODEL FOR ECOOKING LOGIC

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Implementing the concept of battery swapping could depend on several factors, including:

- ‘Goldilocks conditions’ where people do not have access to higher-tier electricity but live clustered enough to make a daily journey.
- A level of socio-economic consumption that enables them to access finance for regular payments to a swap station, yet not enough to upgrade their tiered access to electricity.
- A socio-cultural context where daily collection of a battery is acceptable. Some societies may not want the woman to leave the home regularly, while the man may not be willing to ‘collect the cooking fuel’.

A battery swap station could also be:

- A hub for the community with daily interactions and relationships.
- A place for other service businesses that could use the energy infrastructure, such as hairdressing.
- A place for productive use of energy, adding value to products (e.g. grain milling, sewing).
- A place where eCooking in bulk prepares meals (sit-down or takeaway), or for pre-preparing food to be reheated at home.

Unlike petrol stations, charging stations, or BSS facilities for motor vehicles, a BSS for eCooking is likely to have a more limited and regular set of clientele who come frequently—possibly every day—to collect a recharged battery. This regular interaction could create a new community focal point, and developers of a BSS should take this into account.

6.1 What should be at the station?

6.1.1 Instant swap or sit and chat?

If all is planned well, a customer could enter the swap station, hand over their discharged battery, and take a recharged one—potentially in just a few minutes. It is even possible to imagine a self-service system, with recharged batteries stored in locker boxes that open using a code printed on the lease ticket, allowing customers to complete the swap themselves.

In modern urban settings, particularly in informal settlements where people are often in a hurry to continue with their daily business, such efficiency may be ideal. However, for many off-grid users in rural areas, mini-grids, or market towns, the swap station could also serve as a valued social space. Research on community water points has shown similar benefits, where women gathering to queue for water also gain social connection and time outside the home⁴³.

Similar stories abound about the social benefits of collecting firewood in groups, where women share a common purpose and strengthen community ties. However, these benefits are often outweighed by the vulnerabilities women face during wood collection and the physical strain it places on their necks and backs.

6.1.2 Other business?

A location that people visit regularly and that has access to electrical power could evolve into a small business hub or a community information point. Given that biomass-based cooking poses a major public health challenge, community health workers could engage with people as they bring in their batteries—documenting the health benefits of smoke-free cooking and identifying emerging health concerns. The site could also host small rental spaces for tailors, barbers, and other entrepreneurs whose work benefits from access to reliable power.

It is unlikely that a BSS would be located within the informal settlement itself; more realistically, it would be sited nearby, where grid connections are available. However, locating it inside the settlement poses security risks, as experience shows that businesses reliant on equipment are vulnerable to theft. Developers should account for this and budget for round-the-clock security. Positioning the BSS just outside the settlement may help mitigate these risks, while a delivery service operated by the BSS could ensure convenient access for residents.

6.1.3 Other food uses or demonstrations of eCooking

At the least, there could be a café where the community can sit and chat, and either get drinks or food. In the example of Kachione — the initiative in Malawi where women’s groups run solar shops selling eCooking equipment — the shops also use the solar systems to cook during the day and sell pre-cooked food for reheating at home. This creates a strong synergy with battery swapping, as it reduces the power required in the evening or for breakfast.

Developers of battery swapping stations could anticipate these sociocultural dynamics and plan accordingly.

6.2 Women friendly swapping stations

One of the lessons from the WASH sector has been that, in some traditional societies where women are allowed to leave the house only for specific reasons, the transition from a public water point to a household supply can lead to increased isolation for women. The same question arises here — will women be allowed to swap the battery?

In some traditional societies, technology — and particularly electrical technology such as batteries — is viewed as a male domain. Only men may be permitted to handle or exchange the battery. This could present a challenge, as it is unlikely that in these societies men would be willing to swap the battery every day for cooking. Doing so would, in effect, place them in the role of ‘gathering the cooking fuel,’ which in most such societies is considered women’s work⁴⁴. A battery delivery system provided by the BSS may help address this challenge, allowing batteries to be delivered directly to the home and received by any authorised adult.

As mentioned above, in very traditional societies there are also questions about whether women will be permitted to go to the swap station alone or in groups, or to leave the house every day. The gender of swap station managers and assistants may also influence whether this is seen as acceptable.

6.3 Time of day, sunshade or streetlights?

If customers are coming at the start of the day — perhaps before breakfast in order to cook — or at the end of the day after finishing work or supper and preparing for the next day, developers should plan for good, clear lighting so that approaching the station after dark does not expose users to risks from thieves or other threats.

If customers are coming in the middle of the day but need to wait for ten minutes, is there shade or shelter where they can sit comfortably?



7 DISCUSSION

Having thought through the various elements of a BSS, the exercise has raised a number of questions about its viability for eCooking in various market contexts.

7.1.1 Key markets

Under what conditions would a community be looking for a daily (or three-day) swap?

A rural community with no electricity? There is, of course, strong momentum towards universal access to electricity, with off-grid technologies such as mini-grids identified as a key tool in achieving this goal. Would the battery swap community, then, be a mini-grid with outliers not yet connected? This would effectively mirror the SONG project pilot.

Almost by definition, however, those outliers — members of the community not connected to the mini-grid — are likely to be in that position because of distance. It is not cost-effective to run cables to their homes. Therefore, would such households really want to send someone “into the market” (where the mini-grid and BSS are likely to be located) every day to swap the battery?

A community with limitations on the power that can be drawn. Some rural areas, particularly in India and Indonesia, have been connected to the grid, but the transformers are sized for low power usage by the community, often capping supply at around 300W. Since 300W is not quite sufficient for cooking — though with efficient devices and some patience, 400W can provide a viable cooking experience — the battery could serve as the mechanism by which higher power can be consumed for a 1kW kitchen appliance⁴⁵ the appliance would need to be DC, or the battery–appliance system would require an inverter so that regular AC equipment could be used.

As discussed above, the BSS might restrict home charging (through bespoke terminal connections) to prevent overcharging and maintain battery quality. However, if a household has a low-power grid connection, a question arises as to why they could not simply charge the battery overnight themselves so that it is ready for high-power delivery the next morning. One can speculate that

such households may not be able to afford the upfront cost of purchasing a battery and would prefer to rent or lease one.

In that case, the business model would shift from a battery swapping model to a battery loan model. For a daily rental cost, a business could supply batteries and suitable eCooking appliances (with or without inverters) to enable low-power-connected communities to cook and recharge overnight. While there are markets where this might currently be viable, the momentum toward universal access to higher-tier electricity suggests that these low-power connections will eventually be replaced by better local transformers, limiting the long-term potential of this model.

Urban informal settlements may not have authorized grid connections.

If land tenure is uncertain, the utility may be unwilling to provide an authorised electricity connection. Many informal settlements therefore rely on informal arrangements, often where landlords supply power to their tenants. This can result in low voltage, restricted use — with landlords sometimes prohibiting cooking because they charge a fixed monthly fee — and generally poor-quality, unsafe wiring.

In such a situation, informal urban dwellers may live close enough to a battery swap station to make daily swapping practical. However, even here, the swap model could face competition from a battery loan model, where the battery is recharged within the household rather than exchanged at a central point.

This latter market should not be underestimated in size. The official designation of an informal settlement includes the absence of at least one of the five core services⁴⁶. As a result, a significant proportion of urban areas are classified as informal settlements, representing many millions of households — for example, 6.5 million in Kenya and 6.9 million in Uganda in 2022.

7.1.2 Advantages of swap over recharge at home

For the user, the model should ensure that a fully charged battery is available on demand, that the battery remains within its useful life, and that if it runs out, it can be recharged almost instantly through a swap. This allows the household to manage its own energy supply and consumption with minimal dependence on the utility or on weather conditions. Energy can be purchased in small quantities to match household cash flow, and there is little need for upfront capital investment. The household may need to own a cooking appliance, although even that could potentially be rented from the BSS as part of an expanded business model.

For the BSS developer, the system enables tracking and management of batteries, while spreading the risk of charging shortfalls — whether due to load shedding or poor weather — across multiple batteries and over longer timeframes. It could represent a profitable enterprise that leverages broader capital investment in grid connections or larger energy systems. The BSS could also serve as an anchor ‘productive load’ for a mini-grid.

7.1.3 Challenges

The BSS developer will need significant upfront capital. They must not only maintain a sufficient stock of batteries to serve their clientele but also have nearly twice as many to enable daily swapping. One set of batteries must be recharging while the other is in use. In practice, a BSS might be able to operate with around 1.5 times the number of user batteries, but this has yet to be modelled or tested.

Regardless of whether the requirement is 1.5 or two times the number of active users, this represents a major investment. Energy storage is typically the most expensive component of mini-grids, and careful sizing of storage relative to demand is key to profitability. The need for additional batteries would also have to be reflected in user pricing. Each user would need to cover not only the cost of charging but also the recovery of the capital cost of the batteries — effectively paying for two units rather than one.

7.1.4 Battery as a backup

One potential use of a battery swap station could be as a backup for users who have electricity but experience unreliable supply. During periods of load shedding, the user could go to the station and collect a fully charged battery to complete their cooking, or in anticipation of a planned maintenance outage of the grid.

However, this model would require the BSS developer to make the same level of investment as for a regular swap station, while facing the added challenge of uncertain and irregular demand.

7.1.5 Potential significant consumer advantages of battery swapping

TABLE 2 Exploring the role of battery swapping in various market contexts.

Possible consumer experience	eCooking on the grid (or mini-grid) with no battery	eCooking on the grid (or mini-grid) with own battery	eCooking 'off-grid' with a solar (PV) home system with no battery	eCooking 'off-grid' with a solar (PV) home system with own battery	eCooking off-grid using a swap battery	eCooking on-grid with a swap battery
Significant upfront cost	<p>Connection fee for grid (mini-grid).</p> <p>Adding eCooking - Appliance only</p> <p>Possibly need to upgrade wiring for higher power appliance.</p>	<p>Connection fee for grid (mini-grid).</p> <p>Adding eCooking - Appliance and battery.</p>	<p>Investment in Solar Home System</p> <p>Adding eCooking - Appliance only.</p>	<p>Investment in Solar Home System inclusive of battery</p> <p>adding eCooking - appliance only (but battery sizing larger due to eCooking)</p>	<p>Deposit for battery swapping leasing.</p> <p>Adding eCooking - Appliance only*</p>	<p>Deposit for battery swapping leasing.</p> <p>Adding eCooking - Appliance only as a backup</p>
	Low-Medium (Appliance + Wiring)	Medium (Appliance + Battery)	High (SHS investment)	Very High (SHS + Battery)	Medium (Deposit + Appliance)	Medium (Deposit + Appliance)
Reliability	<p>Dependent on grid supplier.</p> <p>Backup is to revert to stacking, but a sudden power cut in middle of eCooking is very inconvenient.</p>	<p>Ok for power cuts of a few hours. Vulnerable to multiple day power cuts - reverts to stacking?</p>	<p>Will need to eCook in middle of day.</p> <p>Vulnerable to cloudy days and rainy seasons.</p>	<p>Vulnerable to cloudy days and rainy seasons.</p>	<p>Ok for any situation, as long as they swapped the battery that day.</p> <p>(Are rainy season roads passable?)</p>	<p>Not dependent on grid supplier.</p> <p>Has a backup in case of sudden power cut in middle of eCooking.</p> <p>In cases where users are unable to reach a swapping station, they might attempt to charge the battery at home instead, which might not be acceptable by the BSS.</p>
	⚠ Vulnerable to power cuts	✓ Backup from battery	⚠ Midday cooking only	⚠ Weather dependent	✓ Reliable if swapped	✓ Backup for grid cuts

■ Significant potential contribution of battery swapping

Possible consumer experience	eCooking on the grid (or mini-grid) with no battery	eCooking on the grid (or mini-grid) with own battery	eCooking 'off-grid' with a solar (PV) home system with no battery	eCooking 'off-grid' with a solar (PV) home system with own battery	eCooking off-grid using a swap battery	eCooking on-grid with a swap battery
Monthly cost	Dependent on National Tariff bands. Likely to be using part of their lifeline tariff (cheap)	Dependent on National Tariff bands. Potentially cheap time used in the middle of the night? (common in eVehicle charging) Likely to be using part of their lifeline tariff (cheap)	Repayments if there was credit for upfront costs only.	Repayments if there was credit for upfront costs only – but battery would have added significant extra costs so repayments higher.	A monthly lease arrangement is likely, with pricing dependent on the swap station's negotiations with the utility if grid or mini-grid power is used for charging. The applicable tariff—whether a business rate or time-of-use rate—will strongly influence costs. Where the BSS relies on renewable energy sources such as solar PV, hydro, or wind (potentially supported by a generator hybrid), the lease rate would instead reflect the investment costs and expected returns on those systems.	Dependent on National Tariff bands. They are likely to benefit from applying a portion of the lifeline tariff to cooking
	Low (lifeline tariff)	Low–Medium (TOU tariff)	Loan repayments	Loan repayments (higher)	Lease fee (variable)	Lease + grid cost
Sustainability	Repair and replacement of appliance	Repair and replacement of appliance and battery	Repair and replacement of renewable energy generation technology and appliance. Possible threat of theft.	Repair and replacement of renewable energy generation technology, appliance and battery. Possible threat of theft.	No concern for repair and replacement of battery (undertaken by station operator). Possible Repair and replacement of appliance*	No concern for repair and replacement of battery (undertaken by station operator). Possible Repair and replacement of appliance*
Battery Maintenance	N/A	Household responsibility	N/A	Household responsibility	✔ Station-managed	✔ Station-managed

■ Significant potential contribution of battery swapping

Possible consumer experience	eCooking on the grid (or mini-grid) with no battery	eCooking on the grid (or mini-grid) with own battery	eCooking 'off-grid' with a solar (PV) home system with no battery	eCooking 'off-grid' with a solar (PV) home system with own battery	eCooking off-grid using a swap battery	eCooking on-grid with a swap battery
Climate and Planet friendly?	Dependent on National emissions	Dependent on National emissions, and critical minerals in battery	Renewable energy technology thought to be planet friendly, limited manufacturing emissions.	Renewable energy technology thought to be planet friendly, limited manufacturing emissions. Critical minerals in battery	Dependent on the swap station's grid emissions (or mini-grid), or on the use of renewables such as solar PV, hydro, or wind, including hybrid systems with generators. Also dependent on the sourcing and management of critical minerals used in the batteries.	The overall environmental impact of a battery swap station will depend on national emission factors, the carbon intensity of the electricity used for charging (whether from the main grid or a mini-grid), and the extent to which renewable sources such as solar PV, hydro, or wind are incorporated—either independently or in a hybrid system with a generator. It will also depend on the sourcing and lifecycle management of the critical minerals used in the batteries.
	Depends on grid	Grid + battery footprint	✔ Clean (solar)	⚠ Battery footprint	Depends on BSS energy source	Depends on grid/BSS mix
Other use	Convenient grid connection can power whole house as life expands.	Convenient grid connection, backed up by battery, can power whole house as life expands.	Convenient can power whole house but during the day. Irrigation pump.	Convenient can power whole house as life expands, possibilities of upgrading. Irrigation pump.	Convenient grid connection, backed up by slightly inconvenient fetching of battery, can power whole house as life expands.	Convenient grid connection and back up for cooking

Possible consumer experience	eCooking on the grid (or mini-grid) with no battery	eCooking on the grid (or mini-grid) with own battery	eCooking 'off-grid' with a solar (PV) home system with no battery	eCooking 'off-grid' with a solar (PV) home system with own battery	eCooking off-grid using a swap battery	eCooking on-grid with a swap battery
Convenience / UX	✓ Simple but vulnerable	✓ More reliable	⚠ Day cooking constraint	⚠ Complex maintenance	⚠ Requires battery fetching	✓ Easy backup
Scalability	✓ Expandable	✓ Grid + battery synergy	⚠ Power limited	✓ Expandable with investment	✓ Swappable upgrades	✓ Ideal hybrid solution
Spin-off benefits					Daily interaction outside the house could strengthen community connections and create new social spaces.	Irregular interaction out the house because they will not swap every day.
Community Interaction	Minimal	Minimal	Minimal	Minimal	✓ Daily swap = social	⚠ Irregular interaction

*Assumes the appliance is not part of the lease hire. Many battery swapping developers would do well to offer appliance hire as part of the deal.



8 CONCLUSION

While on the face of it a Battery Swap Station (BSS) offers users access to batteries for eCooking with energy-efficient appliances, there appear to be only a limited set of circumstances where such a model might be viable.

Its four strongest market opportunities seem to be:

- **Rural off-grid areas:** Outlying households not yet connected to the grid could benefit if a nearby market location offers a BSS within reasonable distance for daily swapping.
- **Rural low-power grid connections:** In areas where utilities have planned for lower-tier electricity use (typically capped at around 300W), a BSS could rent out systems that connect a battery with a compatible energy-efficient appliance operating at 1kW or higher. These systems could be DC or AC. The BSS would need to decide whether to allow home recharging or require centralized swapping. The market potential could be unlocked through remote digital monitoring that tracks battery use and condition while enabling carbon credit verification.
- **Informal urban settlements:** A lack of land tenure often prevents utilities from providing safe, high-quality connections. Many residents rely on poor wiring or informal links from landlords that cannot support high-power cooking. A BSS or battery rental facility in or near these settlements could expand eCooking options for such households.
- **Humanitarian settings:** Displaced communities and refugee camps often lack access to reliable energy infrastructure due to restrictions on land and service rights. A BSS established by host communities could provide sustainable energy access to refugees and internally displaced people. In contrast to BSS models for eMobility, a BSS for eCooking would likely have regular, predictable demand. Once a stable customer base is established, the developer would be able to forecast daily battery requirements. However, this also implies significant upfront capital investment, since the BSS must hold more batteries than there are active users—typically one set in use and another charging.

To manage logistics effectively, the BSS may develop delivery systems based on remote data or learned user habits, ensuring timely battery replacement at the household level. Depending on the local context, the developer may also need to design bespoke batteries that cannot be easily

charged outside the station. This could help maintain quality control and reduce theft risks in high-density or informal areas.

Other advantages to a BSS include:

- Helps manage the charge of the battery to ensure timely use for eCooking.
- Can use larger solar PV arrays or grid electricity to smooth, match, and manage power generation across multiple batteries, improving overall efficiency and maximizing energy utilization.
- Where grid electricity is used for charging, the station can take advantage of off-peak power at night and help smooth or manage brief power outages.
- Can manage battery failures and ensure safe disposal or recycling.
- Spreads the lifetime cost of the batteries across multiple users and allows an enterprise to manage and account for system costs more effectively than individual households.

On paper, the concept is attractive in certain contexts. It offers the advantage of professional battery management, which could extend battery lifetimes and ensure safe handling. However, where consumers already have some access to electricity, a battery swapping model could easily be confused with a battery loan arrangement.

It appears that a battery swap station or business model would only thrive under quite specific conditions. It needs to be close enough to households for convenient access, situated near a grid or mini-grid connection—or have its own solar generation capacity—and ideally supported by additional revenue streams, such as serving as a community or business hub.

In short, it requires just the right balance of factors—not too far, not too near; not too costly, not too simple—a kind of “Goldilocks” situation.



9 RECOMMENDATIONS

We recommend that **Battery Swap Stations for eCooking** be piloted in a range of contexts and locations to generate practical learning about the concept.

The insights gained from multiple pilots would **inform the planning of the Universal Energy Access Facility**, contributing a new mechanism for extending access to hard-to-reach communities.

To ensure that the learning is widely applicable, it will be important to establish pilots across several different market settings:

- Market towns located near electrified rural communities.
- Market towns or denser rural settlements that currently have only low-power electricity connections.
- Urban and peri-urban informal areas without electricity provision, but bordering zones where official grid connections are available.
- Displaced and refugee communities where host governments restrict access to national infrastructure, allowing a BSS to be created and operated by the host community. These pilots should generate quantitative outcome data—for example, battery swap rates, user savings, cooking times, and user retention. Incorporating dashboards or clear metrics would strengthen credibility and help assess replication potential.

In addition to market descriptors, the BSS pilots should also reflect **diverse cultural contexts**. For instance, in communities where women face restrictions on movement, does the technology encourage men to participate in battery swapping? Does the swap station evolve into a hub for small businesses or a site of social interaction? While socio-cultural barriers—particularly those affecting women—have been discussed above, there remains a lack of data on user segmentation by cooking practices, income levels, preferences, and human-centered design insights such as stove-stacking behavior or perceptions of battery-related risks.

It would also be valuable to **pilot alternative operational models**, including collection and delivery options. These should assess potential risks such as theft, grid outages, fire hazards, or data breaches, and explore generic strategies for insurance, training, and safety certification.

Digital monitoring should be central to each pilot. It not only provides real-time data on battery use but also creates baseline evidence for potential carbon finance projects.

Finally, **financial and business model deep dives** will be essential. While pilots naturally require higher proportional budgets per user than scaled operations, they should still provide the foundational economic data and sensitivity analyses needed to develop a robust BSS viability model. Although leasing and rental frameworks have been outlined in this paper, detailed economic modelling—covering elements such as capital structure, operating costs, and tariff design—remains to be completed.

Deep dives will need to cover:

- Levelized cost of cooking energy via BSS compared to home-based systems.
- Return on investment (ROI) or payback periods for BSS developers.
- Cost comparison between battery swapping and alternative fuels such as LPG.

Such context-specific modelling should be undertaken using the data generated from the pilots.

Environmental and Lifecycle Assessments (LCA)

While this paper briefly mentions e-waste and battery recycling, pilot projects should aim to deepen understanding of lifecycle emissions through simplified comparisons across biomass, LPG, and battery-based eCooking. They should also integrate the latest research on critical mineral sourcing, ethical supply chains, and end-of-life management, including reuse and second-life applications for batteries.

Standardisation and Policy Frameworks

The paper discusses issues of battery shape and standardisation in practical terms, but further data and coordination are required to advance toward national or international standards for eCooking interoperability. Pilots should also contribute insights on policy mechanisms that could support BSS development—such as subsidies, carbon credits, or licensing frameworks.

10 REFERENCES

Links by endnote.

All hyperlinks accessed on 16/7/2025

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ABOUT SUSTAINABLE ENERGY FOR ALL

Sustainable Energy for All has a global mandate to accelerate progress on the energy transition in emerging and developing countries. Hosted by UNOPS, we work at the intersection of energy, climate and development, partnering with governments and organizations worldwide to end energy poverty, double energy efficiency, significantly expand renewable energy and combat climate change.

ABOUT MODERN ENERGY COOKING SERVICES

Modern Energy Cooking Services (MECS) is an eight-year research programme funded by UK Aid (FCDO). We are a geographically diverse, multicultural and transdisciplinary team working in close partnership with NGOs, governments, private sector, academia and research institutes, policy representatives and communities in 16 countries of interest to accelerate a transition from biomass to genuinely clean cooking.

ABOUT THE GLOBAL ELECTRIC COOKING COALITION

The Global Electric Cooking Coalition (GeCCo) is comprised of eCooking advocates who work alongside other existing global and national initiatives promoting higher-tier cooking transitions by providing leadership, integration, knowledge, and funding that is exclusively focused on the rapid global scaling of electric cooking. GeCCo's target is to enable a mass transition into eCooking in at least 10 countries in SSA, Asia, & LAC by 2030, where electricity is the cooking fuel of choice for at least 10% proportion of households and institutions.