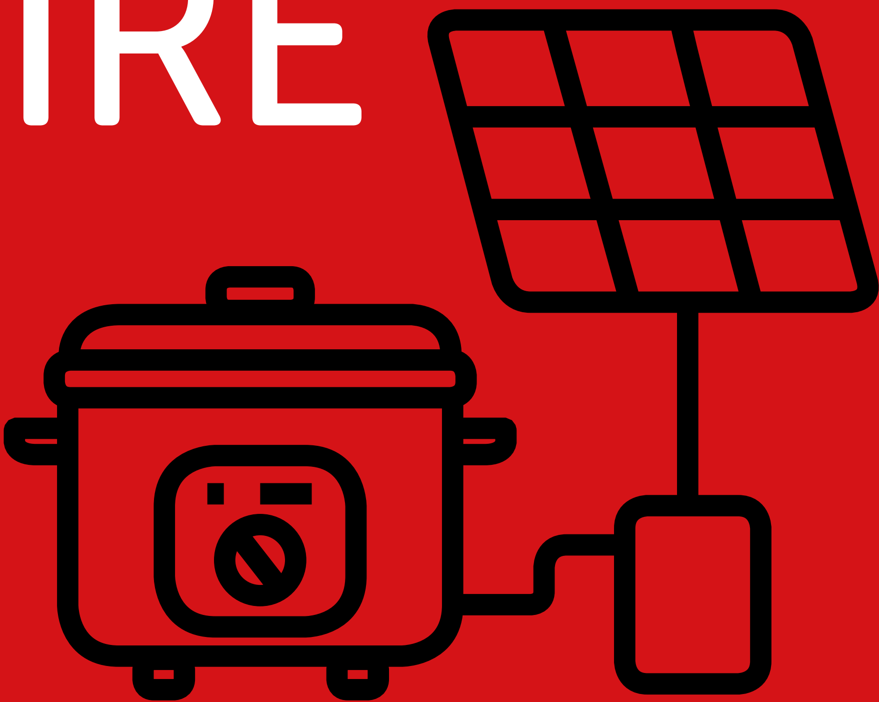
BEYOND FIRE



HOW TO ACHIEVE ELECTRIC COOKING

World Future Council

Hivos
people unlimited

BEYOND FIRE **HOW TO ACHIEVE ELECTRIC COOKING**

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"For almost two decades we have inadvertently narrowed the debate of clean cooking to just cook stoves. We need to look at the sources of energy and clean fuels"

Kandeh Yumkella

EXECUTIVE SUMMARY

Achieving sustainable cooking is one of the great challenges of our time. An estimated 4 million premature deaths are caused each year by indoor air pollution caused by existing cooking practices still widespread in many parts of Southeast Asia, Latin America, and Africa (WHO 2018). In Africa alone, the African Development Bank (AfDB) estimates that over 600,000 deaths per year are caused by existing cooking practices, the majority of which are concentrated in sub-Saharan Africa (AfDB 2017).

The difficulty of finding cost-effective substitutes for traditional cooking fuels, most notably wood and charcoal, is made even more challenging by a range of cultural, behavioral and other factors that hinder the adoption of alternatives (Brown et al. 2017). Hundreds of millions of citizens worldwide have rarely if ever known any other form of cooking than traditional firewood and charcoal: this makes the adoption of alternatives a slow and often piecemeal process.

Over the past three decades, the majority of the focus in the cooking sector in Southeast Asia and Sub-Saharan Africa has been on promoting improved cook stove technologies rather than on a fundamental transition of the underlying energy sources or fuels being used; this can be seen in the many of the national energy strategies recently developed, notably in sub-Saharan Africa (AfDB 2015; GACC 2016; ECREEE 2014). While the promotion of more efficient cookstoves remains an important interim solution and has delivered impressive results in certain countries, t**his report argues that focusing on improved cookstoves is neither a truly long-term nor a truly sustainable solution to the challenge of cooking.**

In light of these various interrelated challenges, this second edition of the Beyond Fire report sets out to build on the report's first edition, which was originally published in 2016. This revised edition draws on new data and analysis to provide an update on how the economics of cooking with electricity in a stand-alone solar home system (SHS) as well as in a mini-grid context have evolved since then.

Clearly, overcoming the economic cost barrier is only part of the challenge: **sustainable cooking technologies must be well adapted to individual communities' way of life,** and must be able to be easily integrated with prevailing cooking habits (Goodwin et al. 2014; Ekouevi 2014; Diehl et al. 2018). This means that the transition to other fuel types, whether electricity or otherwise, is likely to be a gradual process, underscoring the need to increase efforts to accelerate this transition now. Raising awareness of the alternatives, and better adapting solutions to people's actual behaviors and cooking preferences, is critical.

In order to provide a comprehensive comparison of existing cooking options and of alternative cooking pathways, this report calculates the costs range for cooking with various different appliances and presents them in hanging bar charts in order to provide a snapshot of their relative cost-competitiveness. As can be seen, the costs of cooking with electricity both in mini-grid contexts and via solar home systems is now well within the range of cost competitiveness of other cooking alternatives, a significant improvement from three years ago when the first edition was published. Also, similar to the first edition, this report finds that biogas-based cooking remains an economically attractive option, particularly for households with livestock or other suitable feedstocks.

A key improvement of this revised edition is that it sheds light on the tremendous cost-saving potential of using higher efficiency cooking appliances, in particular appliances like slow cookers and pressure cookers:

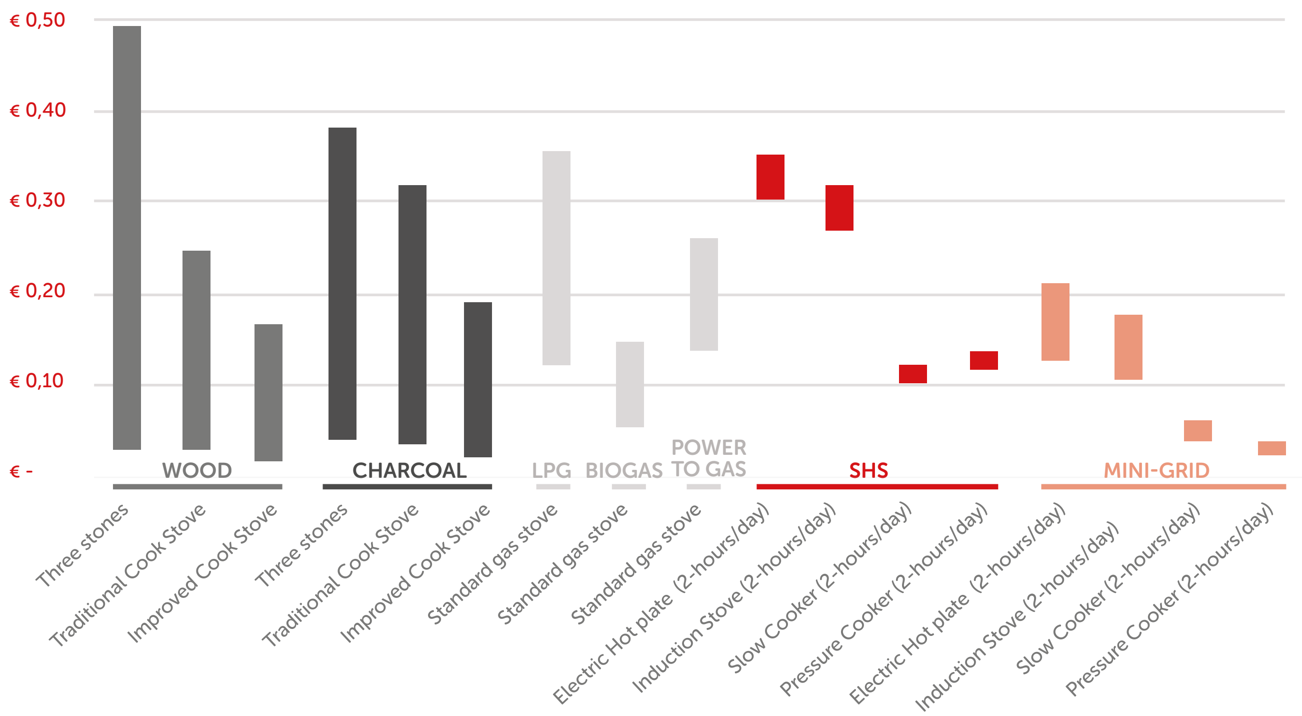
- Over a one-hour cooking period, a pressure cooker uses approximately one quarter (¼) of the electricity of an electric hot plate.
- Over a 4-hour cooking period, the gains increase further: a pressure cooker is twice as efficient as a slow cooker, six (6) times as efficient as an induction stove, and fully seven (7) times as efficient as an electric hot plate.
- In terms of costs, there is currently a 3-to-4-fold cost differential between a solar home system dimensioned for use with high-efficiency cooking appliances versus one that is dimensioned for use either with hotplates or induction stoves.

Given the limited financial resources available to most households currently cooking with firewood and charcoal, **it is therefore critical to focus on deploying high-efficiency end-use appliances, despite their slightly higher upfront cost, as the system-level cost savings pay for themselves multiple times over.**

In light of these substantial cost savings, **using high-efficiency end-use appliances has the potential to lead to a similar "inflection point" as the emergence of LED lighting technologies on the off-grid solar sector.**

The figure below provides a summary of current cost ranges, in EUR/GJ, of the various cooking options considered within the report.

FIGURE ES1: COST RANGES OF VARIOUS COOKING TECHNOLOGIES
(Per Person, Per Day, in EUR), 2019



There are two main reasons why the revised cost analysis has seen such a significant improvement in the economic viability of electricity-based options:

1. **First, the cost of both solar modules and batteries has come down significantly;**

since early 2016, the costs of solar and storage systems have come down by between 30-50%, and continue to decline as markets scale-up and technologies improve;

2. **Second, this analysis applies an updated methodology:**

in particular, it moves away from the 1 GJ per person per year benchmark in terms of final energy use, and models much more precisely the actual electricity consumption of different end-use appliances. Instead of needing 308 – 397kWh per person per year of electricity, as assumed in the first edition, this revised analysis finds that the per person electricity consumption when using a higher efficiency slow cooker or pressure cooker ranges from 61 – 131kWh. Such energy efficiency savings make it possible to significantly reduce the overall size (and cost) of both the solar panels and the battery bank required to enable electric cooking.

These two changes recast the economics of cooking in a new and far more competitive light than the first edition.

One key finding that emerges from this updated cost analysis is that cooking with electricity (whether with solar home systems or in a mini-grid context) using high-efficiency appliances can even make cooking cheaper than what many households currently spend on firewood and charcoal. The World Bank's bottom-up research from across Sub-Saharan Africa indicate that households spend on average between EUR 1 – EUR 31/month on cooking fuels (World Bank 2014).

With slow cookers and pressure cookers enabling household cooking costs of between EUR 15 and 21/month for SHS and between EUR 3.56 – 9.53/month for mini-grids, **the economics of cooking with high efficiency cooking appliances are becoming increasingly compelling.**

It is hoped that this revised analysis helps put electric cooking more firmly on the map.

BEYOND FIRE: 6 STEPS TO ACHIEVE SUSTAINABLE COOKING

1 Governments need to set clear goals to transition away from firewood and charcoal. The current energy strategies being developed by national governments and donor community for most of Africa and Asia are not doing enough to drive a meaningful transition toward sustainable cooking solutions. Current strategies still largely focus on improved cookstoves and the build-out of LPG infrastructure, failing to recognize the tremendous potential of alternative cooking solutions such as renewable electricity. By focusing largely on improved cookstoves, the international community might contribute to further entrenching technological path dependencies which might be a barrier for the de-carbonization of the cooking sector in the long-run. In order to make meaningful progress toward sustainable cooking, governments and donors will need to commit to far more ambitious goals, including clear strategies, more research on behavioral, cultural, and willingness-to-pay issues, as well as financing resources.

2 Stakeholders spanning governments, foundations, donors, investors and others involved in financing projects in the cooking sector need to allocate more resources to support the availability of pay-as-you-go (PAYGO) contracts. Such contracts convert the high upfront cost of investments into smaller, more affordable payments that can be made on a regular basis (e.g. monthly or bi-monthly). A greater focus on providing affordable consumer finance, including more local currency financing and longer loan tenors, is critical to support the transition toward sustainable cooking.

3 Governments should introduce policies and incentives to reduce upfront costs. This can involve targeted grants to encourage adoption and foster economies of scale; it can also involve other policies to help bridge the cost gap, such as "feebates" (e.g. additional fees on certain items such as air conditioning units or automobiles that are allocated to support rebates on other technologies, in this case, sustainable cooking technologies); a further approach might involve the targeted use of tax or duty exemptions, such as those frequently offered on solar PV components, or on high-efficiency cooking appliances such as electric pressure cookers. These measures may be combined with other legal and regulatory measures, such as restrictions on charcoal use and distribution.

4 Governments should undertake root and-branch reform of fossil fuel subsidies, which often benefit middle and upper-income residents, and re-allocate them to support a rapid scale-up in sustainable cooking technologies. In contrast to existing fossil fuel subsidies around the world, which tend primarily to benefit citizens with medium to high income levels, targeted support for sustainable cooking technologies tend, by default, to support lower income households. Re-allocating fossil fuel subsidies to accelerate the transition toward sustainable cooking would bring massive and lasting benefits to sustainable development, and would contribute significantly to re-balancing the major inequities that continue to persist between urban and rural regions. Reforming fossil fuel subsidies and re-allocating the proceeds to support sustainable cooking is perhaps one of the single most impactful steps that governments around the world can take to accelerate the transition.

5 Governments and donors around the world need to fund a greater range of R&D projects, including projects to demonstrate the viability of sustainable cooking solutions. Such initiatives could focus specifically on providing further analysis of cooking with different electric appliances such as slow cookers, pressure cookers and even infrared cookers,[2] analysis of the behavioral and cultural acceptance of slow cookers and pressure cookers, as well as to support the scale-up of new business models in the cooking sector. These kinds of projects can be extremely valuable in order to gather cost and performance data, analyze behavioral and other challenges, while driving further technological innovation and cost reduction. Moreover, strategically supporting the emergence of new business models can help give rise to replicable, scalable projects at various points of the cooking value-chain. Skepticism of alternative cooking solutions remains high, not least among end-users: one of the best ways to overcome this is first to demonstrate their viability, and then to help drive technological improvement and cost reduction by expanding the market, and improving the mechanisms of delivery.

6 International climate finance should be mobilized to play a far greater and more direct role in supporting the transition to sustainable cooking, including through innovative mechanisms such as the Green Climate Fund and the wider use of climate bonds. Scaling up sustainable cooking represents one of the most significant opportunities worldwide to generate major climate change mitigation and adaptation "win-wins": reducing reliance on traditional fuels such as firewood and charcoal, improving human health, while helping to preserve forest ecosystems and improve (or maintain) overall ecosystem resilience. New financing mechanisms such as climate bonds could significantly expand the volume of capital flowing to the sector, and yield wide-ranging benefits for both local citizens and the global climate.

[2] While this report does not look specifically at infrared cookers, they remain another potentially interesting cooking technology for certain applications.

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INTRODUCTION

Approximately 40% of the global population still cook with either wood, dung, coal, or charcoal to feed themselves or their families, placing tremendous strain on the surrounding environment and on human health (Goodwin et al. 2014, Chafe et al. 2013; Lacey et al. 2017).

- While roughly 1.1 Billion people still lack access to electricity worldwide (IEA 2017), almost three times that amount (or roughly 3.06 Billion) still rely on solid fuels for heating and cooking (Quinn et al. 2018; World Bank 2016a; Ekouevi 2014). This is likely to put significant additional strain on already stressed forest resources in many parts of the world (Quinn et al. 2018).

- On current trends, the SEforAll estimates that by 2030, as many as 2.3 Billion people worldwide will still lack access to clean cooking technologies due to a combination of insufficient investment in clean cooking solutions and ongoing population growth (SEforAll 2018a, SEforAll 2018b).

- In several countries in sub-Saharan Africa, the use of wood and charcoal represents over 90% of total final energy consumption (FAO 2015).

- Unsustainable firewood and charcoal use is the single largest source of greenhouse gas emissions (GHGs) in many countries and significantly exacerbates the negative effects of global climate change (Quinn et al. 2018). Burning firewood and charcoal is closely linked to both forest degradation as well as to deforestation, while increasing a region's exposure to a host of other environmental risks such as soil loss, desertification, loss of biodiversity, and water scarcity (Ekouevi 2014; Rosenthal et al. 2018).

- Reliance on such traditional fuels for cooking is directly linked to an estimated 4 million pre-mature deaths around the world, mostly of women and children, due to high levels of indoor air pollution (WHO, 2018).

- There is an estimated USD $123 Billion in annual costs to human health, to the environment, and to local economies caused by the use of solid fuels like wood and charcoal for cooking (GACC 2016).

- The availability and affordability of both firewood and charcoal are likely to emerge as major problems in the coming decades for many countries around the world as the associated pressures from climate change, timber harvesting, and industrial agriculture combine to accelerate the rate of forest loss.

Transitioning to more sustainable forms of cooking in regions like sub-Saharan Africa therefore remains a pressing global issue. As these few facts highlight, finding sustainable alternatives to cooking is not only an environmental imperative; it is critical for improving human health, for poverty reduction, as well as for advancing economic opportunity in the world's poorest and most under-privileged regions. And yet, in contrast to other major global issues, the issue of cooking rarely figures at the top of the policy agenda. Despite the UN's Sustainable Development Goals (SDGs) aim to *"ensure access to affordable, reliable, sustainable, and modern energy for all,"* the volume of finance being allocated to the sector is in fact declining (SEforAll 2018a). This is partly why a growing number of leading international organizations are urging donors and investors to allocate more time and resources to achieving sustainable cooking sector (UNDP 2016; AfDB 2017; World Bank 2017; SEforAll 2018a).

Notably, the Green Climate Fund, in partnership with the World Bank and the GIZ, has made substantial investments in clean cooking solutions, including in Bangladesh,[3] where a total of USD $82.2 Million (EUR 73.3 Million) has been committed over a 3.5 year period, as well as in Kenya and Senegal,[4] where a total of USD $26.7 Million (EUR 23.8 Million) has been committed over a period of 4 years.

Both of these initiatives are a sign that while the total funding commitments being allocated to support the transition to sustainable cooking remain a fraction of what is needed (SEforAll 2017a, SEforAll 2018a,b), awareness is growing of the urgency of the challenge.

Significant declines in the cost of renewable energy technologies (namely solar PV modules, inverters and battery systems) as well as progress in mini-grid and storage technologies is beginning to make solar the most cost-effective source of new electricity supply in many regions of the world, most notably in rural and remote regions (IRENA 2019; BNEF and responsibility 2019; Lazard 2018; BNEF 2018; Agora Energiewende 2018). This is particularly the case in much of sub-Saharan Africa, where solar resources are abundant, and the costs of either diesel systems or of expanding existing transmission and distribution infrastructure is often prohibitive (IFC 2015).

While attention on improving the sustainability of the cooking sector has begun to increase in recent years, much of the effort to tackle the challenge of sustainable cooking in Asia, Latin America, and Sub-Saharan Africa continues to be focused on improving conventional cook stove technologies, promoting the use of pellets from either wood products or agricultural wastes, shifting to LPG, as well as the overall efficiency of charcoal production (CCA 2019; GACC 2018; GACC 2016; ECREEE 2015).

Even though these improvements are certainly needed, continuing to further entrench the reliance on combustible fuels cannot be long-term sustainable solution to the challenge of cooking.

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[3] See: https://www.greenclimate.fund/projects/fp070

[4] See: https://www.greenclimate.fund/projects/fp103?inheritRedirect=true&redirect=%2Fwhat-we-do%2Fprojects-programmes

OBJECTIVES OF THIS SECOND EDITION

The aim the Beyond Fire report is to provide an overview of the main technological pathways to fundamentally transform the cooking sector in developing countries to sustainable sources. The 2016 report provided an analysis of the main technological options and an estimate of their costs, and feasibility, drawing on updated costs and market data. This 2019 update indicates the extent to which changes in the costs of different cooking options impact the economic viability of alternative cooking solutions especially solar home systems and mini-grids and what these changes in costs might mean for future policy regarding the cooking sector.

This update focuses specifically on providing an updated analysis of electric cooking using higher-efficiency appliances in both SHS and mini-grid environments. Since the situation for biogas and power-to-gas (P2G) has not changed significantly since the publication of the first report, it is not featured in great detail in this report. The reader can find a more in-depth treatment of both P2G and biogas options in the 2016 Beyond Fire report.

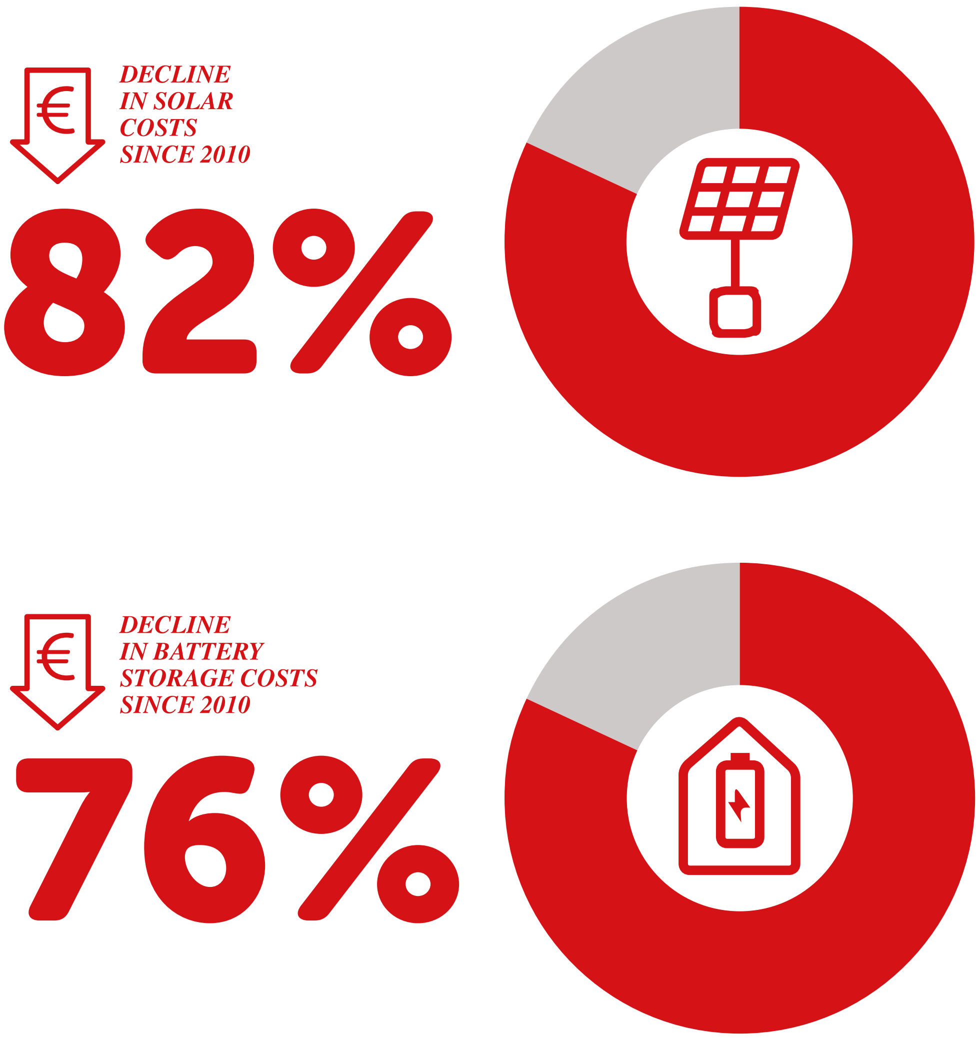
In particular, one of the aspects incorporated into this version of the report that was absent from the first edition is a discussion of electric slow cookers and pressure cookers, two technologies with a number of advantages over traditional cooking appliances. Beyond their higher efficiency, slow cookers and pressure cookers are well adapted to cooking many of the meals traditionally cooked in many parts of the world.

The 2016 report also relied on a basic metric for comparing the costs of different cooking applications. The aim was to enable a simple, apples-to-apples comparison of different cooking technologies, and provide a benchmark against which each could be objectively compared. However, the 1GJ number ignores the potential of high-efficiency end-use appliances to reduce the real energy demand required to cook, thereby ignoring one of the greatest potential areas for cost reduction. While the decline in solar and battery storage costs has helped a lot in terms of improving the economics of off-grid energy access, what was equally transformative was improvements in LED technologies that substantially reduced the total solar PV system size required to meet that lighting need.

As this report finds, high-efficiency end-use appliances like slow cookers and pressure cookers have the potential to replicate the transformative impact of high-efficiency LED lighting on reducing the costs of off-grid electricity access.

The cost of both solar PV and storage units has come down rapidly in recent years.

FIGURE 1: COST DECLINES OF SOLAR PV MODULES AND LITHIUM-ION BATTERIES SINCE 2010



SOURCE: Author's depiction, based on BNEF and Facebook 2018

As a result of the critical importance of end-use efficiency,[5] the update of this report adopts a more granular, bottom-up analysis of energy demand for electric cooking options, rather than applying the simple 1GJ/person/year across the board.

In the process, this report attempts to capture the **system-level savings** from high-efficiency end use appliances, namely, the potential to reduce the size of the PV + battery system by using high-efficiency end-use appliances: in other words, the aim is to optimize the efficiency of the cooking system as a whole in order to reduce the total capital investment required. This reduced upfront capital investment is enough to dramatically reduce the cost to rural households, and enough in certain contexts to justify the more widespread adoption of electric pressure cookers and slow cookers in off-grid settings.

As awareness of the increasing cost-competitiveness of electric cooking grows, it can be anticipated that a growing number of pay-as-you-go (PAYGO) companies currently operating around the world will start offering high-efficiency cooking appliances, helping catalyze the transition beyond fire.[6]

One of the primary objectives of the report is to inform the political and donor discourse and trigger a much wider policy dialogue about future pathways for the cooking sector. As the cost of renewable energy and storage technologies decreases, technological options are likely to open in the coming years that are not yet part of the international discussion on sustainable cooking options. This relates to a further objective of report, which is to help policy-makers better understand the challenge of achieving sustainable cooking and **to suggest concrete steps to drive this transition.**

So far, much of the global energy debate with regard to renewable energy technologies is focused on electricity generation. However, as pointed out above, in many developing countries cooking-related energy use represents over 90% of total primary energy demand. For such countries, attempting to scale up renewable electricity supply without focusing on the cooking sector is therefore inadequate, as it leaves much of the energy supply mix as well as many of the most significant challenges untouched. In light of these and many other changes taking place worldwide, it is time to consider how these various technologies could help accelerate the transition toward sustainable cooking.

In order to clarify the path toward implementation, **the 2019 Beyond Fire report focuses on two (2) different technological pathways (the use of electric cooking appliances in a solar home system as well as in a mini-grid context) and assesses their overall technical viability as well as their *scalability*.** While the report analyses different technological pathways, it recognizes that a purely "technical" fix alone is not enough. Indeed, all successful technological transitions (e.g. from horses to automobiles, from kerosene lanterns to electric light bulbs) are accompanied by a range of important cultural, administrative, legal, and behavioral changes (Sovacool 2016; Ekouevi, 2014). Moreover, this report recognizes that in order to be successful, any new technology must be embraced by end-users, it must be both affordable and convenient to use, and its market adoption must be both affordable and convenient to use, and its market adoption must scale from the bottom-up on the basis of consumer demand, rather than be introduced or imposed top-down (IFC 2012; Palit and Bhattacharyya 2014).

While the report will not be able to provide in-depth answers to all of the challenges it lists, it aims to engage decision-makers critically in this debate and to encourage them to think beyond improved cook stove (ICS) technologies and the continued reliance on wood and charcoal-based solutions; in the process, it aims to explore whether other pathways are possible, and if so, what challenges will need to be overcome for them to become credible, scalable alternatives.

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[5] For a more in-depth look at end-use efficiency, see Lovins, 2005. https://d231jw5ce53gcq.cloudfront.net/wp-content/uploads/2017/04/OCS_Energy_End-Use_Efficiency_2005.pdf

[6] Note that most PAYGO companies enable their customers to own the system once it is paid off. This means that most PAYGO contracts are in fact a form of "lease-to-own" contract.

OVERVIEW OF THE REPORT

PART 1 of the report sets the stage by first defining what is meant by sustainable cooking while providing a brief discussion of why the traditional focus on improved cookstoves does not go far enough.

PART 2 of the report focuses on the tremendous opportunity of transitioning to more sustainable forms of cooking, with a focus on the various health, economic, and environmental benefits that it could bring.

PART 3 of the report provides an analysis of the overall challenge of achieving sustainable cooking, and highlights many of the limiting factors, focusing mainly on Sub-Saharan Africa. It also discusses some of the questions and concerns commonly raised when the possibility of cooking with solar, with mini-grid supplied power, or with new technologies like power-to-gas is discussed.

PART 4 of the report contains the main body of the analysis on alternative cooking solutions. Section 4.1 examines the potential of solar home systems (SHS) accompanied by storage and examines each of the four main cooking appliances available, including electric hot plates, induction stoves, slow cookers (often referred to as crock pots), and pressure cookers. Section 4.2 considers the potential of scaling-up cooking within mini-grids. Like the SHS section, the mini-grid section factors in the different efficiencies of the four different cooking appliances outlined above.

In examining each of these different pathways, the report provides an analysis of the approximate costs of each technology, the various technical, social, financial, and cultural barriers each pathway faces, as well as an analysis of a number of relevant cultural and behavioral factors that influence the viability of each.

PART 5 of the report provides a synthesis of the key findings, while Part 6 lays out a five-point action agenda for donors, policymakers and international investors.

1.

WHAT IS SUSTAINABLE COOKING?

This report adopts the traditional definition of sustainable development to approach the challenge of achieving truly sustainable cooking. According to this framework, this **means transitioning to a future where cooking needs are met in a way that is economically, socially and environmentally sustainable.**[7] According to this definition, the continued large-scale use of wood-based fuels is deemed to be unsustainable due to the significant health and environmental impacts associated with wood harvesting and use. While plans are afoot in certain countries (e.g. the Democratic Republic of the Congo) to significantly increase the share of plantation-grown wood in the production of charcoal and firewood in the years ahead, this is unlikely to be sustainable either: not only are the objectives themselves often unrealistic (in the case of the DRC, the target is to replace between 90-100% of total cooking-related biomass use with plantation-grown wood by 2030), they are likely to accelerate already unsustainable rates of deforestation while potentially worsening the food-vs-fuel dilemma frequently faced in the biofuels sector.

Some argue that pellets or other forms of biomass can be made sustainable if the production and harvesting are improved and if more regulation and certification bodies are put in place to oversee the sector. These arguments, however, ignore (or fail to fully appreciate) the sheer power of demographics: the population of Sub-Saharan Africa (SSA) is projected to almost triple by 2060, reaching as high as 2.7 Billion up from 1 Billion in 2015 (World Bank 2015).

Given that the overwhelming majority of citizens in SSA continue to rely on biomass to meet their cooking needs (either in the form of firewood or charcoal), **failing to fundamentally change the energy mix in the cooking sector away from biomass will all-but-ensure that the rates and extent of harvesting and deforestation will be unsustainable**. Thus, given the size of the coming demographic boom, **scalable and affordable alternatives to wood-based fuels are needed**, and this is likely to remain the case regardless of how efficient the pellets or the cookstoves are made to be.

Thus, for the purposes of this report, **plantation-based wood supply, pellets, and other alternatives that rely primarily on wood are not considered a long-term solution to the challenge of achieving sustainable cooking.**

[7] This is based on the widely used definition of sustainability that includes social, economic, and environmental dimensions, reflected also in "triple bottom line" framework now in common use to govern investment decisions around the world.

BOX 1: WHY FOCUSING ON "IMPROVED COOKSTOVES" IS INSUFFICIENT

While much effort continues to be devoted to deploying improved cook stove technologies, this report argues that in order to solve the enormous challenge of sustainable cooking in developing countries, we will have to move beyond these traditional options.[8] Despite significant improvements in recent years, improved cookstoves, when considered collectively, still require huge amounts of charcoal and wood, the harvesting and production of which continue to have significant negative impacts on the environment and on human health. Indoor air pollution is directly linked to roughly four (4) million premature deaths every year, mainly of women and children (WHO 2018).

While improved cookstoves help mitigate this problem, they do not eliminate it, as the widespread air pollution surrounding densely populated areas such as the "ger" districts outside Ulan Bator in Mongolia or the informal settlements around Abuja in Nigeria illustrate (Bittner, 2016; Hassan and Abdullahi, 2012). In other words, while efficient cookstoves may significantly reduce indoor air pollution, they continue to contribute significantly to air pollution in the surrounding area, particularly in regions with high population densities such as urban and peri-urban areas. Furthermore, informal production and distribution structures along the entire value chain of charcoal (even when efficiently produced) still leaves many producers and harvesters vulnerable to economic exploitation, particularly women and children (GACC 2015). On the environmental front, wood harvesting, charcoal burning, transport and trade are in most cases unregulated, making it difficult to obtain reliable data about rates of extraction and consumption. The rampant pace of wood and charcoal consumption for cooking, particularly around the large urban areas such as Lagos (Nigeria), Kinshasa (Democratic Republic of Congo), and Dar es Salaam (Tanzania), is exacerbating unsustainable forestry practices and leading to increased soil erosion, reduced agricultural output, as well as a deterioration in both the quantity and the quality of fresh water (Sanga and Jannuzzi 2005; Hilderman 2010).

And finally, in light of the rapid population growth anticipated in many regions reliant on wood-based cooking, the continued over-reliance on wood-based cooking (however efficiently used) is likely to become less and less sustainable in the long-term simply due to the underlying demographic trends, which will put an increasing burden on forest resources, exacerbate desertification, reduce access to potable water, and further jeopardize long-term prosperity (UNESCO 2012). These concerns are increasingly urgent: in light of the anticipated rate of population growth, rapid deforestation caused in part to meet cooking needs is likely to continue across the region, and this is likely to remain the case even if more efficient cookstoves or charcoal production techniques are utilized.

Thus, this report proposes that **efficient cookstoves and improved charcoal production techniques are best understood as interim measures, rather than truly long-term, sustainable solutions.** Some point to the use of pellets derived from agricultural wastes as a potentially sustainable alternative to firewood and charcoal (Fulland 2016). However, while agricultural wastes remain a valuable resource, they are often not present in sufficient quantities to durably meet local cooking needs, making them a partial solution at best; this issue is likely to remain a challenge for biogas systems as well (see Section 4.3). In light of the importance and urgency of this topic, **there is a need to explore the potential for more transformational solutions that move beyond wood or charcoal-based cooking altogether.**

[8] Note that "improved cookstoves" in this section refers particularly to those stove models designed to operate using firewood and charcoal.

Much national government and donor-based support in the cooking sector is currently focused on accelerating the transition to LPG, as the latter is seen as a cleaner, more modern fuel than traditional cookstoves and is associated with far lower human health and environmental impacts.

However, the use of traditional liquefied petroleum gas (LPG) derived from fossil fuels is also deemed unsustainable in the long-term, first and foremost as it is non-renewable. Beyond the fact that LPG is non-renewable, it is also inherently volatile in price as it is linked to oil prices: this increases the risk of a sudden reversion to traditional cooking fuels such as wood and charcoal in many of the regions of the world when prices spike. LPG prices in many key markets including in East Africa, West Africa, and the Asia Pacific region has increased in recent years, pushing many households to revert back to traditional firewood (Asante et al. 2018). LPG is also exposed to greater geopolitical and other related risks, as many countries reliant on LPG do not refine their own domestically, making supply inherently interruptible. In light of these and other factors, LPG may be seen as a transitional fuel: it is arguably not, however, a long-term solution to the challenge of achieving sustainable cooking.

In defining what is meant by "sustainable cooking", this report retains the approach outlined in the first report. According to this definition, a technology has to be **environmentally, socially**, as well as **economically** sustainable to be considered truly sustainable in the long-term.

If sustainability, as defined by the landmark Brundtland Commission in 1987 as meeting ***"the needs of the present without compromising the ability of future generations to meet their own needs"***, remains our long-term goal, the cooking sector as a whole remains still has a long way to go (World Commission on Environment and Development, 1987).

2.

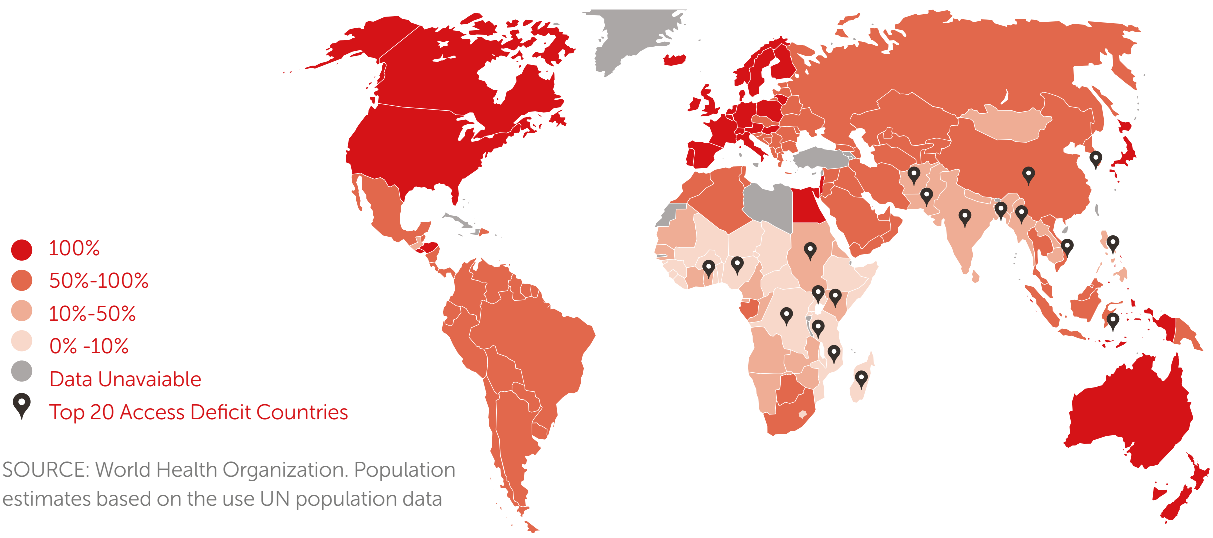
THE OPPORTUNITY
OF ACHIEVING SUSTAINABLE COOKING

TABLE 1: FACTS AND FIGURES

93%	Percentage of households in Sub-Saharan Africa rely on wood energy for their daily cooking needs (Cerutti et al. 2015)
3 BILLION	Approximate number of citizens worldwide that relies on open fires and simple stoves using wood, dung, charcoal, and coal to cook their food (GACC 2015).
4 MILLION	Premature deaths worldwide associated with household air pollution caused by cooking with traditional fuels like wood and charcoal (WHO 2018).
30%	Share of the population of Sub-Saharan Africa living on less than USD $1.25/day (World Bank 2014)
1GJ	Estimated wood or charcoal energy required per person per year for cooking purposes in Sub-Saharan Africa (Demierre et al. 2014; Sanga and Jannuzzi 2005). This represents approximately 35kg of charcoal, or just over 60kg of firewood per person per year of final energy use. Due to the inefficiency of most cookstoves used to burn firewood and charcoal, the actual firewood and charcoal use is far higher.
83%	Proportion of households in Sub-Saharan Africa that still do not have access to clean cooking (IEA 2017)

Currently, the level of access to clean cooking solutions remains lowest in Sub-Saharan Africa (SEforAll 2018b).

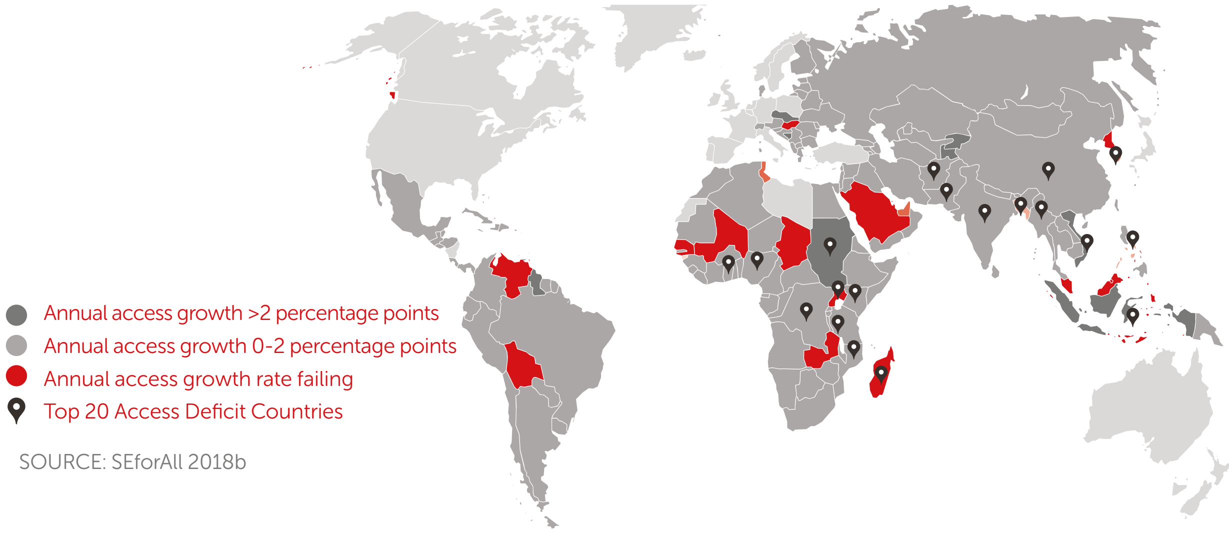
FIGURE 2: SHARE OF POPULATION WITH ACCESS TO CLEAN COOKING[9]



SOURCE: World Health Organization. Population estimates based on the use UN population data

[9] Note: the top 20 Access Deficit Countries refer to the twenty countries in the world with the largest per capita energy access gaps. These access gaps are calculated both for electricity access as well as for access to clean cooking.

FIGURE 3: ANNUAL INCREASE IN CLEAN COOKING ACCESS RATE (2010-2016)



SOURCE: SEforAll 2018b

And in contrast to the rate of electricity access, which is growing in virtually all countries worldwide, the rate of access to clean cooking is actually falling in certain countries, notably in Mali, Chad, and Zambia (SEforAll 2018b).

Transitioning to sustainable cooking could yield a wide range of benefits to hundreds of millions of citizens around the world, including:

- Improved health and life expectancy through reductions in household air pollution;
- Increased economic opportunity by freeing residents (primarily women and children) from the burden of gathering, preparing, and transporting wood and charcoal products;
- Improved educational outcomes and literacy rates, as children need to spend less time gathering firewood;
- Significant reductions in deforestation, which brings a host of direct and indirect benefits for local communities, including improved water quality and availability;
- Improved resilience against drought and desertification;
- Reduced soil erosion;
- Reductions in greenhouse gas emissions and other harmful air pollutants.

As this short list underscores, many of the benefits of reducing reliance on wood and charcoal-based cooking fuels extend far beyond energy or even climate change, helping address a range of other key international priorities, such as reducing gender inequity, improving child literacy rates, as well as reducing deforestation (SEforAll 2015; SEforAll 2018b).

As such, any analysis of the challenges of achieving sustainable cooking needs to take this complex set of factors into consideration, as the costs and risks of continuing with the status quo are enormous and often under-appreciated. Transitioning to more sustainable cooking solutions around the world can therefore play a key role in delivering on the global Sustainable Development Goals (SDGs), as cooking cuts across many of the key areas of focus.

As described above, this report attempts to critically examine some of the main questions raised about the viability and scalability any alternative pathways to sustainable cooking. The table below provides an overview of a number of questions that frequently emerge.

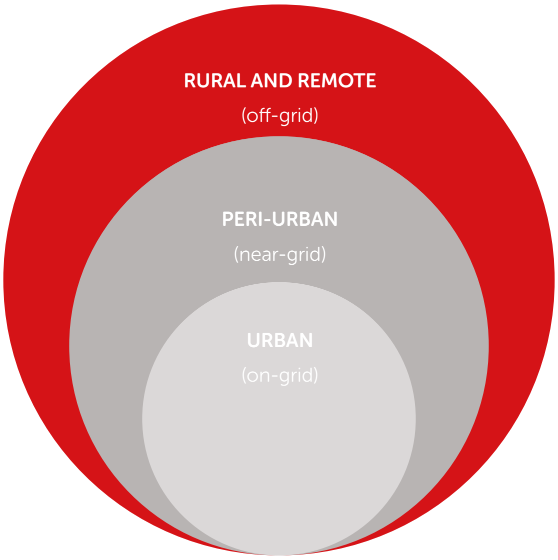
TABLE 2: COMMON QUESTIONS CONCERNING ALTERNATIVE COOKING SOLUTIONS

Common Questions	Short Answers
Isn't it more efficient to cook with a primary fuel like wood, rather than first generating electricity which is then converted into thermal form? What about the thermodynamic losses?	This is certainly the case if the electricity is first generated by burning a primary fuel such as coal, natural gas, or diesel. However, with RE technologies like solar and wind, there are no large thermodynamic losses at the beginning of the process, as wind and solar power can be used directly in electrical cooking appliances, and overall conversion losses are small. Also, once installed, the marginal cost of technologies like solar is effectively zero, although routine maintenance is required and both battery systems and inverters need to be replaced at regular intervals (e.g. every 4-7 years, depending on customer usage behavior).
Aren't wood and charcoal far more "energy dense" than solar? How can solar ever provide the amount as well as the density of energy required to meet cooking needs?	Energy density is an important challenge. One consequence of this is that large amounts of solar (or wind, or other RE source) are required to produce the same thermal energy as that found in solid fuels like wood, or charcoal. While this remains a challenge, it is beginning to be overcome in part through improved technologies (e.g. storage, P2G), and through the improved efficiencies of cooking appliances. Also, it is estimated that the conversion efficiency of trees at converting sunlight into energy is approximately 1-8% (Hall and Rao 1999), compared to a range of 9% for the least-efficient modules to over 40% for more advanced solar technologies (Green et al. 2015).
Rural residents in many developing countries already struggle to pay for basic electricity services such as lighting and mobile charging, and often do not pay for their cooking fuel, opting to gather wood fuel instead. Won't any electricity-based solution therefore be unaffordable for such low-income residents?	All new energy technologies face an upward challenge to reach wide-scale adoption. Transitioning to more sustainable forms of cooking is likely to require considerable public support and investment, including greater research and development (R&D). As the use of sustainable cooking technologies grows, this is likely to help drive down the costs, which is likely to help make them even more affordable for residents in rural areas. Meanwhile, the prices of charcoal continue to go up while firewood also faces hidden costs in terms of the time required to harvest it, a reality that especially impacts women and children.

Won't increasing reliance on electricity for cooking significantly increase the total peak demand requirements, which is often concentrated primarily in 2-3 hours of the day, leading to an inefficient over-investment in generation capacity? Can such a massive increase in electricity generating capacity ever be affordable, particularly in rural and remote areas where income levels are low?	Meeting evening demand peaks caused by cooking with either battery storage or with back-up supplies is one of the biggest challenges of electricity-based pathways for achieving sustainable cooking, particularly in mini-grids and for small SHS. In SHS, peak demand can be decreased by using more energy efficient appliances and by potentially storing electricity during the day in order to use it in the evening hours. This possibility is one of the main reasons why technologies like pressure cookers emerge as a promising technology for meeting off-grid cooking needs: they involve a high power demand in the first 8-12 minutes (which can be initiated during the daylight hours), followed by a long period of very low demand, enabling household electricity use to be rationed once the sun has set. In mini-grids, efforts have already been made using new signaling technologies to encourage households to slightly shift the timing of their electric cooking in order to maintain the proper and reliable functioning of the mini-grid system and avoid high peak demand because of parallel usage of energy intensive appliances. Such load-management technologies are increasingly the norm in mini-grids around the world and this extends to mini-grids designed to support electric cooking. The aim of such load-management technologies is not to regulate demand patterns strictly or to require users to cook at inconvenient times of the day, but rather to provide signals to residents in rural areas to inform them when supply is more limited (e.g. when the battery bank is low) and when it is more abundant.
Isn't power-to-gas (P2G) far too expensive and complicated to be used in a context such as SSA?	While the technology to produce synthetic methane is itself complicated, the same may be said for automobiles, welding machines, or a number of other appliances commonly used in rural or peri-urban regions. The important point is that the end product is not, and in the case of cooking gas, it is already in wide use throughout SSA and large parts of Asia in the form of liquefied petroleum gas, or LPG. If the business case for P2G can be made investable by making the end product cost-competitive with other alternatives like LPG and charcoal, the complexity of production should not pose a significant barrier to scale-up.

In order to better organize the various technological pathways and potential policy interventions, this report distinguishes between urban areas, peri-urban or near-grid areas, as well as rural and remote areas. The figure below provides an overview of these three regions:

FIGURE 4: CATEGORIZATION OF THREE KEY REGIONS WITH DIFFERENT COOKING NEEDS AND REALITIES



Distinguishing between these three key regions is important, as the various benefits as well as the various policy and technological interventions required to create them are also likely to look different depending on which region is targeted. For instance, citizens living in urban areas may face higher costs of charcoal and have a higher willingness or ability to pay as well as greater access to alternatives, potentially making it easier to encourage large-scale substitution.[10] In contrast, many rural and remote regions where there is little to no electricity access, lower cost for firewood and considerably lower willingness to pay, making it more difficult to encourage large-scale substitution. In addition, the cost of new technological solutions (e.g. electricity-based cooking pathways or power-to-gas pathways) may be more expensive to deliver in rural and remote regions, widening the gap that needs to be bridged in order to make alternative cooking solutions widely adopted by local residents, who are the ultimate end-users of cooking technologies.

In order to sharpen the focus, this report focuses primarily on rural (off-grid) and peri-urban (near-grid) areas, rather than in urban centers, though some of the solutions explored could also be applicable in urban areas, while some (such as renewably-powered P2G) could even be better suited to areas with higher population densities.

[10] However, despite easier access to alternatives, this is not always the case: in certain urban areas such as those in Tanzania, charcoal use has continued to grow rapidly despite the presence of alternatives (TATEDO 2016). http://www.tatedo.org/news.php?readmore=5

3.

UNDERSTANDING
THE CHALLENGE

Despite the many benefits listed above, a number of crucial barriers continue to stand in the way of a sustained scale-up beyond unsustainable wood-based cooking. This section is broken down into four different sub-sections that serve to set the stage for rest of the report: the first examines the various negative effects associated with continued reliance on wood and charcoal for cooking (3.1.); the second focuses on better understanding the barriers to sustainable cooking (3.2.); the third outlines the methodology used to quantify cooking-related energy needs (3.3.); and the fourth provides an overview of the different cooking appliances available, as distinct from the actual energy sources used to power them (3.4.).

3.1. Negative Effects of Cooking with Wood and Charcoal

In order to understand the case for accelerating the transition to more sustainable cooking, it is important to consider the various negative effects of continued reliance on the primary existing fuel sources, namely, wood and charcoal. This section considers seven (7) different negative effects.

Wood Consumption:
Sub-Saharan Africa continues to have the highest average per-capita wood consumption in the world, with an estimated 0.69m3/year (or roughly 480 kg per person per year, or 1.3kg per person per day) (Cerutti et al. 2015). Estimates for highly forested countries like the Democratic Republic of the Congo (DRC) are closer to 1 m3/year (or roughly 700kg per person per year, or 1.9kg per person per day) (Mayaux et al. 2013). This compares to a global estimated average of 0.27m3/year. Concerns over unsustainable deforestation have led the government of Tanzania to enforce a temporary ban on the charcoal trade (Hayduk 2017), a move that Kenya has recently followed (Rodriguez 2018). The sheer rate of cooking related wood consumption, when combined with anticipated population growth, makes the concerns over deforestation real, and increasingly urgent.

Moreover, since most fuel wood used for cooking in Sub-Saharan Africa is not purchased, but gathered from the surrounding environment, this makes it more challenging to introduce alternatives into the market, as the benchmark price of gathering fuel wood is effectively zero. This singular fact poses a unique challenge, particularly in the regions that are most reliant on fuel wood for their cooking needs, as it is in these regions where the ability or willingness to pay are typically the lowest.

Environmental Impacts:
Reliance on wood and charcoal for cooking has a number of well-recorded negative effects, including forest degradation, soil erosion, loss of many critical ecosystem services, loss of biodiversity, loss of food sources from indigenous plants and animals, among others. (GEF 2013; Sanga and Jannuzzi 2005; Hilderman 2010; UNESCO 2012). Compounding these various impacts is the fact that most areas deforested for either firewood or charcoal production are rarely replanted, resulting in further negative impacts while undermining local ecosystems' capacity to recover.

Human Health Impacts:
Health impacts related to exposure to poor air quality include a wide range of issues including increased infant mortality, reduced life expectancy, pulmonary and other respiratory diseases, as well as a heightened risk of cancer (WHO 2018; GACC 2015). Out of the estimated 4 million pre-mature deaths per year globally directly linked to indoor air pollution associated with cooking with wood and related fuels, 12% are due to pneumonia, 34% from stroke, 26% from ischemic heart disease, 22% from chronic obstructive pulmonary disease (COPD), and 6% are estimated to come from lung cancer (WHO 2018).

Gender Inequality:
Data gathered from Sub-Saharan Africa

suggest that men and women over fifteen (15) years of age spent between eight (8) and nine (9) hours per week collecting wood to meet their household cooking needs (World Bank 2006). Women and in particular children remain exposed to much of the negative health impacts of cooking due to high levels of indoor air pollution.

Opportunity Costs:
There are significant negative economic consequences and tremendous opportunity costs of spending so many hours engaged in gathering and transporting wood and/or charcoal. In some villages in western Tanzania, for instance, residents travel up to 10km per day to collect wood (Mwampamba 2007). This underscores the significant opportunity cost of gathering traditional biomass for cooking purposes: if women and children are out gathering wood, this limits their opportunities to go to school, improve their education, or engage in other more productive activities. This restricts literacy among the young and significantly harms long-term economic prosperity. Thus, lifting the burden that gathering firewood imposes on residents, particularly those in rural and peri-urban areas, could significantly assist in lifting millions out of poverty both by improving their health, as well as by freeing up their time.

3.2. Barriers to Transition

There are many crucial challenges that continue to limit the uptake of new and more sustainable cooking technologies. These include:

- A number of **cultural and behavioral barriers** linked to cooking habits, traditions, and taste preferences (Goodwin et al. 2014; Palit and Bhattacharyya 2014; Diehl et al. 2018; Brown et al. 2017);
- **High upfront cost** of alternatives, including both the cooking appliances themselves (the stoves or ovens) and the costs of procuring the energy required to run them (i.e. paying for the gas, the electricity, or the pay-as-you-go plan) (GEF 2013; Puzzolo et al. 2016);
- **The availability in many regions of zero-cost fuel wood,**[11] gathered by residents directly from the surrounding environment, which hampers the adoption of alternatives and impedes substitution (Schlag and Zuzarte, 2008); it is estimated that only some 50% of households in Sub-Saharan Africa pay something for their cooking fuels, with the remaining 50% gathering firewood directly from the surrounding area (Leach and Oduro, 2015);
- **The risk of reversion,** which occurs when residents revert to traditional cooking technologies even though cleaner options are available, typically due to cost, preference, or other factors (Asante et al. 2018);
- **Low income levels,** which make it difficult to finance and support the market uptake of more sustainable solutions, particularly for lower income residents, or those at the bottom-of-the-pyramid (Puzzolo et al. 2016);[12]
- **Lack of familiarity** with (and occasionally even resistance to) the use of new technologies (Palit and Bhattacharyya 2014);
- **The remoteness** of many regions reliant on wood and wood-based fuels for cooking, which increases the cost and logistical challenges of delivering interventions.

As the above list highlights, the barriers facing the uptake and diffusion of more sustainable cooking technologies are significant and in many cases, difficult to overcome. Foremost among these barriers are **cultural and behavioral factors:** cooking choices, taste preferences and behaviors

[11] Assuming that the costs of gathering wood is free; this of course is not entirely true, as there is always an opportunity cost.
[12] The term « bottom of the pyramid » refers to the portion of the global population with the lowest average income levels.

are deeply tradition-based and location-specific, making it difficult to drive large-scale substitution in the market, while also limiting the potential scalability of alternatives (Goodwin et al. 2014; Leach and Oduro 2015; Brown et al. 2017; Diehl et al. 2018). Overcoming both the cultural barriers as well as the underlying economic barriers of cooking in developing countries presents a formidable challenge. **Cooking is deeply embedded in people's way of life, and is woven into the very fabric of communities,** which means that communities are likely to remain more resistant to change than they might be with other innovations such as the advent of mobile technologies (Goodwin et al. 2014; Palit and Bhattacharyya 2014; Ekouevi 2014). Thus, any effort to scale-up alternative cooking solutions needs to be based on a sound analysis of what actually drives the adoption and diffusion of new technologies. Behaviors often run deep and the cultural and other social factors surrounding the question of cooking make this uniquely so with sustainable cooking.

A further challenge relates to the level of awareness of cleaner cooking alternatives, including in particular of the possibility of adopting electric-based cooking solutions: **a number of high-profile reports recently published on the clean cooking sector scarcely discuss cooking with electricity at all, focusing instead on improved cookstoves, LPG, and other options** (Puzzolo et al. 2016; Price 2017; Rosenthal et al. 2018; Quinn et al. 2018, among others).

The prevailing consensus among those working in the clean cooking sector emerges as one of the greatest barriers: electric cooking options are widely thought to require a national grid, and are therefore not believed to be a viable option for rural and remote regions, which is where most households reliant on firewood and charcoal for cooking typically live. In such regions, grid infrastructure often does not exist, income levels typically are much lower, and power generation costs are often higher, making electricity use at the scale required for cooking purposes impractical, if not prohibitive, for most households. A further challenge is that even in regions that do have access to the national grid, power supply is unreliable, particularly in the evening hours when most households do most of their cooking (BNEF and ResponsAbility 2019).

All of these factors, combined with the many cultural and behavioral barriers to electric-based cooking, combined with the lack of awareness of alternatives, have led many to argue that cooking with electricity is not viable, especially in rural and remote regions.

The first edition of the "Beyond Fire" report attempted to challenge this prevailing narrative, and cast a different light on the question of sustainable cooking.

Recent examples of rapid adoption of new communication tools such as smart phones in areas where not even landline phones existed suggests the transition to the widespread adoption of new technologies can be quite rapid, provided the right conditions are in place.[13] Key among these conditions are strong customer demand, the presence of significant and tangible benefits over alternatives, and the product being available at an affordable cost. The question of cost is important in two different senses: both the **upfront cost,** as well as the ongoing, **usage-related cost.**

As Adkins et al. show for both Tanzania and

[13] There is, however, an important difference between cleaner cooking technologies and mobile phones, namely, that there is currently no alternative to communicate remotely with friends, colleagues, or family members other than via a mobile phone. By contrast, there are many different ways of cooking (Fulland 2016).

Uganda, the willingness to invest in more expensive (though significantly more efficient) cookstoves dropped dramatically when the price rose from USD $10 per unit to $17.5 per unit (Adkins et al. 2010). This suggests a significant customer reluctance to spend much more than USD $10 per stove, and points to an important insight for any successful interventions in the cooking sector: **the business model used to scale up the use of the new technology must strive to make the technology affordable from the outset, as well as on an ongoing basis.**

Making new cooking technologies affordable to residents, particularly those in rural and remote regions where income levels are quite low, may therefore require bundling the cost of the technology and/or cooking appliances into an affordable, flat (e.g. monthly) payment in order to circumvent the high upfront cost barrier, and in order to ensure that the actual costs of using the technology remain affordable. Failure to do so increases the risk that residents will revert to their previous cooking behaviors as soon as economic or social circumstances change. This points to the need either for targeted support (e.g. subsidies) or customized financing solutions that allow end-users to amortize the cost of both the cooking appliances themselves, as well as the systems (or cylinders) used to power them.[14]

A further critical factor is the **low income levels i**n many of the regions that are most reliant on traditional cooking fuels. It is often the lowest-income countries in Sub-Saharan Africa, for instance, that have the highest reliance on wood and charcoal for their cooking needs (Leach and Oduro, 2015). Over twenty (20) countries in Sub-Saharan Africa, for instance, have more than 50% of their populations living on a daily income level of less than USD $3.20 per day (World Bank 2016b). In such countries, many of the poorest citizens live in rural or in peri-urban regions and often do not have the income required to afford significant changes in their cooking habits, even if such changes would bring significant benefits for their family health and future economic prospects.

Thus, **developing interventions, policies, or investment plans to support the transition to sustainable cooking technologies in these regions has to be designed to work in an environment with low income levels, and with a correspondingly low willingness (and/or ability) to pay.**

A further problem complicating the situation is that research shows that most households do not fully "substitute" from one fuel to another, as was previously implied by the traditional "energy ladder" model of development, but instead combine different fuels for different purposes in a process known as "fuel stacking" (IEA 2006). Modern forms of energy such as electricity are typically used very sparingly at first and are only used for particular services such as radio or watching television, while other fuels such as LPG might be used to boil water, and charcoal might be used to cook traditional dishes. Moreover, research suggests that people are likely to switch away from both cooking and heating last, the two single largest sources of household energy use (IEA, 2006). For instance, in Nigeria and Ghana, two of the countries with the highest rates of electrification in West Africa, 60 to 70% of the population continues to rely on either charcoal or wood for their cooking needs. This figure rises to over 90% for countries like Liberia and Sierra Leone.

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[14] An example of this that has begun to emerge in certain regions is a business model in which pellet producers are beginning to offer residents the option of signing up for a "cooking service contract" that combines the use of a stove and a monthly supply of pellets for a flat monthly rate (Fulland 2016). New business models like this could play an important role in accelerating the adoption of more sustainable cooking technologies (see World Bank 2014).

Indeed, relying on multiple fuels can provide a sense of energy security: relying primarily or exclusively on only one fuel source is likely to leave households vulnerable to sudden disruptions of supply, or rapid increases in price. As has been pointed out in a recent landmark report, *"As incomes increase and fuel options widen, the fuel mix may change, but wood is rarely entirely excluded."* (World Bank 2014).

It is important to underscore that **the choice of cooking technologies is rarely if ever driven strictly by economic considerations:** as pointed out above, a range of factors including convenience, history, individual habits, and local culture play a significant role (Hosier et al. 1987; Zulu et al. 2013; Ekouevi 2014; Palit and Bhattacharyya 2014; Clemens et al. 2018; Diehl et al. 2018). Thus, sustainable cooking technologies must be well adapted to individual communities' way of life, and must be able to be easily integrated with existing cooking habits. This means that the transition to other fuel types, whether electricity or otherwise, is likely to be a gradual process; this underscores the need to accelerate this transition now.

3.3. Overview of Cooking Appliances

A further factor that is critical to understand in order to understand the challenge of achieving sustainable cooking is that the primary energy sources used are only part of the problem: there is also the actual technology or device used to convert that energy into a usable form. In this sense, the actual energy efficiency of the cooking device plays a critical role, and can be an important factor in improving the affordability of sustainable cooking solutions.

There are three main types of cooking appliances:

Electric:

These can be used either with the SHS pathway or under the mini-grid pathway, as well as in urban and peri-urban areas where there is sufficient access to electricity; this includes hot plates and hot coils as well as induction stoves, which operate by heating up a surface. The newest models available for electric hotplates range from 800W to 2300W and feature a price range of between as little as EUR 5 to EUR 100 or more (Thompson 2019; Konga 2016). Other reports confirm the availability of electric cooking appliances in the EUR 12-20 range in key markets in Sub-Saharan Africa such as Tanzania, Kenya, Nigeria and Ghana (Leach and Oduro 2015).[15] The average efficiency of traditional hotplates and electric coils ranges around 50%, while that of induction stoves typically ranges between around 60% up to around 85%.[16]

For this update/second edition of the Beyond Fire report, two additional cooking appliances are considered: slow cookers, as well as pressure cookers. Electric slow cookers (or so-called rice cookers) have a far lower wattage than either a hot plate or an induction stove, and therefore require less electricity overall. They also have an attractive electricity demand profile, requiring a smaller overall solar PV system in order to operate. Prices for slow cookers range from as little as EUR 10 up to EUR 100 or more, while sizes range from as little as 4 Liters to 12L or more.

Pressure cookers are another cooking appliance considered here: they operate by creating a pressurized environment in which a given meal can be heated, and therefore need to be cooked, over a shorter time period. This kind of long, slow-cooked meal is common in countries throughout Africa, Latin America, and Asia, where grains

[15] Note that the costs for cooking appliances provided by major platforms such as Alibaba and Amazon are misleading, in that they often exclude delivery, transport, and other costs. As such, the prices used in this analysis have been adjusted to reflect these differences. See: http://hot-plates-review.toptenreviews.com/

[16] The efficiency of hot plates and induction stoves has been adjusted downward in this version of the report on the basis of recent evidence of actual electricity consumption of such appliances (see Lovelands 2018 and Wirfs-Brock and Jacobson 2016).

and various forms of beans are frequently cooked over long durations. Due to their higher efficiency, such pressure cookers provide a number of advantages over hot-plates and even induction based stoves. Currently, prices for electric pressure cookers range from EUR 20 to over EUR 100; like slow cookers, the sizes range from as little as 4 Liters up to over 12 Liters.

An overview of the electric appliances featured in this report is provided in Table 6.

Gas based:
these stoves consist of a gas burner that can be supplied with different gas- or liquid-based fuels, including kerosene, LPG, ethanol, biogas, and natural gas. These stoves are widely available in key markets and have a price range of between EUR 20 – 85 (Konga, 2016). The conversion efficiency of natural gas or LPG use when used in a standard gas stove for cooking ranges from 50-60%.

Solid fuel based (wood, dung, pellets, briquettes, and charcoal):
Many households continue to rely on cooking with three stones, positioned to hold a pot directly above the fire or burning coals. Traditional cookstoves range in cost, but most are available for only a few Euros or may be built directly by end-users.

Improved cookstoves, however, have a wider price range, and can be priced at between EUR 5 for basic models and EUR 65 per stove for the most advanced (World Bank 2011). The efficiency of cooking with solid fuels ranges widely depending on a range of factors including how dry the fuel is, the design of the cooking stove, as well as the ambient environment (wind, etc.); it is assumed to range from 5-20% for conventional firewood, and from to 20-50% on the high end for more efficient charcoal and pellet-based stoves.

Next to purchasing the modern cooking equipment, the fuel or energy input costs for each option are critical.

There is limited data available on the costs (and energy demand) of cooking appliances in the African market. Due to the limited market for DC appliances, they are generally more expensive than standard AC appliances (Global LEAP, 2016). However, cost reductions for DC appliances can be expected for the near? future as the market for these products continues to grow. The table below provides an overview of the main categories of electric appliances available as well as the approximate daily energy consumption per household of each different cooking approach:[17]

[17] For conversion factors, see Figure 5 in Part 5 below.


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TABLE 3: BASIC DATA ON COOKING TECHNOLOGIES AND ENERGY USE

Appliance	Cost of the Stove (in EUR)	Watts (Range)	Approximate Daily Household Consumption (in Wh/d for electric options, or in kg/day for solid and gas-based fuels)	Approximate Daily Household Consumption (in MJ)
Three Stones (Wood)	0	N/A	4.15 – 20.76kg/d	68.48 – 342.54MJ
Traditional Cook Stove (Wood)	0 - 5	N/A	3.32 – 8.3kg/d	54.78 – 136.95MJ
Improved Cook Stove (Wood)	5 - 65	N/A	2.08 – 5.53kg/d	34.32 – 91.25MJ
Three Stones (Charcoal)	0	N/A	1.92 – 4.81kg/d	54.72 – 137.09MJ
Traditional Cook Stove (Charcoal)	0 - 10	N/A	1.6 – 4.01kg/d	45.60 – 114.29MJ
Improved Cook Stove (Charcoal)	5 – 65	N/A	1.2 – 2.4kg/d	34.20 – 68.40MJ
Improved Cook Stove (Wood-based Biomass Pellets)	16 – 80	N/A	1.76 – 3.96kg/d	30.41 – 68.43MJ
Improved Cook Stove (Agro-waste Pellets)	16 – 80	N/A	2.42 – 5.44kg/d	30.49 – 68.54MJ
Single Burner Hot Plate	8 - 35	600 – 2000	1200 – 4000 Wh/d	4.32 – 14.40
Induction Hot Plate	45 - 95	1000 – 2300	2000 – 4600 Wh/d	7.20 – 16.56MJ
Slow cooker / rice cooker / crock pot	10 - 130	120 – 300	175 – 700Wh/d	0.63 – 2.52MJ
Electric Pressure Cooker	19 - 140	500 - 1000	160 – 340Wh/d	0.58 – 1.22MJ
Microwave Oven	50 - 100	600 - 1200	100 – 1200 Wh/d	0.36 – 4.32MJ
Gas Stove (single burner)	20 – 60	N/A	0.3kg/d	13.7MJ
Gas Stove (double burner)	30 - 90	N/A	0.3kg/d	13.7MJ
Gas Stove (four burner)	40 - 100	N/A	0.3kg/d	13.7MJ

SOURCES: Atteridge et al. 2013; World Bank 2011; http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,20041&_dad=portal; Lotter et al. 2015; IEA 2006; Various Internet sources and manufacturers for the cooking stoves; note that these prices may differ by location, and may be costlier in certain regions than in others. Assumed energy density ratios: Firewood = 16.5MJ/kg; Charcoal = 28.5MJ/kg; Wood pellets = 17.28MJ/kg; Agro-waste pellets = 12.6MJ/kg; LPG = 45.9MJ/kg. Conversion ratio for electricity = 3.6MJ/kWh.

3.4. Quantifying Annual Cooking-Related Energy Needs

It has been estimated that the total annual cooking-related energy needs per person is 1GJ (Sanga and Jannuzzi 2005; Demierre et al. 2014). This figure of 1GJ per person per year provides the basis for the cost analyses of the firewood and charcoal cooking solutions included in this report. However, in contrast to the first edition, where the 1GJ benchmark was used to provide an apples-to-apples price comparison for all of the different cooking solutions surveyed (except biogas; see Section 4.3), this updated edition adopts a different approach for both the solar home systems (SHS) and the mini-grid based pathways.

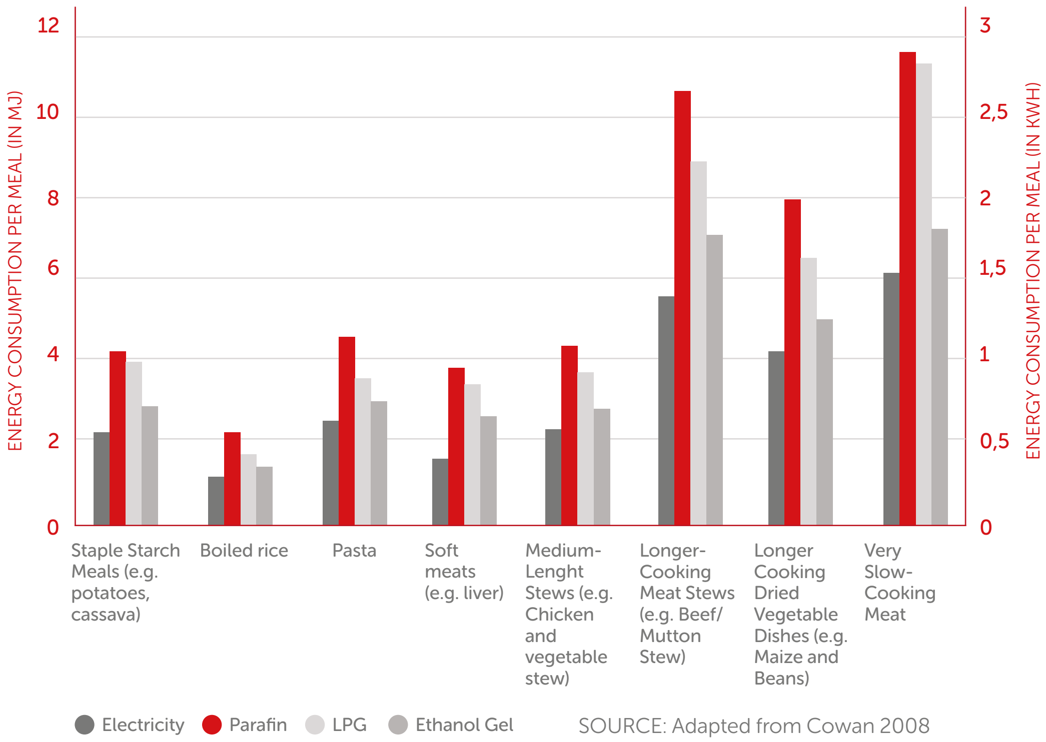
It is important to underscore that for both the firewood and charcoal cases, the 1GJ approach is based on final energy consumption, rather than on primary energy consumption: in other words, it represents 1GJ of final energy use in the process of cooking, rather than the total embodied primary energy of the firewood or charcoal. As such, the actual firewood and charcoal requirements, in terms of volume, were multiplied according to the (in)efficiency of the particular stove type being used (three stones (5-10% efficiency), traditional cookstove (10-20% efficiency) and improved cookstoves (20-50%)

One concern of the 1GJ across-the-board approach is that it ignores the fact that different cooking technologies may in fact require less energy in total to provide a given amount of cooking. While the 1GJ value appears broadly accurate for firewood and charcoal-based technologies, it arguably overstates the amount of cooking energy required to provide electricity-based cooking solutions, namely due to the fact that electric pathways involve much higher efficiency end-use appliances. By increasing the end-use efficiency of the cooking process, including the efficiency of the cooking pot, it is possible to reduce the total energy use of cooking by a factor of roughly 10.

Based on technology-specific assumptions for each of the different cooking pathways examined, it is possible to estimate the total cooking-related energy needs for a wide range of different energy sources and associated cooking appliances.

However, a critical factor remains the average energy-intensity of the meals being cooked. According to Batchelor (2015), the energy required to cook each individual meal varies widely, and will play a significant role in determining the total energy needs (and total system size requirements) for any system equipped to meet this cooking need (see also Diehl et al. 2018). The figure below provides an overview of the main meal types and the total energy requirement to cook them in MJ; what is not specified however is which cooking appliance is used to derive these ranges. Based on the performance characteristics of slow cookers and pressure cookers, it is likely that even the long-cooked meals on the far right can be prepared for less than 1kWh.

FIGURE 5: PER-MEAL ENERGY CONSUMPTION FOR A HOUSEHOLD OF FIVE
(Left Axis = in MJ; Right Axis = kWh)



SOURCE: Adapted from Cowan 2008

Thus, the types, size, as well as the frequency of meals cooked, whether it is cooked at home or professionally (e.g. in a restaurant) will have a significant impact on the total average energy (or electricity) needs in a given village or region, and thus will impact the total system size required (in the case of solar PV or mini-grids). This is one reason why global comparisons of the cooking sector are inherently difficult, as regional differences even within countries are sometimes quite large in terms of the most common meals cooked. As a result, this report relies on broad ranges of energy consumption per household, as well as a range of appliance efficiencies in order to arrive at comparable figures for each of the pathways examined.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4.

MAIN TECHNOLOGICAL PATHWAYS FOR ACHIEVING SUSTAINABLE COOKING

This section will outline a wide range of different potential technological pathways to replace traditional biomass-based cook-stoves, including solar home systems, mini-grids, biogas and power to gas (P2G). **The reason that this report focuses on these technologies as opposed to more common cooking alternatives such as solar cookers and solar water heaters is that they are seen to have greater overall potential to significantly accelerate the transition to sustainable cooking.** Solar cookers and other technologies have a number of limitations, including social, cultural and weather-related, that make it unlikely that they will ever significantly transform cooking behavior. Thus, this report focuses instead on technologies that are believed to have greater long-term viability and scalability.

For each different energy source used to meet cooking needs, there is a range of different cooking appliances, as seen in the table above. As a benchmark, it is helpful to draw on the current ranges for firewood and charcoal:

TABLE 4: ACTUAL COOKING ENERGY DEMAND AND COSTS FOR FIREWOOD AND CHARCOAL[18]

Cooking Fuel	Actual Primary Energy Demand per Person for Electric Cooking (Range in MJ and kg), per person per year	Cost Range of Supplying 1GJ of Cooking Energy	Approximate Cost Range, per person per year
Firewood	2.5 – 20GJ (approximately 151kg – 1212kg)	EUR 2.12 – 9.09	EUR 5.3 – 182
Charcoal	2.5 – 10GJ (approximately 88kg – 351kg)	EUR 3.51 – 14.04	EUR 8.78 – 140.40

[18] Assumptions: Cooking efficiencies range from 5% for the basic three-stones configuration up to 50% for efficient charcoal stoves. Cost of firewood ranges from EUR 0.035/kg (for wood that is simply gathered from the surrounding environment) to EUR 0.15/kg for dried wood. The cost of charcoal ranges from EUR 0.10/kg to EUR 0.40/kg, based on the price range currently seen across sub-Saharan Africa. The energy density of firewood is assumed to be 16.5MJ/kg while that of charcoal is assumed to be 28.5MJ/kg. It is also noteworthy that charcoal prices have been going up rapidly in many of the major markets in sub-Saharan Africa, including Kenya, Tanzania,

TABLE 5: ACTUAL COOKING ENERGY DEMAND AND COSTS FOR SOLAR HOME SYSTEMS USING DIFFERENT COOKING APPLIANCES

Cooking Appliance (actual wattage assumed)	Actual Wattage Modelled	Low Electric Cooking Household (kWh per day)	Average Electric Cooking Household (kWh per day)	High Electric Cooking Household (kWh per day)	Approximate Cost Range per person per year (EUR): 3-year repayment*
Hours of Cooking		**1 Hour/day**	**2 Hours/day**	**4 Hours/day**	
Electric Hot Plate	**2000W**	0.6kWh	1.2kWh	2.4kWh	**110 - 130**
Induction Hot Plate	**1500W**	0.5kWh	1kWh	2kWh	**98 - 115**
Slow Cooker	**190W**	0.178kWh	0.355kWh	0.710kWh	**36 – 43**
Pressure Cooker	**700W**	0.164kWh	0.221kWh	0.334kWh	**43 - 50**

Assumptions: This analysis assumes a solar home system (SHS) equipped to cover strictly the cooking load of the household, not other appliances. A further analysis below provides an overview of the costs of a fully-equipped SHS able to power both standard appliances and cooking. Electric and induction hot plates cycle on-and-off during their cooking period and as such do not use their full rated capacity each hour (see graphs in Table 8 below). Appliance usage based on real field test results and reflect real electricity consumption for a four-hour cooking period. Note that both the slow cooker and the pressure cooker are slightly below their maximum consumption (e.g. for the slow cooker: 190 x 4 = 0.760kWh). This is due to the fact that even on high, such appliances rarely consume their full, maximum rated capacity.

4.1. Solar Home System Pathway

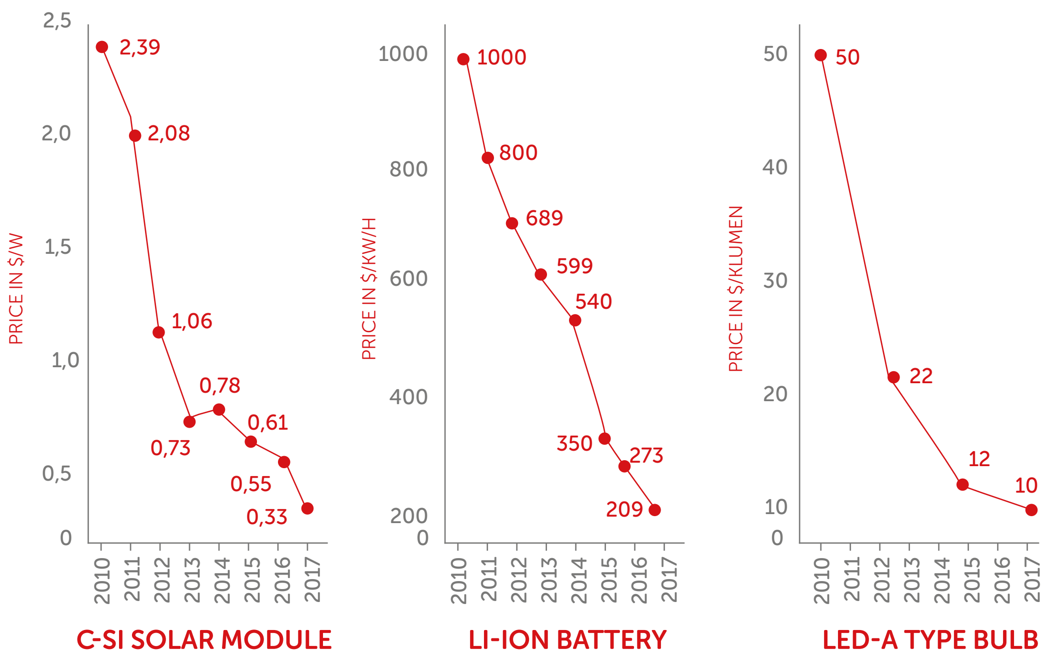
In order to accurately characterize the costs of cooking with electricity from a solar home system, it is necessary to move beyond the metric of 1GJ of cooking energy per person per year based on solid fuels (as assumed in the first edition of this report), largely due to the fact that the actual electricity required to cook depends fundamentally on the actual appliances used. Equally importantly, the total cost of the system will depend on the electricity consumption of the particular appliances: larger, less efficient cooking appliances like hot plates will require a far larger solar array and battery bank in order to enable cooking. These "system-level" cost savings are substantial, and need to be taken into account in order to generate a more accurate picture of how solar home systems could be dimensioned to meet cooking needs.

In the case of firewood and charcoal, it is possible to estimate the impacts of different cooking appliances (traditional cookstoves and improved cookstoves, for instance), by increasing their efficiency. The range of efficiencies assumed for different cooking appliances used with wood and charcoal range from 5% for a three-stones configuration to 50% for the most efficient charcoal stoves used with efficient and well-sized cooking pots.

However, in the case of solar home systems, one of the most decisive factors is the system-level cost savings that can be harnessed by scaling down the total electrical demand requirements of the solar home system. By scaling down the actual demand of the appliances used, it is possible to install a much smaller SHS, saving substantial amounts of money in both the solar array and battery bank required. These cost savings translate directly into a lower cost for the end-user.

A parallel development played an important role in the off-grid solar sector in recent years: while the decline in the cost of solar panels was one aspect that made pay-as-you-go (PAYGO) solar more affordable to end-users in Africa, Asia, and Latin America, an equally important factor was the increasing efficiency of end-use appliances, in particular the increased efficiency of LED lighting technologies.

FIGURE 6: THE COSTS OF SOLAR MODULES, LITHIUM-ION BATTERIES, AND LED LIGHTBULBS



SOURCE: IFC 2018

A similar trend is now poised to redefine the off-grid cooking sector. As the costs of solar and storage systems continue to decline worldwide, combined with the substantial savings that can be unlocked by using high-efficiency end-use appliances like slow cookers and pressure cookers, a new economic reality is dawning: long thought of as unrealistic, even utopian, the idea of cooking with electricity drawn from a stand-alone solar home system is looking increasingly compelling.

Many PAYGO companies operating in Africa and Asia already offer a range of other high-demand appliances to their customers, driven mostly by customer demand. In the process, such companies are starting to dimension systems that can meet not only basic lighting loads and phone charging, but also higher-demand appliances such as refrigerators and television sets. While these SHS packages carry a higher price tag (typically bundled in the form of a higher monthly payment), they are part of a trend that is starting to sweep across Sub-Saharan Africa and parts of Asia as customers start to increase their power demand and start exploring a wider range of productive uses. Such higher demand appliances include battery powered razors for cutting hair in rural villages, sewing machines, and even welding machines. [19]

Against this backdrop, it is time for solar PAYGO companies to start exploring the economics of adding cooking technologies to their product lists, supporting not only electricity access but also access to clean cooking. In this way, PAYGO companies and other stakeholders can start playing a role in driving the transition "beyond fire".

In order to assess the viability of different electric cooking appliances, it is necessary to take a closer look at the actual electricity demand profile of different electric cooking appliances.

In contrast to the first edition of this report that focused on electric hot plates and induction cookstoves, and did not consider the system-level savings of using higher-efficiency end-use appliances, this report broadens the scope to examine four different electric cooking appliances, each with their own unique operational and cost-related characteristics.

[19] For a field trial of a SHS-powered welding kit, see: https://www.youtube.com/watch?v=uIPdbSuzOSw and Nigeria, which may make cleaner alternatives even more attractive in the years ahead. A further factor worth bearing in mind is that the upper end of this cost range (and total firewood or charcoal consumption range) would rarely be reached in practice, as very few households purchase all of their firewood, and even fewer are paying the upper end of the price range at all times.

TABLE 6: OVERVIEW OF FOUR APPLIANCE TYPES

Appliance Type	Wattage Range on the Market	Approximate Cost Range
Electric Hot Plate: Report assumes a 2000W appliance, which is common for large hot plates that would be used with the types of large cooking pots common in Africa, Latin America, and Asia	1000 – 3000W	EUR 5 - 25
Electric Induction Stove: Report assumes a 1500W appliance, which is common for induction stoves currently on the market	1000 – 2000W	EUR 10 – 50
Electric Pressure Cooker: Report assumes a 700W appliance, which is common for pressure cookers available on the market today	500 – 1000W	EUR 30 - 100

It is worth taking a broader look at the advantages and disadvantages of these four appliances before diving into the more detailed cost analysis. Table 7 below highlights the main advantages and challenges of the different cooking appliances surveyed for use with a solar home system.

TABLE 7: SHORT SUMMARY OF PROS AND CONS OF THE FOUR DIFFERENT COOKING APPLIANCE TYPES:

Appliance Type	Pros	Cons
Hot Plate Overall Assessment: Unsuitable for use with SHS due to extremely high demand peak and relatively low efficiency	- Widely available - Low upfront cost for the appliance (EUR 5-10) - Familiar technology to many	- High demand spikes - Highly inefficient - Requires large PV and battery system - Increases wear-and-tear - Higher likelihood of deep discharges, which shortens battery life (esp. for lead acids) - Likely to result in shorter inverter life - Contributes to heating of the household, which is often undesirable in hotter climates
Induction Stove Overall Assessment: Unsuitable for use with SHS due to high demand peak	- Slightly more efficient than a traditional hot plate - Not hot to touch, reducing the risk of fires and/or personal injury	- Less widely available (both induction stoves and pots) - High demand spikes - Inefficient - Requires special cookware, increasing overall upfront costs - Requires large PV and battery system - Higher likelihood of deep discharges, which shortens battery life (esp. for lead acids) - Likely to result in shorter inverter life as well - Contributes to heating of the household, which is often undesirable in hotter climates
Slow Cooker Overall Assessment: Suitable for use with SHS	- Safe, user-friendly appliance (can be opened and closed repeatedly during cooking) - Low electricity demand profile - High efficiency - Suitable for long-cooked meals common in Asia, Latin America and Africa	- May not be suitable for all meal types - Contributes to heating of the household, which is often undesirable in hotter climates
Pressure Cooker Overall Assessment: Suitable for use with SHS	- Safe - Low electricity demand - Electricity demand skewed to the beginning of the pressure cooking cycle, which can occur during the daytime when solar panels are still producing (reduces reliance on the battery system) - High overall energy efficiency - Suitable for long-cooked meals common in Asia, Latin America and Africa - Contributes far less to heating of the household: ideal for hotter climates - Requires far less water than the other cooking appliance types, which may prove an important further advantage in many regions	- Higher upfront cost - Relatively "high-tech": may take time for users to get familiar - May not be suitable for all meal types - Currently limited availability in many regions (e.g. Africa)

Each of these appliances has a fundamentally different electricity demand profile, which has significant impacts on the SHS required.

FIGURE 7: OVERVIEW OF ELECTRICITY CONSUMPTION PROFILES OF DIFFERENT COOKING APPLIANCES (ILLUSTRATIVE)

ELECTRIC HOT PLATE (2000W)

Operating for 14 Minutes on high, and the remaining time on low.

CONSUMPTION AFTER 1-HOUR:

0,600 KWH

ELECTRIC INDUCTION STOVE (1500W)

Operating for 14 Minutes on high, and the remaining time on low.

CONSUMPTION AFTER 1-HOUR:

0.500 KWH

ELECTRIC SLOW COOKER (190W)

perating for 1-hour on high. Note: once it has attained its target temperature, the slow cooker cycles on-and-off to maintain a constant heat level.

CONSUMPTION AFTER 1-HOUR:

0.177 KWH

ELECTRIC PRESSURE COOKER (700W)

Operating for 1-hour. Note: field tests indicate it takes approximately 9 - 10 minutes to reach thepressurized state, after which point the pressure cooker simply cycles with occasional spikes in demand.

CONSUMPTION AFTER 1-HOUR:

0.164 KWH

SOURCE: Own depiction based on a wide range of industry sources, field tests, and academic literature for different appliance types. See Pipattanasomporn et al. 2014; Lovelands 2014; https://www.youtube.com/watch?v=kf6U2N9vySU; https://www.youtube.com/watch?v=mnUwoB4D3RI

For detailed load curves of these cooking appliances, please see Annex.

One remarkable aspect of the demand profiles above is how widely they differ: the slow cooker draws a mere 186W of power compared to the almost 2000W of the hot plate. These differences have significantly implications for the viability of electric cooking using SHS.

After a one-hour cooking period, the pressure cooker uses only slightly over ¼ of the electricity of the electric hot plate. Compared to the other cooking appliances over a 4-hour cooking period, a pressure cooker is twice as efficient as a slow cooker, six times as efficient as an induction stove, and fully 7 times as efficient as an electric hot plate.

Although it is commonly assumed that an appliance with a given wattage (e.g. 2000W) will consume 2000Wh (i.e. 2kWh) if turned on for 1-hour, field tests reveal that this is an inaccurate characterization of the electricity demand profile of cooking appliances. For certain appliances, the conventional logic applies: for instance, a 10W lightbulb will consume 10Wh if left on for 1-hour. However, cooking appliances are not "on" all the time: they cycle on-and-off in rhythms. This is why the demand profiles shown above feature a series of demand spikes.[20]

The table below presents four different SHS, each dimensioned to meet the electricity demand needs of each cooking appliance featured in this report.

[20] For more examples of demand profiles of different households appliances, see: Pipattanasomporn et al. 2014. and Nigeria, which may make cleaner alternatives even more attractive in the years ahead. A further factor worth bearing in mind is that the upper end of this cost range (and total firewood or charcoal consumption range) would rarely be reached in practice, as very few households purchase all of their firewood, and even fewer are paying the upper end of the price range at all times.

TABLE 9: OVERVIEW OF BASIC SOLAR HOME SYSTEM DIMENSIONED FOR COOKING NEEDS, BY APPLIANCE TYPE

Appliance Type	Required Battery size (kWh)	Required PV Module Size (kW)	Solar Home System Price Range (EUR)	Solar Home System Price, Monthly, 3-Year Loan (EUR) - Range	Cost per Person per Day (based on 3-year plan), 5 person household
Electric Hot Plate (2000W)	1.5	0.400	1.400 – 1.650	46 - 54	0.30 – 0.36
Induction Hot Plate (1500W)	1.2	0.300	1.275 – 1.500	41 - 48	0.27 – 0.32
Slow Cooker (190W)	0.45	0.100	450 - 525	15 - 18	0.10 – 0.12
Pressure Cooker (700W)	0.36	0.080	550 - 625	18 - 21	0.12 – 0.14

Note: The cost range for solar home systems is based on the dimensioning of SHS to meet the requirements of each cooking appliance, excluding other major appliances and loads. However, a SHS equipped to meet cooking needs would, due to its size and battery storage capacity, naturally be able to meet other small system loads such as lighting and phone charging without significantly impacting the operation, or the overall cost, of the cooking appliance. In other words, a SHS dimensioned to meet cooking loads is automatically able to support other small ancillary loads like lighting and phone charging. As such, it is difficult to fully isolate the "cost of cooking" from the provision of an electric SHS dimensioned for cooking. Larger loads such as television sets, refrigerators, etc. would, however, likely require a larger system, leading to higher monthly costs. The monthly price ranges are based on SHS PAYGO plans currently available on the market from the major providers (see www.mangoo.org).

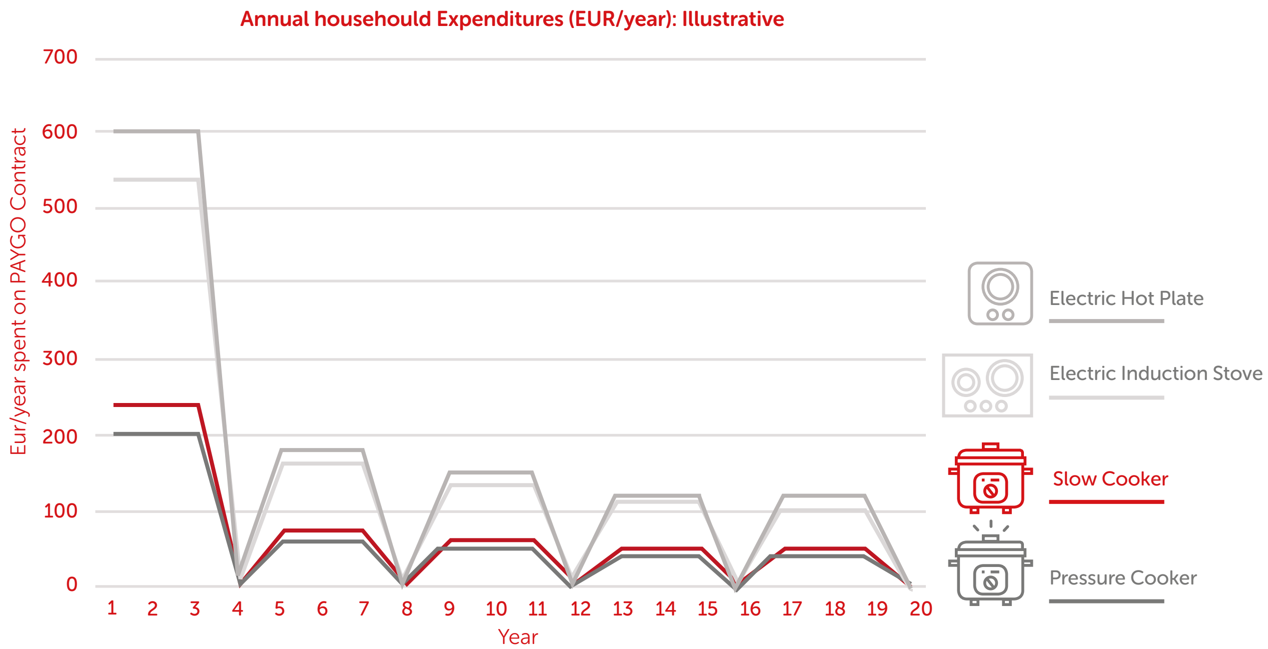
Assuming a household signs a PAYGO contract for a SHS equipped specifically to meet their household cooking needs, the actual household cooking costs fall fully within the range of current firewood and charcoal costs, which range between EUR 0.05 – 0.40 per day (see Figure ES1). This is in many ways remarkable. However, it is important to note that the total upfront cost remains prohibitive for most households, ranging from EUR 450 – 1.650. Thus, **without the availability of PAYGO contracts that enable this high upfront cost to be paid off over a longer period of time, cooking with a SHS would remain well beyond the reach of most off-grid households.**

After the 3-year period, the PAYGO customer owns their own SHS, and would therefore have access to an effectively zero-cost source of cooking. In this sense, PAYGO contracts are effectively lease-to-own contracts (SEforAll, 2017b). No longer having to spend time to gather firewood or make charcoal could free up both time and resources to focus on other things. However, it is common that off-grid SHS need to replace either their inverter or their battery bank (or both) after a period ranging from 3-7 years, depending on customer behavior and overall usage patterns.

While the battery and inverter replacement only represents approximately 30% of the total SHS cost, it is still a fairly substantial cost that the household will have to pay in order to extend the lifetime of their cooking-equipped solar home system. It is therefore critical that a PAYGO or other company remains active in the area to provide this battery and inverter replacement.

Assuming that this battery and inverter replacement can be financed on a similar 3-year plan to the original PAYGO contract, the individual household will have continued access to clean electric cooking, and at a cost that is lower than the original monthly cost of the contract they signed. Figure 7 below provides an overview of how this payment schedule would operate in practice.

FIGURE 8: EVOLUTION OF ANNUAL HOUSEHOLD EXPENDITURES FOR A PAYGO CONTRACT PRE- AND POST-BATTERY AND INVERTER REPLACEMENTS



Assumptions: this depiction assumes that signing a new PAYGO contract strictly for the inverter and battery replacement remains possible and that the battery and inverter will need to be replaced after four (4) years while the other components will have a useful life of 20 years. It also assumes that the combined inverter and battery replacement cost represents 30% of initial CAPEX for the first replacement, 25% of initial CAPEX for the second replacement, and 20% of initial CAPEX thereafter. This lower cost for battery and inverter replacement is assumed in order to anticipate future battery and inverter cost reductions.

As shown here, after the initial PAYGO contract (which financed the entire SHS), **the annual costs drop from a range of EUR 204-600 down to a range of EUR 62 – 180** for the first battery and inverter replacement, depending on the cooking appliance used.

Under these assumptions, the actual "levelized" cost of gaining access to clean cooking via a SHS would be less than the original range shown above of EUR 15 – 54 per household per month. This original range assumed that the entirety of the SHS costs would have to be paid off in three (3) years and that afterwards, the SHS would provide no useful service, cooking or otherwise. Thus, in order to provide a more accurate picture of the "true" costs of cooking with a SHS (including periodic battery and inverter replacements), it is necessary to take the longer asset life into account and to model the effects of replacing the battery and inverter.

TABLE 10: MONTHLY PAYGO CONTRACT COSTS: PRE- AND POST-REPAYMENT (ILLUSTRATIVE)

PAYGO SHS Type, by Appliance	Monthly Cost of 3-year PAYGO Contract (Years 0 – 3), in EUR	Post 3-Year PAYGO Contract (Strictly for Battery and Inverter Replacement) (Years 4 – 6, etc.), in EUR
Electric Hot Plate (2000W)	46 - 54	14 - 16
Induction Hot Plate (1500W)	41 - 48	13 - 15
Slow Cooker (190W)	15 - 18	5 - 6
Pressure Cooker (700W)	18 - 21	6 - 7

Combining the higher initial PAYGO contract cost with the lower battery and inverter-only replacement cost contract, it is possible to provide an indicative levelized or "lifecycle" cost of cooking with a SHS. In other words, if we assume the monthly costs shown above, and sum them over a 20-year period, it is possible to arrive at a total 20-year "spend" on the system (including battery and inverter replacements).

The table below shows the results, assuming that the battery and inverter replacement cost 30% of the initial CAPEX and decline slightly over time for the subsequent replacements. In other words, Table 11 below shows the cumulative household spending that would be required to maintain a functioning electric-based cooking system for an individual home, as well as how that total "life-cycle" spending translates into average annual, monthly, and daily costs. While hypothetical, the resulting daily costs demonstrates just how affordable cooking with SHS can be when analyzed over a longer time horizon than the standard 3-year PAYGO contract.

TABLE 11: AVERAGE LIFECYCLE HOUSEHOLD COSTS (ILLUSTRATIVE)

Total Cumulative 20-year Expenditure on Cooking-equipped PAYGO System	Average Annual Cost	Average Lifecycle Monthly Household Cost	Daily Average Lifecycle Household Cost
EUR 3.510	175.50	14.63	0.48
EUR 3.159	157.95	13.16	0.43
EUR 1.201	60.05	5.00	0.16
EUR 1.404	70.20	5.85	0.19

Assumptions: The first battery and inverter replacement occurs at the end of year 4 and represents 30% of initial CAPEX; the second replacement occurs at the end of year 8 and represents 25% of initial CAPEX; the third and fourth replacements occur in years 12 and 16 and represent 20% of initial CAPEX. These reductions approximate anticipated battery and inverter cost declines.

The table above underscores the importance of ensuring that households that adopt electric cooking have access to a refinancing option for their battery and inverter replacements: being able to do so significantly cuts the average annual cooking cost (versus having to pay the entire PAYGO system off purely to serve three (3) years of a household's cooking needs). **If households can secure such a PAYGO contract for the battery and inverter replacement, their monthly costs after the initial 3-year period drop off significantly from between EUR 15 – 54 per month to between EUR 5 – 16 per month.**

At these costs, cooking with solar emerges as a highly cost-competitive option. As highlighted previously, **the main challenge remains financing the high upfront cost.** Rather than needing to reinvent the wheel, this report suggests that the logical way for this high upfront cost to be financed would be via a PAYGO contract.

A further factor to consider is the **battery lifespan**. How batteries are used, how deeply they are discharged, as well as how they are stored all affect a battery's life span. Perhaps the most important factor is how deeply the battery is discharged each time. As a general rule, for lead-acid batteries, it is best to avoid discharging the battery below 50% of its total available charge. This means that lead-acid batteries operate best, and last longest, when they are sufficiently large to accommodate roughly twice the total daily power demand they will be expected to supply. As a rule of thumb, a lead-acid battery that is discharged to 80% of its charge every day will last half as long as a battery that is only discharged to 50 percent every day.[21]

In this regard, particularly when trying to use high-demand appliances like cooking devices, it is likely to prove advantageous (particularly for systems using lead-acid batteries) to over-dimension the battery bank to minimize the risks of deep discharging. However, adding battery capacity significantly increases the overall system costs.

[21] https://koa.com/blog/what-you-need-to-know-about-your-rv-batteries/

In this regard, it is important to consider which battery technology types (i.e. which battery chemistries) are likely to prove best suited to serving the off-grid cooking sector. The following table shows the pros and cons of the different battery types.

TABLE 12: ADVANTAGES AND DISADVANTAGES OF LEAD-ACID VS. LITHIUM-ION BATTERIES FOR ELECTRIC COOKING

Lead Acid	Lithium-ion
Pros: - Lower cost - Widely in use - Widely available - Relatively reliable - More familiar	**Pros:** - Higher performance - Better at maintaining stable voltage, which improves overall user experience - Less damage caused by deep discharging - Costs, while higher than lead-acid, are declining rapidly - Longer battery life
Cons: - Vulnerable to deep discharging - Mature technology, hence lower potential for significant cost reduction - Can have a short battery life - Sensitive to hotter climates - Polluting - Lack of cost-effective recycling solutions in many countries	**Cons:** - Higher cost - Less widely available in some markets

Based on these few pros and cons, Lithium-ion batteries appear to be a better option and tend to have better performance and longevity; however, they remain more expensive. This is one reason why most PAYGO companies operating in Africa continue to use lead-acid rather than lithium-ion batteries.

Challenges:
There is a wide range of challenges facing the SHS cooking pathway:

High Upfront Capital Cost:
Another commonly cited challenge is the generally high upfront capital cost, which has historically acted as one of the leading barriers to the successful roll out of renewable energy technologies (Jacobs et al. 2016). In addition, the ability to pay for the PV-battery systems sufficiently large to accommodate electric cooking appliances depends fundamentally on the efficiency of the cooking appliances used, as well as the financing conditions available (e.g. via PAYGO providers). Based on current market trends in the SHS sector, the total upfront cost ranges from approximately EUR 450 for a SHS system dimensioned to operate with high efficiency appliances up to EUR

1.650 for a SHS dimensioned for use with inefficient hotplates: given the 3-to-4-fold cost differential between systems dimensioned for use with high efficiency appliances and for the use of either hotplates or induction stoves, attempting to scale-up the market for electric cooking by using the latter types of appliances is deeply ill-advised.

However, it is important to note that even with high-efficiency end-use appliances, the upfront cost barrier remains substantial, particularly for households living on a few dollars per day. Thus, in the absence of well-tailored PAYGO contracts that enable citizens to pay their systems off over time, **the high upfront costs of equipping households with solar and battery systems equipped to meet cooking needs is likely to remain a persistent challenge for the widespread adoption of SHS-based cooking.**

Reversion Risk:
A notable risk remains, however, that if the ongoing operating costs of cooking with electricity remain too high, residents may be inclined (or driven) to revert to relying on traditional cooking fuels instead of continuing to use their SHS for cooking purposes. As long as the costs of electric cooking remain markedly higher than firewood, charcoal, pellets, or other similar options, encouraging rural residents to adopt and stick with electric cooking is likely to prove difficult. Analysis from the World Bank indicates that the displacement rate for solar systems (namely, the rate at which traditional fuels are displaced by the new technology in practice) ranges from 10-40% (World Bank 2014). **Thus, the continued availability of traditional alternatives, combined with the persistence of habits, are likely to continue to pose a significant challenge for SHS-based electric cooking pathways' ability to fully displace reliance on conventional fuels such as firewood and charcoal.**

Shortened Battery Life:
A further challenge is that the use of cooking appliances in SHS can have a negative effect on battery life; the deeper a battery discharges, the shorter its total lifetime and therefore the more often it has to be replaced (IRENA, 2015). Given that battery systems for SHS range can cost several hundred EUR, significantly shortening the battery life can significantly increase overall system costs and increase the risk that citizens simply abandon their systems after the first battery is exhausted (Leach and Oduro 2015). In the case of cooking appliances powered by lead-acid batteries, a deep discharge is likely to occur more frequently due to the high power consumption of hot plates and other cooking appliances.

Lithium-ion batteries are better able to deal with deep discharges, and as such may be better suited for off-grid cooking.

Lack of DC cooking appliances: While there is a growing number of off-grid appliances that run on direct current (DC), at the time of writing the authors have found no major cooking appliances available in DC. This remains a major gap in the market. Using DC appliances is significantly more efficient than having to convert power to alternating current (AC), and helps reduce overall system costs by avoiding the need for an inverter. This could further improve the underlying economics of cooking with electricity.

Cost of Capital:
A further challenge is related to the cost of capital. Naturally, a discount rate of 5% (consistent with subsidy programs by government agencies) leads to significantly lower levelized costs than a discount rate of 20 - 30% (broadly reflecting the return expectations of typical private investors for investments with a similar risk profile in regions such as Sub-Saharan Africa). Keeping the cost of capital low for scaling-up sustainable cooking is likely to remain critical in the years ahead.

Failure or Inability to Internalize Externalities
Another challenge is the fact that the significant external costs of relying on traditional cooking fuels such as firewood and charcoal are rarely if ever fully internalized in the cost of cooking. Moreover, the full internalization of the external costs of cooking with firewood and charcoal arguably remains distant, and may even be unachievable in practice, for at least two key reasons:

- First, unlike electric lighting, or mobile phone charging, **the need to cook constitutes the basis for survival in many parts of the world;** as a result, decision-makers are unlikely, in practice, to impose the full internalization of external costs, as doing so would directly impact the poorest households hardest; in addition, doing so could risk worsening rather than improving human health and development outcomes;

- Second, **the markets for firewood and charcoal are widespread and largely under-regulated**, making it difficult in practice to introduce far-reaching taxes or surcharges to account for human and environmental externalities.

These many challenges notwithstanding, **there are now ample grounds for optimism:** based on the rapid decline in the cost of both batteries and solar PV modules, which have declined by 76% and 82% respectively since 2010, the SHS pathway is likely to become an increasingly cost-effective solution for sustainable renewable energy cooking in rural or peri-urban areas in the future (BNEF 2018). In turn, adopting electric cooking will help free up valuable time that would otherwise be spent gathering firewood that can be used for other, more valuable purposes such as going to school, looking after family, or engaging in other productive or income-generating activities.

Concluding Remarks:
Overall, the cost analysis above shows that **electric cooking is now broadly cost-competitive with traditional cooking technologies such as LPG, firewood and charcoal.** Depending on the system size and the electricity needs for cooking appliances, the costs per household of cooking with a SHS currently range from EUR 5 to EUR 15 per month depending on the specific system configuration and usage patterns (over a 20-year period, with regular inverter and battery replacements). Without factoring in such replacements, the entry-level cost for a SHS equipped to supply cooking needs ranges from EUR 15 – 54 per household per month. **When compared with typical spending per household on traditional cooking fuels of between EUR 1 – 31 per month (World Bank 2014), the relative cost-competitiveness of solar home cooking systems comes clearly into view.**

4.2. Mini-Grid Pathway

TABLE 13: ACTUAL COOKING ENERGY DEMAND AND COSTS FOR MINI-GRIDS USING DIFFERENT APPLIANCE TYPES

Cooking Appliance (actual wattage assumed)	Actual Wattage Modelled	Low Electric Cooking Household (kWh per day)	Average Electric Cooking Household (kWh per day)	High Electric Cooking Household (kWh per day)	Approximate Cost Range per person per year (EUR)*
Hours of Cooking		**1 Hour/day**	**2 Hours/day**	**4 Hours/day**	**Assuming 2 hours per day on average**
Electric Hot Plate	**2000W**	0.6kWh	1.2kWh	2.4kWh	**46 – 77**
Induction Hot Plate	**1500W**	0.5kWh	1kWh	2kWh	**39 – 64**
Slow Cooker	**190W**	0.178kWh	0.355kWh	0.710kWh	**14 – 23**
Pressure Cooker	**700W**	0.164kWh	0.221kWh	0.334kWh	**9 – 14**
Mini-Grid Cost per kWh[22]	**EUR 0.53 – 0.88/kWh**				

*Note that the costs of the mini-grid-based cooking options are somewhat misleading when compared to the SHS costs, because the SHS costs entail a full repayment of the SHS within a three-year (36 month) period. After this period, the SHS itself belongs to the customer; aside from the battery and inverter, most components of the system will continue to last for 15-20 years, if not longer. Batteries and inverters are likely to need replacing every 4-7 years, depending on usage patterns. This means that if the household keeps its SHS operational after year-3, they are likely to benefit from lower "lifecycle" costs, as their total household "cost of cooking" after the three-year period will drop from between EUR 18 – 54 down to approximately EUR 5 – 15, as shown in Table 11. In a mini-grid, by contrast, the monthly household costs are likely to remain at least as high over the mini-grid's life, and may even go up to track inflation, rising operating costs, and other factors.

Mini-grids are responsible for powering millions of rural households around the world (Schnitzer et al. 2014). They involve the use of different technologies to provide power to customers connected via a distribution network and limited to a specific geographic area that is not connected to the central power grid.

Mini-grids can combine many different technologies in order to meet customer demand, and like all power systems, can add new generating capacity over time in order to track demand growth. Like all power systems, however, they also need to generate sufficient revenues in order to cover operating costs in order to be sustainable in the long-term.

[22] RMI 2018

Note that while this section focuses primarily on solar mini-grids, other mini-grid configurations are possible and may provide better system economics depending on the region especially mini-grids based on locally available hydro resources. Other technologies that can be used effectively in a mini-grid configuration include wind power, hydropower, as well as both biomass and biogas-powered systems. However, some of these technologies tend to be more site-specific in their applications and only viable in certain locations (e.g. wind and hydropower), while others like biomass and biogas rely on the continued availability of feed stocks. The need to secure long-term and reliable feed stocks can make it challenging to operate a mini-grid system reliably and sustainably (i.e. over a 10 to 20-year period) while also meeting electricity demand growth within the village or community (Schnitzer et al. 2014). However, each of these technologies can be combined in different configurations to power mini-grid systems that could replace in part or in full the reliance on wood-based fuels for cooking.

Moreover, many residents in countries like South Africa, Nigeria, and Ghana, to name a few, already cook with electric appliances to meet at least a portion of their total cooking needs (Leach and Oduro, 2015). Furthermore, electricity is also a reliable source of energy that can be generated with a wide range of different technologies enabling mini-grids to be customized based on the best or most cost-effective local configurations. Depending on the geographic context and the overall resources available, this might involve different configurations in different markets. While the challenges of maintaining system reliability and operation in a mini-grid system are often more acute due to the smaller number of households, sudden demand peaks, higher operations and maintenance costs, as well as the difficulties associated with maintaining reliability, **there is no inherent technical barrier to electric cooking within mini-grid systems**. As explored further in this section, there may even be a number of advantages for mini-grid operators of encouraging high-efficiency electric cooking.

Current and Projected Costs of Cooking with Electricity from a Mini-Grid

Since each system has unique costs, and faces unique operational and maintenance related challenges over the course of its life (e.g. battery replacement, weather related damages, theft, etc.), it is difficult to definitely calculate the "true" levelized cost of generation from any mini-grid system. A further complicating factor is that the currencies with which power from mini-grid systems is often paid (particularly in developing countries) are often volatile and vulnerable to rapid inflation. Since some of the costs related to the operation of a mini-grid are necessarily borne locally and paid in local currency (such as labor costs, fuel costs for transport, replacement parts, etc.) while some are paid for in international currencies (such as module costs, battery system costs, etc.), each mini-grid is a complex agglomeration of different cost factors, making it difficult to compare the "true" costs of supply between a mini-grid in one country and one in another. As such, this report focuses primarily on cost ranges in order to provide an approximate picture of the costs of mini-grid supply.

For mini-grids, the costs of supply range from as little as EUR 0.20/kWh on the low-end (e.g. for larger mini-grids based on hydropower serving significant populations of several hundred or a few thousand residents that are not too remote) to as much as EUR 1.80/kWh for highly remote systems serving small communities fully reliant on diesel (IEA-RETD 2012).

In this regard, the lower end of the cost range assumed in the first edition of this report (of EUR 0.20/kWh) was unrealistic as it assumed the cost of existing mini-grids operating on a micro-hydro facility. Since the aim of this report is to attempt to calculate the approximate costs of cooking within a newly built solar-powered mini-grids, where the additional cooking loads could help support the mini-grid's economic viability by providing a major new source of demand, a higher cost range of **EUR 0.53/kWh to EUR 0.88/kWh** (USD $0.60 - $1.00/kWh; see RMI 2018) is assumed.

The table below provides a breakdown of the costs of cooking in a mini-grid context for each of the four cooking appliance types:

TABLE 14: DAILY, MONTHLY, ANNUAL COSTS PER PERSON OF COOKING WITHIN A MINI-GRID CONTEXT

Appliance Type	Daily Cost Range per Person, in EUR	Monthly Cost Range per Person, in EUR	Annual Cost Range per Person, in EUR
Electric Hot Plate (2000W)	0.127 – 0.211	3.81 – 6.33	46.25 – 77.09
Induction Hot Plate (1500W)	0.106 – 0.176	3.18 – 5.28	38.54 – 64.24
Slow Cooker (190W)	0.038 – 0.063	1.14 – 1.89	13.73 – 22.88
Pressure Cooker (700W)	0.023 – 0.039	0.69 – 1.17	8.55 - 14.26

As mini-grid costs continue to decline, the attractiveness of encouraging electric cooking in mini-grids will continue to grow. The RMI study cited above indicates that costs could be reduced by more than 50% in the coming 2-3 years with the right policy, regulatory, and market support.

Furthermore, public support (e.g. in the form of end-user subsidies, results-based financing, or access to dedicated financing facilities providing local currency financing, for instance) could help reduce overall mini-grid costs as well, further improving their economics in the years ahead.

Challenges:
This notwithstanding, there is a number of challenges related to meeting cooking needs within a mini-grid:

Substantial Need for Storage:
In order to sustain the large cooking loads, which are often clustered in the early morning hours and the evening hours, the total size of the supply source (whether PV, wind, biomass, hydro, or otherwise), the wiring, the grid ties, as well as the battery system itself must be significantly increased beyond what they would otherwise need to be in a system powering mostly lighting and other small appliances. This is due to the large loads that cooking appliances add to the system, which includes appliances with wattages between 120W – 3000W. Due to the high peak load requirements that characterize mini-grid systems designed to accommodate electric cooking appliances, **the need for storage grows considerably.**

For such mini-grid systems, storage can represent a significant cost factor (Leach and Oduro 2015; EUEI 2015; RMI 2018). However, the costs of storage are widely expected to decline in the years ahead, driven by improved efficiencies, increased investment and R&D, as well as the significant economies of scale due to the rapid growth of batteries in the automotive sector (Lazard 2018; RMI 2018; BNEF 2018). This may help bring the costs down of cooking with electricity within mini-grid systems.

Co-incidence of cooking-related electric demand:
A related problem is **the co-incidence of cooking related electric demand**, which is comprised of dozens if not hundreds of individual appliances (depending on the size of the mini-grid) being turned on and off suddenly; this can put rapid and significant strain on the system's operation and reliability, rapidly depleting battery systems, accelerating wear-and-tear, shortening the mini-grid's overall operating life, increasing maintenance and other related costs, and even forcing the system either to rely frequently on emergency back-up sources, such as diesel, or to shut down completely, interrupting service to the entire community (Schnitzer et al. 2014; EUEI, 2014). Thus, **configuring mini-grid systems to deal with massive synchronous loads (i.e. loads occurring at the approximately the same time of day) such as cooking therefore presents a considerable challenge for any mini-grid pathway to overcome.**

This is one reason why a growing number of mini-grid systems are beginning to make use of automatic feedback systems that provide real-time information to users about the state of the grid and the amount of power left in the battery bank, so that users can modify their usage patterns accordingly (Quetchenbach et al. 2012; Graillot 2015). In order to meet cooking-related needs with electricity in a mini-grid context, such feedback and so-called "load-limiting" technologies are likely to be indispensable. In a recent trial in Bhutan, the use of such technologies reduced the occurrence of brownouts in the system by 92%, which had primarily been caused by the surge in demand caused by electric cooking appliances, (Quetchenbach et al. 2012). Business models are also being developed that provide real-time price signals to end-users that fluctuate widely over the course of the day to provide direct information to end-users and encourage more efficient and system-sensitive behaviors and choices (Easy Smart Grid, 2016).

The difficulties with meeting high synchronous power demand may also be alleviated with the use of pressure cookers in particular. As seen in the previous section, the demand profile of pressure cookers involves high demand for an initial period of roughly 8-10 minutes, followed by much lower power demand thereafter. Since one of the main challenges of operating a mini-grid is meeting high evening demand peaks, any appliances that can help create demand during the daytime (rather than at night) is beneficial. Creating demand especially during the daytime is also one of the many ways in which the economics of mini-grids can be improved, as daytime demand reduces the risk of having to dump excess solar power when the batteries are full, while also creating additional revenues for the mini-grid operator.

For these and other reasons, **pressure cookers emerge as a promising technology for use within mini-grids.**

Shortened Battery Life:
A further challenge that parallels one of the challenges listed above under SHS is the negative effects that high peaks in electricity demand, and deep discharging in particular, can have on battery life (see Section 4.1. above). Given that battery systems represent between 20-30% of mini-grid capital costs, decreasing the operating life of battery units used within a mini-grid system, thereby forcing them to be replaced much more frequently, can have significant impacts on the overall costs of operating the mini-grid and further push up the required tariff levels and/or subsidies required (RMI 2018). Driving tariffs higher is likely to worsen the competitiveness of electric cooking versus other alternatives and further strengthen the incentives for users to revert back to other fuels (see below).

Low Income Levels/Ability to Pay:
As pointed out previously, a further financial challenge is that residents relying on electricity supply from mini-grids are typically in rural or peri-urban areas and typically have low average income levels. This reduces their overall willingness (or ability) to pay for energy services, particularly as many rural residents often struggle to pay for even modest monthly bills for lighting and other basic uses such as radio. Total electricity demand in a rural mini-grid context for a typical household in SSA rarely exceeds 20 - 30kWh/month (EUEI, 2014). Adding cooking loads on top of this would increase household electricity demand by between 25% to over 100% (i.e. by 7 - 36kWh) depending on the appliance used (assuming 2-hours of cooking time per day on average).

While this may still be within many households' ability to pay, given the rapid cost declines seen in solar and battery costs, households' ability to pay may also be constrained by exogenous factors (e.g. droughts), or by the basic cyclicality of harvest time. This is one reason why continuing to focus on bringing costs down further, even in mini-grid contexts where cooking with electricity is effectively cost-competitive, remains important.

Lack of DC cooking appliances:
Similar to the challenges in the SHS sector, there are currently no major cooking appliances available that operate on direct current (DC). This remains a major gap in the market. Using DC appliances is significantly more efficient than having to convert power to alternating current (AC), and helps reduce overall system costs by avoiding the need for an inverter. This could further improve the underlying economics of cooking within a mini-grid context.

Reversion Risk:
A related challenge is that the high cost of cooking with electricity drives residents to revert back to traditional cooking fuels such as firewood and charcoal. For this reason, efforts to expand electric-based cooking in mini-grid systems are likely to seem Sisyphean at first in many communities, as residents continue to opt for traditional solutions over the cleaner but costlier supply provided by electric-based options in order to save money. Alternatively, certain residents may opt to use only electricity for certain specific meals, or purposes. As highlighted previously, one cooking technology rarely if ever fully replaces another, as residents often "stack" cooking solutions upon one another as income levels rise rather than abandoning the old technologies entirely (IEA 2006).

Reversion risk is likely to remain in virtually all mini-grid contexts as multiple cooking technologies continue to co-exist with one another and be preferred by different households for different purposes. Thus, equipping a village with a mini-grid designed to meet cooking loads does not necessarily mean that electric cooking will be the single or even primary mode of cooking used by local residents. As pointed out above, the displacement rate of traditional fuels for households equipped with solar systems for cooking (namely, the extent to which traditional fuels are actually displaced by the new technology) ranges from 10-40% (World Bank 2014).

Concluding Remarks:
Currently, electric cooking based on mini-grids is broadly cost-competitive with firewood and charcoal. Remarkably, this is the case even without internalizing the associated health and environmental costs of cooking with firewood and charcoal. Depending on the size and total electricity demands of the village, the costs per household of cooking with a mini-grid currently range from approximately EUR 4 to EUR 36 per month (assuming 2-hours of cooking per day on average). When compared with typical spending per household on traditional cooking fuels of between EUR 4 – 25 per month, cooking with high efficiency appliances such as slow cookers and pressure cookers is now fully within the

range of affordability for most households. This indicates that mini-grids have tremendous potential to help households reduce their reliance on firewood and charcoal and transition to more sustainable forms of cooking in the years ahead (World Bank 2014).

While there are no inherent technical barriers to electric cooking within mini-grids, a number of important technical and financial challenges remain. On the technical side, dealing with the issue of large, co-incident loads caused by the simultaneous use of cooking appliances throughout a given village or area is likely to continue to pose a considerable challenge for years to come, one requiring both improved electronic interfaces and/or real-time pricing to encourage citizens to respond to the changing scarcity and abundance of electrical energy (stored or otherwise) available in the system. The use of pressure cookers can help in this regard by helping shift a substantial portion of the cooking load to daylight hours, alleviating stress on the system and potentially helping reduce the incidence of power outages or rationing, both of which remain relatively common in mini-grids worldwide.

Given the transformative effects of high-efficiency appliances on reducing the overall electricity demand associated with cooking, it is now possible to imagine a future where a growing number of mini-grid operators start offering (i.e. selling) slow cookers and pressure cookers to village residents themselves, helping create new power demand within the system while also alleviating children and mothers from the time-consuming work of gathering wood and charcoal. With the additional time they have available, many may well start engaging in other activities such as sewing, milling grain, or opening a village shop, all of which can help further accelerate the economic development (and boost electricity demand growth) of the community.

5.

SYNTHESIS AND KEY FINDINGS

In order to transition to truly sustainable cooking, it is necessary to think beyond improved cookstoves and beyond traditional fuels such as firewood and charcoal. The current demographic trends in most regions of the world where reliance on biomass-based fuels is high make continued reliance on biomass-based fuels unsustainable in the medium-term, and arguably impossible in the long-term.

In addition to helping reduce unsustainable rates of deforestation and biomass harvesting, the cooking options presented here can contribute significantly to reducing greenhouse gas emissions in many regions of the world. Indeed, **reducing emissions from the cooking sector must be at the heart of efforts to tackle global climate change**. It can also play an important role in reducing the millions of pre-mature deaths caused by indoor air pollution linked to traditional cooking technologies. Concerted efforts to help rural and peri-urban residents transition away from traditional biomass can therefore contribute to a significantly higher quality of life for millions of citizens around the world.

Furthermore, by freeing up the time of young children and mothers from the burden of gathering and **transporting solid fuels like wood or charcoal, transitioning to sustainable cooking can also help promote future economic prosperity, contribute to reducing gender inequality, all while supporting improved literacy and numeracy in countries around the world.**

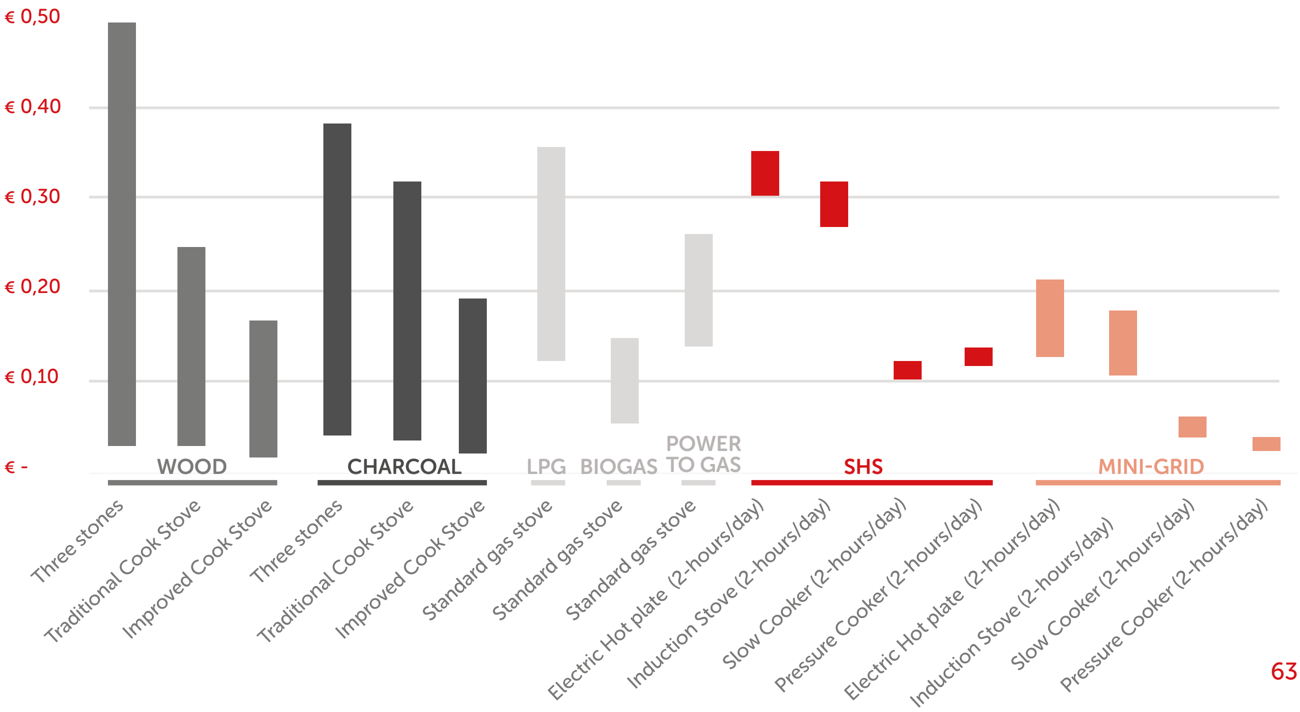
Another key finding of this report is that **focusing on cost alone is insufficient**: policymakers, government officials, and donors should factor in the very real negative externalities (both near-term and long-term) of wood and charcoal use. Doing so would bring far greater attention to the issue of sustainable cooking and demonstrate that even though large-scale interventions in the cooking sector may seem expensive at first glance, the total savings through reduced human and ecological impacts make these investments increasingly urgent, if not necessary. Grasping the sheer magnitude of the negative externalities associated with traditional cooking technologies can help in building the political will required and mobilizing the investments needed.

Based on the cost data gathered and presented above, it is possible to provide a comparative analysis of the different costs for each technology. For firewood, charcoal, **the estimated useful energy used for cooking per person is 1GJ per year,** based on Sanga and Januzzi 2005, and supported more recently by Demierre et al. 2014.

Drawing on this, the figure below provides a summary of current cost ranges, in EUR per person per day, of the various cooking options considered within the report. Note that costs vary largely within each technology category due to the wide range of cost factors, including total system costs, appliance efficiency, user behavior, etc.

While the cost range for the SHS and mini-grid options are narrower, this reflects the fact that the real-world range in solar and mini-grid system costs is smaller than the real-world range for fuel costs. Although important local differences exist in SHS and mini-grid costs between markets, these differences remain smaller proportionally than the differences between fuel costs paid by different users within a given market. Some users produce (or harvest) their fuel themselves, others obtain discounted prices by buying larger quantities of fuel at a time, while others have to purchase it at a premium in small quantities, often from local street-side vendors. This variety of access points for obtaining cooking fuels helps explain why the fuel-based ranges are considerably wider than the ranges for either SHS or mini-grids.

FIGURE 8: COST RANGES OF VARIOUS COOKING TECHNOLOGIES (PER PERSON, PER DAY, IN EUR), 2019



SOURCES: Authors' elaboration, based partly on RMI 2018; BNEF 2018; Leach and Oduro, 2015; Goodwin et al. 2014; GACC 2015; Adkins 2010; Smith et al. 2013; FNR 2016.

Assumptions: The high end of the cost range for all technologies assumes that 100% of cooking needs are met with this technology or fuel source, under the least efficient/most expensive conditions. Cooking efficiencies range from 5% for the basic three-stones configuration up to 50% for efficient charcoal stoves. **Wood:** Cost of firewood ranges from EUR 0.035/kg (for wood that is simply gathered from the surrounding environment, in order to capture the economic value of the time spent gathering wood) to EUR 0.15/kg for dried wood. It is important to note, however, that the upper end of the cost range shown here would rarely ever be attained, as most households gather a portion of their own firewood, and few pay a rate as high as EUR 0.15/kg at all times. The energy conversion rate for wood is assumed to be EUR 60.6kg/GJ, or 16.5MJ/kg. **Charcoal:** The cost of charcoal ranges from EUR 0.10/kg to EUR 0.40/kg, based on the price range currently seen across Sub-Saharan Africa. The energy conversion rate for charcoal is assumed to be 35.1kg/GJ, or 28.5MJ/kg. **Liquefied Petroleum Gas (LPG):** the cost estimates for LPG ranges from EUR 1.2/kg to EUR 3.0/kg, based on prices currently seen across Sub-Saharan Africa. This translates into a cost per GJ ranging from EUR 26.16/GJ to EUR 65.4/GJ. The energy conversion rate of LPG is assumed to be 21.8kg/GJ, or 45.9MJ/kg. **Biogas:** The cost range for a household-sized biogas digester with a production capacity of 6m3 of biogas per day is estimated to range between EUR 400 and 800 per digester unit, plus maintenance costs of EUR 30/year. The methane content of the biogas is assumed to be 60%, which results in an energy density of 23.2MJ/m3. At an average daily production rate of 3m3 per day (50% of its maximum output), this provides a total energy output of 69.6MJ per day. Due to the greater weight of biogas compared to methane (1.15kg/m3 for biogas vs. 0.75kg/m3 for pure methane), the resulting energy density of biogas is calculated at 20.2MJ/kg. The biogas system operating life is estimated at 10 years. The modeling assumes an interest rate of 15% with no upfront payment, structured over a 10-year amortization period. This results in a monthly cost of between EUR 8,31 and EUR 21,79 (including maintenance costs), and assumes a steady operation of the system over its useful life including the use of appropriate feed stocks, continuous access to water to maintain proper system functioning, etc. Although households do occasionally pay to obtain the necessary feed stocks, it is assumed here that feed stocks as well as water are gathered from the surrounding environment and are therefore free. Note that based on the estimated energy needs per person (1GJ/person/year), a biogas system producing 3m3 per day would actually produce significantly more than the total daily household needs. **Power to Gas (P2G):** the cost estimates for P2G range from 29.2EUR/GJ to roughly 50EUR/GJ. The energy conversion rate of methane produced via P2G is assumed to be 21.8kg/GJ, or 45.9MJ/kg. **Solar Home Systems (SHS):** The cost range for solar home systems is based on the dimensioning of SHS to meet the requirements of each cooking appliance, excluding other major appliances and loads. The monthly price ranges are based on SHS PAYGO plans currently being offered on the market by the major providers (see www.mangoo.org). The energy conversion rate is 277.7kWh per GJ, or 3.6MJ/kWh. **Mini-grids:** the estimated levelized generation cost range for mini-grids ranges from EUR 0.53 to 0.88/kWh, depending on the system size, configuration, as well as the associated operation and maintenance costs (RMI 2018). The energy conversion rate is 277.7kWh per GJ, or 3.6MJ/kWh.

TABLE 15: SUMMARY TABLE

Energy Source	Cooking Appliance Used	Conversion efficiency of cooking appliance (range)	Actual primary energy demand per person per year (in GJ)	Cost per person per day (in EUR) (Low)	Cost per person per day (in EUR) (High)	Actual primary energy demand per house-hold per year (in GJ)	Cost range per year per house-hold (in EUR) (Low)	Cost range per house-h¬¬¬¬-old per year (in EUR) (High)
Wood/ Dung	Three Stones	5-20%	5 - 20GJ	0.029	0.498	25 - 100 GJ	53.03	909.00
	Traditional Cook Stove	10-25%	4 - 10GJ	0.023	0.249	20 - 50GJ	42.42	454.50
	Improved Cook Stove	15-40%	2.5 - 6.66GJ	0.015	0.166	12.5 - 33.3GJ	26.51	302.70
Charcoal	Three Stones	10-25%	4 - 10GJ	0.038	0.385	20 - 50GJ	70.20	702.00
	Traditional Cook Stove	12-30%	3.33 - 8.33GJ	0.032	0.320	16.65 -41.67GJ	58.44	584.77
	Improved Cook Stove	20-50%	2 - 5GJ	0.019	0.192	12.5 - 25GJ	35.10	351.00
LPG	Standard gas stove	50 - 60%	1.67 - 2GJ	0.120	0.358	8.33 - 10GJ	218.30	653.59
Biogas	Standard gas stove	50-60%	1.67-2GJ	0.055	0.150	8.33 - 10GJ	99.70	261.50
Power to Gas	Standard gas stove	50-60%	1.67-2GJ	0.140	0.270	8.33 - 10GJ	248.00	500.00
Electricity (SHS)	Electric hot plate	N/A	1.58GJ	0.302	0.355	7.9GJ	552.00	648.00
	Electric induction stove	N/A	1.31GJ	0.270	0.316	6.55GJ	492.00	576.00
	Slow Cooker	N/A	0.47GJ	0.099	0.118	2.35GJ	180.00	216.00
	Pressure Cooker	N/A	0.29GJ	0.118	0.138	1.45GJ	216.00	252.00

Electricity (Mini-Grid)	Electric hot plate	N/A	1.58GJ	0.127	0.211	7.9GJ	231.26	385.44
	Electric induction stove	N/A	1.31GJ	0.106	0.176	6.55GJ	192.72	321.20
	Slow Cooker	N/A	0.47GJ	0.038	0.063	2.35GJ	68.64	114.40
	Pressure Cooker	N/A	0.29GJ	0.023	0.039	1.45GJ	42.77	71.28

Assumptions: The cost range shown for both SHS and Mini-grids is based on providing two hours per day of cooking energy, 365 days per day.

The findings for the two different pathways examined here can be summarized as follows:[23]

Solar Home Systems: When combined with high-efficiency end-use appliances like slow cookers or pressure cookers, solar home systems (SHS) provide a viable path-way to support the transition to sustainable cooking. As the costs of SHS components continue to decline, notably solar panels and batteries, SHS will become even more affordable for households in rural and peri-urban areas. This report finds that based on currently available technologies and current cost ranges, **the cost of cook-ing with a SHS ranges from EUR 0.10 – EUR 0.32 per person per day, or from EUR 14.85 to EUR 53.25 per household per month for a five-person home**, depending on the specific technologies used, the size of the household, the efficiency of the appliances, etc. On an annual basis, **this works out to between EUR 180 and 648 per household per year to meet their cooking needs** (assuming 2-hours of cook-ing per day, 365 days a year) during the initial 3-year PAYGO contract period. Note that when high-efficiency appliances like slow cookers and pressure cookers are used, the actual annual costs would be toward the lower end of this range.

After this initial period (typically 3 years), **establishing a secondary PAYGO contract to refinance the battery and inverter replacement enables the household's monthly costs to drop further down to between EUR 62 – 180 per household per year**, depending on the cooking appliances used. Assuming that most households (and PAYGO companies) will prefer to use either slow cookers or pressure cookers, this brings the costs of cooking down to well within the range of what the average household in SSA currently spends on cooking, which is estimated by the World Bank to range between EUR 12 – 372 per year (around EUR 1 – 31 per month) (World Bank 2014).

Like with virtually sustainable energy tech-nologies, the high upfront costs remain one of the key barriers to widespread adoption. However, combined with the rise of PAYGO business models that help reduce the high upfront cost and enable customers to pay for their systems on monthly basis, a future

[23] Note that in the first edition of this report, both biogas and power-to-gas options were examined in more detail. This report has updated both the solar home system and mini-grid costs due primarily to the significant cost declines that have occurred in solar and storage technologies in recent years, as well as to highlight the many advantages of higher-efficiency cooking appliances such as slow cookers and pressure cookers.

where solar powered cooking becomes widespread may not be far off.

Mini-grids: mini-grids is a category that includes a wide range of different generation technologies that can be combined together to meet the needs of a given village or community, typically in rural or peri-urban regions. This report focuses on mini-grids powered by renewable energy (RE) sources. Meeting cooking needs with mini-grids is found to be more cost-effective than with SHS, at an **estimated cost range of EUR 0.02 – 0.21 per person per day**, depending on the technologies used, the size of the village, the efficiency of the appliances used, etc.

However, adding dozens if not hundreds of high-wattage cooking appliances within a mini-grid, with wattages ranging from 1000W to 3000W for single and double-burner hotplates or electric coils, generates a range of additional challenges.

Since most cooking is done at the same times of day (namely in the early morning and early evening hours), this can create massive peaks in electric demand and in total peak capacity, which can negatively impact mini-grid functioning, reduce reliability, increase operations and maintenance costs, and even induce black-outs (Graillot, 2012). As a result of these and other related challenges, this report finds that appliances like electric pressure cookers are particularly well-suited to cooking in mini-grid contexts as they consume the majority of their power at the beginning of the cooking cycle, which for many households occurs during the mid-to-late afternoon when the sun is still shining, and electricity demand within the mini-grid as a whole remains quite low. As such, pressure cookers in particular are likely to be much easier to scale-up within both new and existing mini-grids around the world.

Governments and donors seeking to support mini-grids equipped to meet cooking needs could assist by providing grants or direct co-financing, as is often done within rural electrification strategies, with subsidies awarded on a per-person or per-household basis (i.e. results-based financing). Such targeted co-financing can bring down the total system costs and help make sustainable cooking solutions even more affordable by reducing the upfront cost barrier. A related approach would be for governments and donors to finance demonstration projects that can help prove the overall technical viability of sustainable mini-grid based cooking solutions while identifying any further issues and challenges that need to be overcome.

Despite these challenges, cooking with either a slow cooker or a pressure cooker in a mini-grid context emerges as a very cost-competitive option. **At a cost of between EUR 3.45 and EUR 31.65 per household per month, it is mirrors almost exactly what the World Bank estimates to be the cost range of what a typical household currently spends on firewood and/or charcoal**, namely between EUR 1 and EUR 31/month (World Bank 2014).

In light of the many downside of traditional fuels such as firewood and charcoal, which 1) are becoming increasingly expensive in many regions, 2) tend to be costlier for the poorest households due to smaller individual purchases, and 3) which impose a tremendous burden on human health and the quality of life of millions, combined with the declining costs of electric-based cooking options, **the multiplicity of benefits of transitioning beyond fire is becoming increasingly difficult to ignore.**

*

The high upfront cost of switching to alternatives is perhaps the most widely cited challenge to the transition to cleaner cooking solutions (IFC 2012; World Bank 2011; World Bank 2014; Leach and Oduro, 2015); overcoming this challenge is therefore critical. As the examples of Tanzania and Uganda cited earlier show, the upfront cost of adopting new technologies is decisive: the willingness to invest in more expensive stoves dropped precipitously when the price rose from USD $10 per unit to $17.5 per unit (Adkins et al. 2010).

Interventions in the cooking sector must therefore be designed to recognize the key role of cultural and behavioral factors in accelerating or slowing down the rate of adoption of cleaner cooking technologies. Ultimately, efforts to promote more sustainable cooking technologies will not work unless accompanied by corresponding behavior change in the targeted populations (World Bank 2014; Goodwin et al. 2014; Atteridge et al. 2013; Brown et al. 2017).

Thus, whatever business model is used to help drive the scale-up of a new technology, be it SHS, renewable mini-grids, LPG or P2G, it has to make the new cooking pathway affordable from the outset, which is likely to involve amortizing the cost of the technology into small, affordable payments, such as in pay-as-you-go structures. And in the early years, **scaling-up sustainable cooking is going to require significant and sustained investment, including from governments, donors, and other international agencies active in the sector.** More local currency financing in particularly is critical, as much of the cooking market is transacted in small denominations using local currencies.

It is commonly argued that the lack of finance is a critical barrier to the uptake of new technologies in regions like Sub-Saharan Africa (IEA 2014). While the scale of the financing need is undoubtedly significant, such large investments are increasingly drawing the attention of traditional investors such as pension funds and sovereign wealth funds, which are increasingly eager to invest in businesses (or business models) that contribute to long-term sustainability. With the right level of both public and political support, it is undoubtedly possible to mobilize billions to tackle the challenge of sustainable cooking – what is needed is concerted policy attention, combined with dedicated long-term financial support, and critically, the political will needed to make sustainable cooking a reality.

Against the backdrop of broader global objectives, especially the UN's Sustainable Development Goal 7, as well as the COP21 Agreement reached in Paris in December 2015, the challenge to transition to alternative modes of cooking may not be as insurmountable as it once seemed.[24]

[24] See UNEP (2015). "The Financial System We Need: Aligning the Financial System with Sustainable Development," Available at: http://apps.unep.org/publications/index.php?option=com_pub&task=download&file=011830_en ; UNFCCC 2015, Available at: https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

6.

BEYOND FIRE:
6 STEPS TO ACHIEVE SUSTAINABLE COOKING

This report closes by outlining a list of six (6) concrete measures that policymakers, investors, donor organizations, and governments can take to accelerate the transition to sustainable cooking:

Beyond Fire: 6 Steps to Achieve Sustainable Cooking

1. Governments need to set clear goals to transition away from firewood and charcoal.

The current energy strategies being developed by national governments and donor community for most of Africa and Asia are not doing enough to drive a meaningful transition toward sustainable cooking solutions. Current strategies still largely focus on improved cookstoves and the build-out of LPG infrastructure, failing to recognize the tremendous potential of alternative cooking solutions such as renewable electricity. By focusing largely on improved cookstoves, the international community might contribute to further entrenching technological path dependencies which might be a barrier for the de-carbonization of the cooking sector in the long-run. In order to make meaningful progress toward sustainable cooking, governments and donors will need to commit to far more ambitious goals, including clear strategies, more research on behavioral, cultural, and willingness-to-pay issues, as well as financing resources.

2. Stakeholders spanning governments, foundations, donors, investors and others involved in financing projects in the cooking sector need to allocate more resources to support the availability of pay-as-you-go (PAYGO) contracts.

Such contracts convert the high upfront cost of investments into smaller, more affordable payments that can be made on a regular basis (e.g. monthly or bi-monthly). A greater focus on providing affordable consumer finance, including more local currency financing and longer loan tenors, is critical to support the transition toward sustainable cooking.

3. Governments should introduce policies and incentives to reduce upfront costs.

This can involve targeted grants to encourage adoption and foster economies of scale; it can also involve other policies to help bridge the cost gap, such as "feebates" (e.g. additional fees on certain items such as air conditioning units or automobiles that are allocated to support rebates on other technologies, in this case, sustainable cooking technologies); a further approach might involve the targeted use of tax or duty exemptions, such as those frequently offered on solar PV components, or on high-efficiency cooking appliances such as electric pressure cookers. These measures may be combined with other legal and regulatory measures, such as restrictions on charcoal use and distribution.

4. Governments should undertake root-and-branch reform of fossil fuel subsidies, which often benefit middle and upper-income residents, and re-allocate them to support a rapid scale-up in sustainable cooking technologies.

In contrast to existing fossil fuel subsidies around the world, which tend primarily to benefit citizens with medium to high income levels, targeted support for sustainable cooking technologies tend, by default, to support lower income households. Re-allocating fossil fuel subsidies to accelerate the transition toward sustainable cooking would bring massive and lasting benefits to sustainable development, and would contribute significantly to re-balancing the major inequities that continue to persist between urban and rural regions. Reforming fossil fuel subsidies and re-allocating the proceeds to support sustainable cooking is perhaps one of the single most impactful steps that governments around the world can take to accelerate the transition.

5. Governments and donors around the world need to fund a greater range of R&D projects, including projects to demonstrate the viability of sustainable cooking solutions. Such initiatives could *focus specifically on providing further analysis of cooking with different electric appliances such as slow cookers, pressure cookers and even infrared cookers,[25] analysis of the behavioral and cultural acceptance of slow cookers and pressure cookers, as well as to support the scale-up of new business models in the cooking sector.*

These kinds of projects can be extremely valuable in order to gather cost and performance data, analyze behavioral and other challenges, while driving further technological innovation and cost reduction. Moreover, strategically supporting the emergence of new business models can help give rise to replicable, scalable projects at various points of the cooking value-chain. Skepticism of alternative cooking solutions remains high, not least among end-users: one of the best ways to overcome this is first to demonstrate their viability, and then to help drive technological improvement and cost reduction by expanding the market, and improving the mechanisms of delivery.

6. International climate finance should be mobilized to play a far greater and more direct role in supporting the transition to sustainable cooking, including through innovative mechanisms such as the Green Climate Fund and the wider use of climate bonds.

Scaling up sustainable cooking represents one of the most significant opportunities worldwide to generate major climate change mitigation and adaptation "win-wins": reducing reliance on traditional fuels such as firewood and charcoal, improving human health, while helping to preserve forest ecosystems and improve (or maintain) overall ecosystem resilience. New financing mechanisms such as climate bonds could significantly expand the volume of capital flowing to the sector, and yield wide-ranging benefits for both local citizens and the global climate.

In light of the estimated EUR $110 Billion in annual costs to human health, to the environment, and to local economies caused by the use of solid fuels like wood and charcoal for cooking (GACC 2016), it is finally time that the transition to sustainable cooking be given the priority it deserves. Although this transition is still in its infancy in many parts of the world, there are promising signs that the technical and business model innovations are already available to make the transition possible worldwide. With sufficient political will at the highest levels, combined with appropriate financial resources, it is indeed possible to imagine a world that has truly and finally evolved "beyond fire".

[25] While this report does not look specifically at infrared cookers, they remain another potentially interesting cooking technology for certain applications.

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