Electric cooking in Rwanda: an actor-network map and analysis of a nascent socio-technical innovation system

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Executive summary

UK Aid wishes to promote modern energy cooking services in the Global South and is funding a multi-partner programme of activities – the Modern Energy Cooking Services (MECS) Programme – led by Loughborough University in the UK to help achieve its ambitions. The MECS Programme, as a whole, encompasses several modern energy carriers that can be used for cooking, such as liquified petroleum gas, ethanol, biogas and electricity. Of these carriers, historically, electricity has enjoyed little attention in attempts to promote modern energy cooking services in the Global South and so the MECS Programme is something of a pioneer in this respect. Together with the global push that is increasing access to electricity and a convergence of several technological advances in, amongst others, energy storage, ICT-enabled payment systems, and cost and efficiency improvements in electricity-generating technologies such as solar PV, cooking with electricity is becoming economically and technically feasible for a much wider group of people in the Global South than has been the case.

Electric cooking (e-cooking) has the potential to realise a number of benefits, including but not limited to cleaner household air, lower cooking costs, shorter cooking times, less deforestation, reduced greenhouse gas emissions (if the electricity is generated from renewable energies) and some improved gender-equity outcomes. Furthermore, there is the potential to nurture local production of e-cooking appliances and related technologies that could contribute to the industrialisation ambitions of Global South countries. In short, e-cooking has the potential to contribute to progress in achieving several of the UN's Sustainable Development Goals. None of these benefits is guaranteed. But the chances of success will be raised, we would argue, by fostering what we call socio-technical innovation systems (STISs) that are centred on relevant e-cooking technologies. Fostering these e-cooking STISs can in part be achieved by bringing together the STISs that currently exist around electricity access (e.g., in solar PV) and around clean(er) cooking that, to date, have largely been unconnected. But work will also need to be done to nurture the nexus of these two systems, especially in terms of the social practices specific to e-cooking that may be, to varying degrees, novel in many contexts at present.

In this paper, we report findings from our project in which we characterise the STIS around e-cooking in Rwanda. The 'map' consists of visualisations of the actor-networks and actor-relations in the system along with elaborations on who the actors are, the extent and nature of their interactions, sketches of significant projects, and discussion of emerging issues relevant to the further development of the innovation system. It also includes some summary attention to the system's context and enabling environment. Based on this characterisation, we conduct a STIS analysis to determine the system's strengths and weaknesses, and we derive several recommendations we argue the MECS Programme could implement to further its aims more effectively.

Our STIS concept has been developed using insights from several academic literatures that share a common interest in understanding how technology and innovation interact interdependently with society to produce the social and technical systems upon which we rely for meeting human development needs. The concept refers to the complex configuration of several elements including a variety of actors, their capabilities and relationships, core technologies, policy context, and social practices (especially those

involving the core technologies). Within this complex of interacting and interdependent elements, we see the diffusion of technologies and other innovations. And, depending on the nature of the interactions among the elements, we can also see further technological development and new innovations emerge.

A strong and well-functioning socio-technical innovation system can help a country enjoy more of the economic added value of technologies and innovations, as well as use its mastery of a technology to gain more control over its own development direction. Insights from the broad field of innovation studies show that new technologies, innovations, markets, and their associated systems need to be protected while they are developed and nurtured; they are likely to fail if exposed too quickly to 'market forces' and will face resistance or hostility from those interests that stand to lose if they succeed. A significant set of ideas in the innovation studies field has given rise to the strategic niche management approach or 'niche theory'. Developed in tandem with numerous historical studies of how new technologies have become widely adopted and adapted, niche theory points to the imperative of protection (as we noted above) and the development and growth of diverse networks of actors around a specific technology, among other evolutionary dynamics. Translated into policy-relevant terms, niche theory tells us that active public interventions are crucial for the eventual success of innovations, especially where they must disrupt a dominant technology. A specific example closely relevant to the promotion of modern energy cooking services is the development of the solar PV markets in East Africa. These markets have become successful through deliberate and active long-term public interventions. The combination of these insights forms our STIS concept.

Applying this concept to e-cooking in Rwanda, we find there is currently only a very small number of actors working with e-cooking technologies – in particular, electric pressure cookers (EPCs). The e-cooking STIS is in its earliest stages of emergence. Nevertheless, this core set of actors is enthusiastic and optimistic about the potential for EPCs to play an important role in clean cooking in Rwanda and these actors are involved in small trials with these appliances, trials that should yield crucial evidence on EPC viability and attractiveness in the Rwandan context. Considering that the e-cooking STIS is still so young, that the overwhelming cooking practice in Rwanda centres on the burning of biomass in simple stoves, and that the policy effort is predominantly focussed on promoting cleaner fuel-based options, there are many challenges facing the promotion of e-cooking and a number of uncertainties about the direction an e-cooking STIS could take. But there are also promising developments and conditions. Electricity access has expanded significantly in Rwanda in recent years, donors and development actors are taking the clean cooking challenge much more seriously along with providing significant levels of funding, finance and technical assistance, and the clean cooking policy environment is opening up to the possibility of e-cooking. Assessing these various challenges, opportunities and changing conditions, we argue that the MECS Programme, and other e-cooking advocates, should employ a strategy to promote e-cooking that starts with targeting wealthier grid-connected and mainly urban households (although there may be opportunities among households connected to rural mini-grids). These households are more likely to adopt e-cooking practice in the short term, albeit most likely in a fuel-stacking form, but can be an important ally in the efforts to refine e-cooking appliances, begin broadening the network of e-cooking actors, help to craft persuasive e-cooking narratives, and act as demonstrators of the practicalities of cooking with

electricity. Together with several other activities, e-cooking advocates can thus begin to systematically develop the STIS in the short term with a view to its expansion thereafter.

Having discussed our assessment of the nascent e-cooking STIS in Rwanda, we finish this summary with some recommendations for the MECS Programme. It is possible that MECS is already pursuing some or all of these recommendations. But we offer them here in any case.

1. **Focus e-cooking efforts for now on wealthier grid-connected households**

   The MECS Programme and other electric cooking advocates in Rwanda could first focus on a strategy of targeting wealthier grid-connected households with e-cooking interventions, generating evidence on e-cooking costs, social practices and the kinds of values and meanings with which e-cooking can resonate. The experimentation needed to generate this evidence will help to build and stabilise the nascent e-cooking STIS.

2. **Move to research and development with more vulnerable households once the e-cooking STIS has begun to stabilise**

   As the e-cooking STIS strengthens and begins to stabilise, research and development among the more vulnerable households in Rwanda – especially those in Ubudehe 1 to 3 (or their equivalent once the new categorisation is operational) – to explore conditions for electric cooking adoption would be useful to make a business case for why other development partners and the private sector should invest in these segments. Other initiatives offer significant subsidies to vulnerable households, and so there may be an opportunity now to explore how households can rapidly rise through the energy access tiers.

3. **Enhance efforts to coordinate the emerging e-cooking STIS**

   The e-cooking STIS needs coordination, as currently there are fragmented activities implemented by different actors, with information-sharing happening mostly at an informal level. There is a lack of awareness of the capabilities that different actors bring to the STIS, and the possibilities for collaboration and interaction.

4. **Investigate the potential to develop EPC and other manufacturing capabilities in Rwanda**

   There is a need to develop the manufacturing capabilities in Rwanda to enable the development of homegrown e-cooking appliances that align to local conditions: e.g., cultural practices, language, literacy and infrastructural constraints. There is evidence some local capabilities related to traditional pressure cooking could be built upon, technical capabilities could be developed by local training institutions, and there are enthusiastic actors interested in local manufacture.

5. **Improve and further develop the evidence base on e-cooking in Rwanda**

   There is a significant lack of accessible and usable evidence on the Rwandan clean cooking sector in general. E-cooking advocates could help mobilise an evidence base and disseminate knowledge broadly in order to inform actor strategies and attract more investment.

6. **Strengthen intra-regional interactions amongst e-cooking advocates and promote a more coordinated approach to regional policy**

   There is positive preliminary evidence of Rwandan enterprises interacting with other actors across the border in e-cooking initiatives through, for example, sourcing of appliances. E-cooking advocates such as MECS could deepen and encourage such interactions. Further, working with others across the East Africa region would draw on their experiences with e-cooking, especially in terms of how ordinary citizens are adopting the technologies and practices, but also in terms of persuading actors at the regional policy level to coordinate their policy support for e-cooking.

Contents

Abbreviations and acronyms

A2EI	Access to Energy Institute
ACE-ESD	African Center of Excellence in Energy for Sustainable Development
ACTS	African Centre for Technology Studies
BEST	Biomass Energy Strategy
BMZ	German Federal Ministry for Economic Cooperation and Development
BRD	Rwanda Development Bank
CMU	Carnegie Mellon University
CST	College of Science and Technology
CSU	Colorado State University
DFID	UK Department for International Development
DGIS	Netherlands Directorate for Development Cooperation
E4I	Energy 4 Impact
EAC	East African Community
EAQIP	Rwanda Energy Access and Quality Improvement Project
EARP	Electricity Access Rollout Program
e-cooking	Electric cooking
EDCL	Energy Development Corporation Limited
EDPRS	Economic Development and Poverty Reduction Strategy
EEP	Energy and Environment Partnership
EnDev	Energizing Development
EPC	Electric Pressure Cooker
EPD	Energy Private Developers association
ESMAP	Energy Sector Management Assistance Program
ESSP	Energy Sector Strategic Plan
EUCL	Energy Utility Corporation Limited
FCDO	Foreign, Commonwealth and Development Office (Department for International Development was absorbed into the Foreign and Commonwealth Office)
GIIH	Grid Innovation and Incubation Hub
GIZ	Gesellschaft für Internationale Zusammenarbeit
GoR	Government of Rwanda
GVEP	Global Village Energy Partnership
ICS	Improved Cookstove
KIST	Kigali Institute for Science and Technology
LEAP	Global Lighting and Energy Access Partnership
LEAP-RE	Long-term Europe-Africa Partnership on Renewable Energy
LPG	Liquified Petroleum Gas

MECS	Modern Energy Cooking Services Programme
MFA	Norwegian Ministry of Foreign Affairs
MINECOFIN	Ministry of Finance and Economic Planning
MINICOM	Ministry of Trade and Industry
MININFRA	Ministry of Infrastructure
NBP	National Biomass Programme
NDF	Nordic Development Fund
NGO	Non-Governmental Organisation
NST	National Strategy for Transformation
PayGo	Pay-as-you-go
Pinnsmap	Participatory innovations system map
PIPA	Participatory Impact Pathways Analysis
RBF	Results-Based Finance
RDB	Rwanda Development Board
ReCIC	Reducing climate impact of cooking in Rwanda through improved cooking energy systems
REG	Rwanda Energy Group
REMA	Rwanda Environment Management Authority
REP	Rwanda Energy Policy
RSB	Rwanda Standards Board
RURA	Rwanda Utilities Regulatory Authority
SDC	Swiss Agency for Development and Cooperation
SDG	Sustainable Development Goal
SE4All	Sustainable Energy for All
SHS	Solar Home System
Sida	Swedish International Development Cooperation Agency
SNV	Netherlands Development Corporation
STIS	Socio-technical innovation system
UNHCR	UN High Commissioner for Refugees
USAID	US Agency for International Development

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1 Introduction

UK Aid wishes to promote modern energy cooking services in the Global South and is funding[1] a multi-partner programme of activities – the Modern Energy Cooking Services (MECS) Programme[2] – led by Loughborough University in the UK to help achieve its ambitions. The MECS Programme, as a whole, encompasses several modern energy carriers that can be used for cooking, such as liquified petroleum gas (LPG), ethanol, biogas and electricity. Of these carriers, historically, electricity has enjoyed little attention in attempts to promote modern energy cooking services in the Global South and so the MECS Programme is something of a pioneer in this respect. Together with the global push that is increasing access to electricity and a convergence of several technological advances in, amongst others, energy storage, ICT-enabled payment systems, and cost and efficiency improvements in electricity-generating technologies such as solar photovoltaics (solar PV), cooking with electricity is becoming economically and technically feasible for a much wider group of people in the Global South than has been the case (Batchelor et al., 2018).

Electric cooking (e-cooking) has the potential to realise a number of benefits, including but not limited to cleaner household air, lower cooking costs, shorter cooking times, less deforestation, reduced greenhouse gas emissions (if the electricity is generated from renewable energies) and some improved gender-equity outcomes. Furthermore, there is the potential to nurture local production of e-cooking appliances and related technologies that could contribute to the industrialisation ambitions of Global South countries. In short, e-cooking has the potential to contribute to progress in achieving several of the UN's Sustainable Development Goals (SDGs). None of these benefits is guaranteed. But the chances of success will be raised, we would argue, by fostering what we call socio-technical innovation systems (STISs) (defined below) that are centred on relevant e-cooking technologies. Fostering these e-cooking STISs can in part be achieved by bringing together the STISs that currently exist around electricity access (e.g., in solar PV) and around clean(er) cooking that, to date, have largely been unconnected. But work will also need to be done to nurture the nexus of these two systems, especially in terms of the social practices specific to e-cooking that may be, to varying degrees, novel in many contexts at present.

In this paper, we report findings from our project, funded by the MECS Programme, in which we characterise the STIS around e-cooking in Rwanda. Two sibling papers report our findings for the e-cooking STISs in Kenya and Tanzania (Byrne, Onsongo, Onjala, Chengo, et al., 2020; Byrne, Onsongo, Onjala, Fodio Todd, et al., 2020). We mention these papers at this point because they share some common text. Consequently, those who have read one or both of the sibling papers may prefer to skip Section 2, as the presentation of the analytical foundations and methodology is similar to the text in these papers, apart from the specifics of how we conducted our workshops online[3] compared with the in-person work for

[1] The level of funding was reduced during 2021 as part of the cut to the UK Aid budget.

[2] See the MECS website for more information https://mecs.org.uk/about/ (accessed 12 July 2020)

[3] The workshops for the Kenyan and Tanzanian research were conducted prior to the onset of the Covid-19 pandemic.

Kenya and Tanzania. Otherwise, the text here is mostly specific to e-cooking in Rwanda. In the rest of this introduction, we explain the nature and purpose of our e-cooking STIS characterisation (or 'map'), define briefly what we mean by the term *socio-technical innovation system*, argue why it is important to develop a STIS understanding of e-cooking in Rwanda, and preview our main findings. We finish the introduction with an outline description of the paper.

This paper provides a first attempt to map several characteristics of Rwanda's e-cooking STIS. The 'map' consists of visualisations of the actor-networks and actor-relations in the system along with elaborations on who the actors are, the extent and nature of their interactions, sketches of significant projects, and discussion of emerging issues relevant to the further development of the innovation system. It also includes some summary attention to the context and enabling environment of the e-cooking STIS. Based on this characterisation, we conduct a STIS analysis to determine the system's strengths and weaknesses and, building on this analysis, derive several recommendations we argue the MECS Programme (or others with similar ambitions) could implement to further their aims more effectively. Readers should take note, however, that the characterisation is only a snapshot of the current system and so the recommendations should be seen as open to further refinement in light of any further research that may be conducted.

Before arguing why it is important to understand a STIS, we should define what we mean by this term. More detailed discussion of the concept is given in Section 2.1, but we provide a brief definition here. It has been developed using insights from several academic literatures that share a common interest in understanding how technology and innovation interact interdependently with society to produce the social and technical systems upon which we rely for meeting human development needs. The concept refers to the complex configuration of several elements including a variety of actors, their capabilities and relationships, core technologies, policy context, and social practices (especially those involving the core technologies). Within this complex of interacting and interdependent elements, we see the diffusion of technologies and other innovations. And, depending on the nature of the interactions among the elements, we can also see further technological development and new innovations emerge. Beyond this, it is possible and often desirable to attend to the broader context of competing or dominant technologies and practices, environmental pressures and the politics of change (from the micro-politics of changing practices to the 'higher' politics around national and international interests). The current paper focusses only on a snapshot characterisation of the e-cooking STIS in Rwanda and so is concerned with the actors, their capabilities and relations, the core technologies, policies and social practices.

It is important to understand the complex configuration we are calling a STIS because such a system is essential for helping a country direct and achieve its self-defined development goals. These goals include economic growth and development as well as more socially oriented goals such as equality and justice along with environmental integrity. In short, a well-functioning STIS can contribute positively to achieving a wide range of SDGs. A narrower analytical focus, such as on economics and technology – which is often the case in the literature on energy access (e.g., see Watson et al., 2012) – can only take us so far. Analysing the economics of a specific technology, for example, is of limited value in showing us how to foster the conditions for the widespread adoption of that technology, and is unable to provide recommendations for how to develop the capabilities needed to further develop the technology or, indeed, how to innovate

completely new solutions. An economics focus is also unable to consider the complex interactions across the many dimensions of social and technical systems that enable those systems to endure, despite the availability of what might be 'superior' technologies or innovations (e.g., sustainable energy technologies, gender-equal practices, healthy work environments).

We need more complex analyses from which we are then able to nurture the STISs required for successful adoption and diffusion of new or unfamiliar technologies and innovations, which are often in need themselves of adapting to new environments, and for building the actor-networks and capabilities needed to move beyond simply using existing technologies. A strong and well-functioning innovation system can help a country to enjoy more of the economic added value of technologies and innovations, as well as use its mastery of a technology to gain more control over its own development direction. Left to free markets, technology design and production, for example, will take place wherever there are already well-functioning appropriate STISs, which are generally in the most industrially advanced countries, even if the technology is then adopted widely in those countries that are less industrially developed (which typically are poorer). Contrary to free market orthodoxy, new technologies, innovations, markets, and their associated systems need to be protected while they are developed and nurtured; they are likely to fail if exposed too quickly to 'market forces' and will face resistance or hostility from those interests that stand to lose if they succeed.

These general insights have arisen over many decades from the broad field of innovation studies, a field initially developed to understand why more traditional economics approaches could not fully explain a nation's economic growth. Early work in the innovation studies field generated the basic notion of a national system of innovation (e.g. see Freeman, 1987, 1997; Lundvall, 1988). But other work over the past two decades has widened the scope of analysis to include sociological insights (e.g. Geels, 2002) and ideas centred on knowledge politics (e.g. Leach et al., 2010), among many other influences. A significant set of ideas, inspired by evolutionary theory and the kinds of sources just mentioned, has given rise to strategic niche management or 'niche theory'. Developed in tandem with numerous historical studies of how new technologies have become widely adopted and adapted, niche theory points to the imperative of protection (as we noted above) and the development and growth of diverse networks of actors around a specific technology, among other evolutionary dynamics. Translated into policy-relevant terms, niche theory tells us that active public interventions are crucial for the eventual success of new technologies, especially where they must disrupt a dominant technology. A specific example closely relevant to the promotion of modern energy cooking services is the development and growth of the solar PV markets in East Africa (Byrne, 2011; Ockwell et al., 2019, 2021; Ockwell & Byrne, 2017). These markets have become successful not through free market orthodoxy but through deliberate and active long-term public interventions, an approach that continues. The combination of these insights forms our STIS concept, the specifics of which are further explained in Section 2.1.

Applying this concept to e-cooking in Rwanda, we find there is currently only a very small number of actors working with e-cooking technologies – in particular, electric pressure cookers (EPCs). The e-cooking STIS is in its earliest stages of emergence. Nevertheless, this core set of actors is enthusiastic and optimistic about the potential for EPCs to play an important role in clean cooking in Rwanda and these actors are involved in small trials with these appliances, trials that should yield crucial evidence on EPC viability and

attractiveness in the Rwandan context. Considering that the e-cooking STIS is still so young, that the overwhelming cooking practice in Rwanda centres on the burning of biomass in simple stoves, and that the policy effort is predominantly focussed on promoting cleaner fuel-based options, there are many challenges facing the promotion of e-cooking and a number of uncertainties about the direction an e-cooking STIS could take. But there are also promising developments and conditions. Electricity access has expanded significantly in Rwanda in recent years, donors and development actors are taking the clean cooking challenge much more seriously along with providing significant levels of funding, finance and technical assistance, and the clean cooking policy environment is opening up to the possibility of e-cooking. Assessing these various challenges, opportunities and changing conditions, we argue that the MECS Programme, and other e-cooking advocates, should employ a strategy to promote e-cooking that starts with targeting wealthier grid-connected and mainly urban households (although there may be opportunities among households connected to rural mini-grids). These households are more likely to adopt e-cooking practice in the short term, albeit most likely in a fuel-stacking form, but can be an important ally in the efforts to refine e-cooking appliances, begin broadening the network of e-cooking actors, help to craft persuasive e-cooking narratives, and act as demonstrators of the practicalities of cooking with electricity. Together with several other activities, e-cooking advocates can thus begin to systematically develop the STIS in the short term with a view to its expansion thereafter.

The paper continues with Section 2, which briefly explains the STIS concept and analytical framework we use as well as describing the study's methodology. Section 3 provides a summary of the context for e-cooking in Rwanda. In Section 4, we report the findings from our primary research, characterising the various elements of the e-cooking STIS in Rwanda as it currently stands. We analyse the system in Section 5 and finish the paper by giving our recommendations for the MECS Programme (and other actors with similar ambitions) in Section 6.

2 Analytical foundations and methodology

2.1 Socio-technical innovation system analysis

The objective of the discussion in this section is to describe the elements of the analytical framework we use to assess the state of play in the current e-cooking STIS in Rwanda. It is from this assessment, provided in Section 5, that we aim to offer thoughts on how the e-cooking STIS could be nurtured, strengthened and evolved to help achieve transformations in clean cooking that work in the interests of poor and marginalised groups in particular. As such, although this section may be of use to those interested in the conceptual and theoretical foundations of the STIS approach, the discussion is primarily intended to help readers understand why we take this approach and what we present in the rest of the paper. Our discussion is, therefore, necessarily brief, summarising conceptual and theoretical work done elsewhere, rather than a full and critical review of the conceptual foundations, and detailed arguments in support, of our approach.

The conceptual underpinnings for the STIS approach originate from various streams of theory including, most notably, the STEPS pathways approach (e.g. Leach et al., 2010), transitions theory (e.g. Geels, 2002, 2004), strategic niche management (Byrne, 2011; Raven, 2005) and innovation systems (e.g. Chaminade et al., 2009; Freeman, 1997; Lundvall, 1992). And a fuller exposition of the STIS approach can be found in Ockwell and Byrne (2016, 2017). We define a STIS in terms that go beyond the more traditional understanding of "innovation system", an understanding that refers to the "network of actors, and the strength and nature of the relationships between them, from which both innovation and technological change emerge" (Ockwell & Byrne, 2017, p. 25). Our extended concept draws from the socio-technical literatures mentioned above (pathways, transitions and niche theory) to incorporate the socio-technical nature of innovation and technological change. That is, our concept includes attention to the co-productive interactions between innovations and the social practices of actors (policymakers, firms, non-governmental organisations, ordinary citizens, and so on), as well as the politics of socio-technical change.

The traditional concept of an innovation system, defined in the preceding paragraph, remains important in our enhanced STIS concept, although our enhanced concept expands the range of actors involved. In the traditional version, the actors of interest are firms and policymakers. Firms each have specific capabilities (skills and knowledge) they use to innovate, which can include creating and developing technologies and production processes, evolving the management of stakeholder relations, and implementing new marketing strategies (OECD/Eurostat, 2019). Policymakers set the policy environment in which firms operate, conditioning what kinds of innovation are possible, what is illegal, and so on, and setting and enforcing the regulatory regime for, amongst other issues, private property protection. Relationships between these various actors are also important because, for example, individual firms are unlikely to be able to perform all the activities necessary to produce a specific technological product or service. They will buy components from other firms, assemble these components, manufacture others, combine services, etc., and sell to customers who may be other firms or so-called final users. In some cases, firms will collaborate with other firms to produce technologies or services. The network of actors is therefore a key

characteristic of any specific innovation system, including how actors are connected to each other and the nature of their interactions.

Although this traditional innovation system concept is useful for certain kinds of analysis, it is entirely technical in its focus and so is blind to the social, cultural, political and ecological dynamics that co-evolve with technical change (Ockwell & Byrne, 2017). Understanding how these other co-evolutionary dynamics work interdependently with technical change to produce the systems that service human needs is important because they influence the direction any system takes as it develops. For example, in response to climate change, we need systems to develop in directions that rely on renewable energy sources. But steering systems away from fossil fuel-based reliance is difficult because of the interdependent relationships between, amongst others, powerful political and economic interests, and established infrastructures of energy generation, storage and distribution. And, looking to what might be described by many as the 'demand side' of these systems, social practices such as car-based mobility, linked with cultural values such as freedom and independence, further stabilise existing social and technical configurations. These social practices, it is important to note, are not just individual behaviours. Rather, as Shove et al. (2012, p. 12) explain the concept of practices[4], we take the notion to be the active combination of materials, competences and meanings that are "embedded in the details of daily life". Materials include technologies and other tangible physical stuff; competences include skills and know-how; meanings include ideas and aspirations (Shove et al., 2012, p. 14). Especially important for our analysis of how to promote innovations that are adopted into everyday practice (as e-cooking appliances might), Shove et al. (p. 12) argue that:

> In so far as desires, competencies and materials change as practices evolve, there are no technical innovations without innovations in practice. In other words, if new strategies and solutions in product or service development are to take hold, they have to become embedded in the details of daily life and through that the ordering of society.

This argument points strongly to the significance of how 'supply side' actors understand the practices they are trying to change – such as promote e-cooking practice in place of traditional cooking practice – as their understanding of a practice can have an important bearing on the kinds of technical innovations they develop. Socio-technical perspectives can enable us to incorporate these different dimensions into analysis, seeking to generate insights useful for guiding our social systems (socio-technical systems) in more sustainable directions. We adopt these socio-technical ambitions in our enhanced concept: hence the use of the term *socio-technical innovation systems*.

In sum, we use several categories to analyse what is happening in any STIS. We need to know which technologies are centrally involved in the system, which actors are involved, how these actors relate to each other (actor-networks), details of the policy environment, what 'supply-side' actors understand about 'demand-side' social practices, what direction the system is taking, and what broader dynamics are at work.

[4] Shove and others prefer to use the word "practice" rather than "social practice" as they would argue that the concept of practice is social by definition. Given this, the use of "social" is redundant.

We also need to understand something about what actors envisage the system will be and why, which links strongly with the direction the system is taking or could take. This brings us to the role of discourse and narratives in shaping a system's directionality. Narratives are important in several respects. They can justify and motivate specific kinds of action, they can mobilise others to join in with these specific actions, they can persuade others to act in particular ways – e.g., policymakers to provide resources for action, customers to buy particular products or services rather than others – and can shape identities around which groups of actors can coalesce (e.g. Byrne et al., 2018; Hudson & Leftwich, 2014; Leach et al., 2010). In short, narratives do essential political work. For analysis, we can also use narratives to infer what actors understand about the system in which they are working or the system they are trying to create. Table 1 summarises these analytical categories. Characterising the specifics of each of these categories to the extent possible provides the basis for an integrated analysis of a STIS, its strengths and weaknesses, and ways in which it could be improved. In turn, this provides the basis for recommendations, whether for policy or practice.

Table 1: Socio-technical innovation system analytical categories

Category	Description
Central technologies	The main technologies towards which actors in the system will focus their innovation efforts
Actors	Who is involved in the innovation efforts in the system: potentially, the full range of actors, not just firms and policymakers but also NGOs, communities, households, private individuals
Actor-network	The ways in which the actors interrelate: what connections they have with each other, the nature of those connections
Policy environment	The range of policies (and regulations, laws, etc.) that can influence the system, including beyond the national level
System directionality	The trajectory of system change: e.g., growing or shrinking use of electric pressure cookers; mainstreaming or marginalising electric cooking
Social practices	The social practices of relevance, especially how these are understood by 'supply-side' actors
Broader dynamics	Various forces that can influence what is possible, desirable, and so on in system development: e.g., climate change translates to pressure to reduce emissions
Narratives	The narratives at work in the system, used to mobilise, motivate, persuade, argue, contest, etc., on issues relevant to system change

2.2 Methodology

For the studies on e-cooking that we have already published on the MECS website (Byrne, Onsongo, Onjala, Chengo, et al., 2020; Byrne, Onsongo, Onjala, Fodio Todd, et al., 2020), primary research began with a day-

long in-person workshop in each of the two countries, Kenya and Tanzania. However, by the time we were able to start work on the Rwanda case, the COVID-19 pandemic response meant strict lockdowns were being implemented in many countries, severely limiting international travel and in-person meetings between people outside of household groups. This forced us to postpone our planned Rwanda workshop until we had more clarity about how the pandemic was likely to unfold. When it became clear the pandemic was unlikely to subside enough to enable safe international travel and an in-person workshop, we decided to explore ways in which we could conduct an online version of the participatory innovation system mapping – Pinnsmapping – method we used previously in Nairobi and Dar es Salaam (see the two papers cited above for more on the original Pinnsmapping method).

In developing an online version of the method, our intention was to maintain the participatory quality of the previous two in-person workshops. We decided that a single two-hour[5] online event involving twenty or more people would not be conducive to deep participation and so designed the encounters as a series of smaller events, each one a two-hour workshop. The workshops were conducted using the Zoom videoconferencing platform alongside Google's Jamboard, used to develop the Pinnsmap itself. Jamboard was chosen because of its simplicity compared with other online whiteboard applications, which meant little time was lost explaining the functionality of the tool.

Planning for the workshops not only involved designing an online format (see below for more details) but also involved identifying and selecting participants from a range of stakeholder groups who would have some interest in, and knowledge about, e-cooking in Rwanda along with others who would have deep knowledge about clean cooking in general in Rwanda, as well as actors who would know about electrification and about the relevant policy environment in the country. The process of identifying participants involved reference to the databases of contacts held by ACTS[6] and the African Center of Excellence in Energy for Sustainable Development[7] (ACE-ESD), consultations with Jon Leary[8], Iwona Bisaga[9] and Bridget Menyeh[10], some snowballing through those identified from these sources, and the project team's additional desk-based research. Selection was based on maximising the depth and range of

[5] The Pinnsmapping portion of the in-person workshops took about two hours.

[6] ACTS were a research partner in project work foundational to the MECS Programme – Low cost energy-efficient products for the bottom of the pyramid, see http://www.sussex.ac.uk/spru/research/projects/lct (accessed 22 June 2020) – and so already had relevant contacts with knowledge about clean cooking in East Africa.

[7] ACE-ESD is based at the University of Rwanda (see https://aceesd.ur.ac.rw/, accessed 28 May 2021) and was the local collaborator for this study.

[8] Jon Leary, a researcher in the broader MECS Programme, has spent extended periods of time working in e-cooking in Kenya and Tanzania, and has extensive contacts in clean cooking across the East Africa region.

[9] Iwona Bisaga has worked in electricity access and clean cooking in Rwanda for several years, first with the company Bboxx and currently with the MECS Programme.

[10] Bridget Menyeh is the MECS Programme link researcher for Rwanda and has worked in the past on clean cooking.

knowledge and perspectives available to us in the workshops. Including members of the project team and ACE-ESD, a total of 19 people took part in the workshops. A list of the online workshop participants is given in Annex III.

Each online workshop was focussed slightly differently to the others such that they built upon each other as we progressed through the series. We conducted three workshops, the first of which involved just three participants selected both for their knowledge of the Rwandan clean cooking space and their closeness to our project. The closeness to our project was important as the first workshop was to some extent a test-run of the online format, and so we needed participants who would be forgiving of any teething troubles that may arise in the experiment.

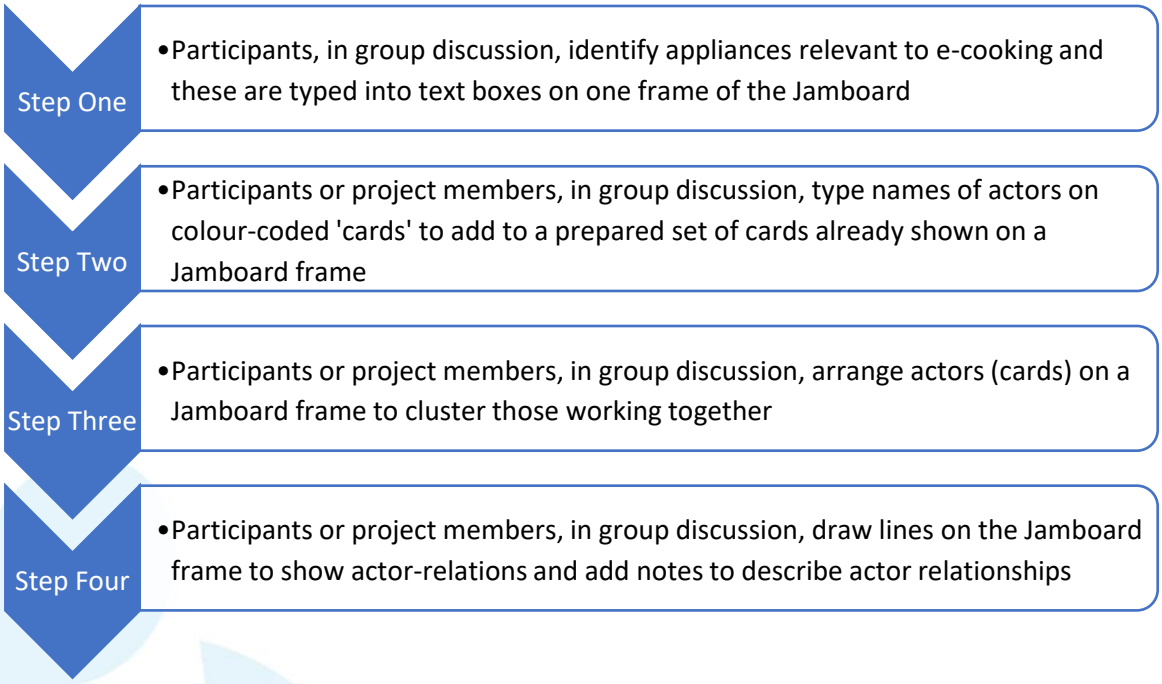


Figure 1: Pinnsmapping steps

Figure 1 shows the basic steps in the Pinnsmapping process. Step one involved the participants identifying the appliances they thought relevant to electric cooking (i.e., not just EPCs but also, for example, electric kettles, rice cookers, and many others). These appliances were recorded on the Jamboard tool using text boxes. For step two, the participants were asked to view a set of prepared ‘cards’ depicting actors our own exploratory research suggested may be relevant to e-cooking in Rwanda, including those directly engaged with e-cooking, those in clean cooking more widely, and others in electrification and in the policy environment. Participants were then asked to add more actors they thought relevant or suggest such actors for the project team to add. One actor was named per card, with the cards colour-coded according

to broad stakeholder groups[11] (i.e., non-profit organisations and civil society, academic institutions, funding agencies, private sector, and regulators and public institutions). Step three involved arranging the actors (cards) so that those working closely together were clustered on the map (to the extent possible), achieved through a process of group discussion during which more actor names were added and the nature of various actor-relations began to emerge. Step four involved drawing lines on the map to show the connections between actors and marking these lines with short notes to indicate the nature of the connections and relationships.

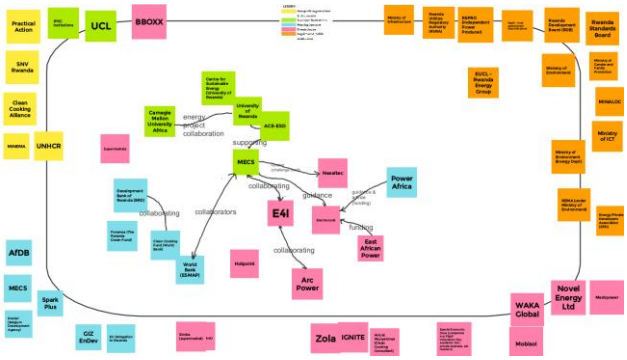
The outputs of the first workshop were an initial list of e-cooking appliances available in Rwanda and a first draft, or baseline, of the Pinnsmap. Participants in the subsequent workshops were then taken through the outputs already developed in prior workshops, given the opportunity to amend those outputs, and given space in which to further develop specific parts of the evolving map. Although the participants were free to use the Jamboard directly themselves, they generally opted to discuss changes to the Pinnsmap and make suggestions, which one of the project team then reflected in the map. All workshops were recorded on Zoom so that we could capture the detail of discussions between participants during each step of the process. The Jamboard version of the Pinnsmap was then replicated in a cleaner and clearer version and presented as a PDF. This PDF was then used in follow-up interviews (also online) with a selection of those who participated in the online workshops and others who had either been unable to attend any of the online workshops, or who had been identified during workshop discussions and follow-up interviews as being important to consult.

Our Pinnsmapping method for this case study is, therefore, a further adaptation of our original mapping exercise, which itself was an adaptation of the STEPS Centre tool *Participatory Impact Pathways Analysis* (PIPA) (Ely & Oxley, 2014) based on a process developed by Boru Douthwaite and colleagues (e.g. see Douthwaite et al., 2009). The final version of the Pinnsmap for the Rwanda case is shown in Section 4.2 while Figure 2 shows the evolution of the Pinnsmap across the workshops as developed on Jamboard. Although it is not easy to read the text in the images from the Jamboard iterations in Figure 2, it is possible to see that the evolution of the map involved capturing an increasing number of actors and their relationships.

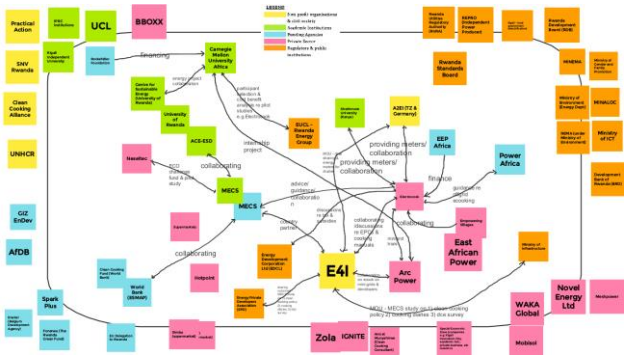
The first workshop, as noted, focussed on developing a 'baseline' map by giving primary consideration to identifying those directly involved with e-cooking. For the second workshop, the Pinnsmapping focus broadened to include not only e-cooking actors but also clean cooking more generally and electrification. The third workshop broadened further to include some actors in the policy environment.

[11] The stakeholder groups were different to the categories used in the Pinnsmapping for Kenya and Tanzania as Jamboard has a more limited range of colours with which to work compared with the physical cards used for the workshops in Nairobi and Dar es Salaam.

Workshop 1 Jamboard



Workshop 2 Jamboard



Workshop 3 Jamboard

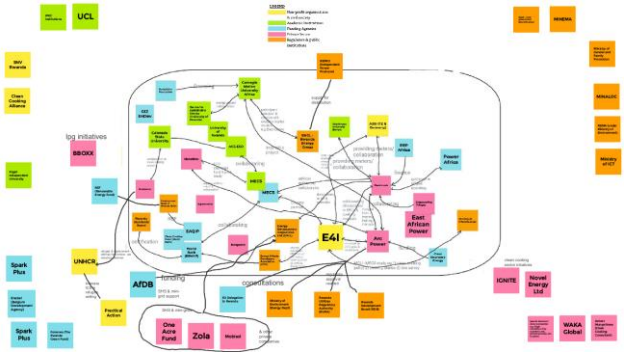


Figure 2: Evolution of the Pinnsmap across three online workshops using Google Jamboard

In the period following the workshops, semi-structured interviews with 15 individuals from 10 organisations were conducted (see the Annex I for the generic version of the questionnaire and Annex II for a list of those interviewed). Because of the COVID-19 restrictions, interviews were conducted virtually using Zoom and recorded. During the interviews, respondents described their organisation and its projects or initiatives in e-cooking, clean cooking, electrification and/or policymaking, the partnerships or collaborations it was involved in, the cooking technologies and fuels on which it was focussed, and its

evaluation of the e-cooking innovation system as a whole. Most of the interviews included a section devoted to the Pinnsmap, during which respondents were shown the draft map and asked to comment on its accuracy. Based on these comments, the draft map was adjusted to produce the version shown in Section 4.2. All interviews also included a question on policy, not just those interviews with policymakers, and this, together with analysis of secondary sources, formed the basis for the context discussion developed in Section 3.

We analysed the information in a series of project-team virtual 'write-shops', in between which we drafted various sections of the text, with designated team members leading specific sections. We used the analytical framework discussed in Section 2.1 above and summarised in Table 1. Triangulation of the evidence involved cross-reference between the workshop material, follow-up interviews and, where available, secondary sources. For the final draft of the text, one author copy-edited the entire paper.

3 The context of e-cooking in Rwanda

3.1 General comments on the Rwandan e-cooking context

Rwanda has enjoyed high economic growth since the 2000s, attracting investment from many bilateral and multilateral development partners and the private sector. It has also developed a strong regulatory and policy environment that has entailed the reform of a range of sectors. In the energy sector, reform has been managed by the Ministry of Infrastructure (MININFRA) since 2015. The energy sector is considered of key strategic value for the Government of Rwanda (GoR) given its important role in the development of the national economy. Significant progress has been made with electricity access advancing rapidly across Rwanda over the course of the last decade both on and off-grid, leveraging the support of the private sector and donors and facilitated by exploiting the energy resources available to the country from solar, peat, gas, biomass, geothermal and hydropower (Hakizimana et al., 2016). Universal access is targeted for 2024.

Reducing the extensive use of biomass, especially firewood – the overwhelmingly dominant fuel used in Rwandan households – is a central ambition of the Government as set out in the Biomass Energy Strategy[12], mainly for environmental and health reasons. Only a tiny minority of the population currently uses alternative cooking fuels and technologies and most rely on traditional biomass stoves. Much of the clean cooking focus so far has been on improved cookstoves (ICSs) and improving thermal efficiency, although recent initiatives such as the forthcoming Rwanda National LPG Master Plan, commissioned by MININFRA, indicate that greater weight is being given to modern energy to reach these ambitious targets. However, given that cash expenditure on cooking fuels remains rare outside of the richest 10% of households (Development Bank of Rwanda, 2021), moving towards modern energy cooking solutions in Rwanda remains an acute challenge.

Yet, with the progress around electricity access, a supportive policy environment, and growing international and domestic interest, the opportunities for clean and e-cooking may never have been greater. High-income grid connected urban households can access a wide range of electric cooking devices, including energy efficient ones, through online and physical retail sites (see Section 4 for availability and prices). Small e-cook pilots are being run and new business models such as pay-as-you-go[13] (PayGo) are being trialled that may make e-cooking accessible to lower income and rural households, alongside government subsidies for electricity tariffs. Additionally, recent research shows that energy-efficient electric devices such as EPCs are highly effective at undertaking – at low cost – the long cooking processes associated with many Rwandan staples such as beans, cassava and beef.

[12] The Biomass Energy Strategy (BEST), published in October 2019, aims to reduce firewood use from 79.9% to 42% and phase out charcoal use in urban areas.

[13] These are mostly being trialled with LPG systems.

3.2 State of electricity access and e-cooking

3.2.1 National grid and off-grid

Historically, Rwanda has had low rates of electricity access, generally remaining below the average rate for sub-Saharan Africa. However, in the late 2000s and early 2010s, the GoR set out ambitious plans to raise electricity access from the rates of 5% or below that existed throughout much of the 1990s and 2000s. Since then, considerable progress has been made, through programmes such as the successful 2009 Electricity Access Rollout Program (EARP), designed to increase access to 16% of the population by 2014. During the latter part of the decade, consistent and rapid progress was made towards extending electricity access in the country, with figures reporting electricity access increasing from 37%[14] in 2019 to 63% in 2021 (Rwanda Energy Group, 2021). The government targets universal access by 2024, with 52% connected to the grid, and the remaining 48% using off-grid solutions (ESMAP, 2019). At present, 46% are connected to the national grid and 16% get their electricity through off-grid systems (Rwanda Energy Group, 2021).

While there is compelling evidence of vastly improved electricity access for the Rwandan population in recent years, especially in urban areas, there remain significant challenges to wider and more productive uses of electricity, which have particular significance for electric cooking. One of the main inhibiting factors, evidenced in the literature and surmised from interviews[15], is the high cost – or perception of the high cost – of electricity in Rwanda, estimated to be around 22% higher than the highest tariff in other East African countries (Bimenyimana et al., 2018). This high-cost issue is relevant for both electricity provided through the national grid and through off-grid options, such as mini-grids, as the nationally determined tariffs set for mains electricity affect off-grid tariffs. The high cost of grid electricity has been attributed to several factors.

Part of the issue has been the reliance on hydropower for electricity, the dominant form of generation in Rwanda. The widely studied risks of hydropower projects include frequent overspend, unintended negative ecological impacts and susceptibility to climate conditions (Sovacool & Walter, 2019), including low rainfall. Droughts, for example, incentivised the development of heavy fuel oil and diesel thermal power plants in the early 2000s, which are still in use although are planned to be phased out, reducing the use of imported fuels, the most expensive source of power (Bimenyimana et al., 2018).

Presently, for the national grid, the GoR has enrolled the private sector to build and develop hydropower, peat and methane gas power plants, employing a variety of technologies through tens of projects (Dye, 2020). A range of energy infrastructure projects has come online in the last few years, and others are planned, to reach the projected energy demands – as forecast by institutions such as the World Bank. This

[14] See the database from the SE4All Global Tracking Framework, shown on the World Bank's website at https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=RW (accessed 5 June 2021)

[15] Interviewees conducted with REG, MeshPower and MECS colleagues all spoke of the perception of the prohibitive cost of electricity.

approach has been successful at quickly increasing megawatt generation but it has led to a not insignificant fiscal burden, with revenues consistently falling below costs (ESMAP, 2019).

The costs of building power stations, some of the technologies employed and the initial associated contractual obligations (e.g., power purchase agreements[16]) to private independent power producers have led to relatively high production costs per unit of electricity (Chemouni & Dye, 2020). The national utility company, Energy Utility Corporation Limited (EUCL), also accrues debt for all potentially generated power over a set period, including unused surplus. In addition, the expansion, maintenance, and modernisation of the power grid, especially with regard to transmission and distribution, requires large financial outlays. Once planned electricity generation and infrastructure updates are achieved and more expensive power generation is phased out, the production costs of electricity should reduce significantly, but it is unclear on what timescale these might fall. Greater regional energy integration and trade is also a Government ambition.

High tariffs for electricity used remain one means to offset high production costs, and perhaps helps to explain why in Rwanda they have remained among the highest in East Africa. That said, initiatives have been put in place to mitigate the costs of the electricity sector on public finances (including rescheduling the opening of new powerplants in line with demand) and, from the consumer side, the government subsidises electricity, and has put in place tariff and other support (e.g. connectivity assistance) to help keep electricity affordable to low-income and vulnerable households (ESMAP, 2019). Despite these efforts, electricity consumption per capita is the lowest in the East African Community (Bimenyimana et al., 2018).

Residential tariffs in Rwanda are banded by monthly consumption. Consumers pay 89 Rwandan Francs (RWF) (USD 0.09) per kWh up to 15 kWh (the 'lifeline' tariff) then pay RWF 212 (USD 0.21) up to 50 kWh, and RWF 249 (USD 0.25) per unit above 50 kWh[17]. The highest band is marginally higher than the regular electricity tariff in Kenya of USD 0.23, the highest of neighbouring East African countries. Rwanda's lifeline tariff is lower at USD 0.09, although limited to a 15 kWh allowance, while the Kenyan lifeline tariff reduces cost per unit to USD 0.17 and is combined with a generous 100 kWh allowance. Tanzania and Uganda have even more significant lifeline tariff reductions to respectively USD 0.04 and USD 0.06 although they also have lower kWh allowances (ESMAP, 2020).

The off-grid sector has developed a strong policy and regulatory framework and, in a similar fashion to the national grid, has relied heavily on the private sector to expand. Solar home system (SHS) companies sell close to 100,000 systems per year (Development Bank of Rwanda, 2021) and, along with solar lanterns, have generally dominated the off-grid market. In recent years, laws and regulations governing the mini-grid sector have been introduced or strengthened, and the small number of solar PV mini-grid developers is growing, attracting further private sector interest (IRENA, 2018). Mini-grid licensees are free to set their

[16] Power Purchase Agreements are often underwritten by MININFRA who are obliged to pay 90% of power made available whether it is used or not.

[17] See the Rwanda Energy Group's website at https://www.reg.rw/customer-service/tariffs/ (accessed 14 July 2021)

own tariffs. However, the regulatory authorities aim to ensure fair prices for end-users as the GoR seeks to keep cost comparable with the national grid (IRENA, 2018)

3.2.2 E-cooking implications

Relatively high regular electricity tariffs for the East African region must be viewed in line with Rwanda's lower GDP per capita (USD 798), which sits significantly below that of Kenya (USD 1,838) and below those of Tanzania (USD 1,076) and Uganda (USD 817)[18]. Nearly 80% of the Rwandan population is based in rural areas and much of the wealth, and the wealthiest, are concentrated in the capital city Kigali (Bird et al., 2019). As part of the GoR strategy to spur economic growth and raise incomes, urbanisation is expected to be important (MININFRA, 2015) and may offer better opportunities for more Rwandans to access cleaner cooking solutions. However, unemployment may have reached 65%, according to a comment made recently[19] in Parliament. So there are uncertainties about whether urbanisation will – at least in the short term – generate the benefits expected by the GoR.

Rwanda is unusual in low-income developing country contexts as having a nationwide social protection scheme that targets the poor, vulnerable older people and those unable to work due to disability or chronic illness. The Ubudehe categories, recently changed from four numerical to five[20] alphabetical categories, offer support based on levels of household income and living standards, with more vulnerable households receiving greater support. Market development activities are often intricately tied to poverty reduction programmes and have differing subsidy and consumer financing implications for the different Ubudehe categories, so need to be taken into consideration when looking at e-cooking initiatives. They have proven important for the markets of other clean energy technologies such as solar lighting products. For further discussion, see Section 4.6.3.

The perception of electricity being expensive persists, especially with regard to novel uses such as cooking, for a population that relies overwhelmingly on biomass acquired at little or no cost. There is low awareness and little knowledge in the public domain about using electric appliances to cook Rwandan food in comparison to LPG or biomass stoves, whether in terms of cost, viability or factors related to the country's unique cooking cultures and processes. This is especially true of new energy-efficient appliances, which have not yet penetrated the market to any significant degree, despite contributing to the greatest potential savings of energy and cost.

Research conducted by the MECS Programme and partners elsewhere in East Africa shows considerable cost savings and a high level of compatibility with dishes commonly cooked in Kenya, Tanzania and Uganda (Leary et al., 2019; Scott et al., 2019). There has also been a small but encouraging adoption of energy-efficient devices such as EPCs and this might augur well for the compatibility of Rwandan cuisine, given a

[18] See 2020 data, shown on the World Bank's website at https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=KE-TZ-RW-UG (accessed 14 July 2021)

[19] One of our co-authors provided this observation.

[20] At the time of writing, the new categories are not yet operational.

similar culinary profile with, for example, the importance of long-cooked food such as beans and cassava to the Rwandan diet.

A recent MECS cooking diary study in the wealthier grid-connected segment of the population in Kigali found that monthly spend was approximately RWF 8350 (USD 9.00) on charcoal and RWF 10,500 (USD 11.50) on LPG (used during a PayGo trial), or approximately 3-4% of household income (Perros et al., 2021). The findings, which revealed that green vegetables, rice, ugali, potatoes, bananas and beans accounted for 74% of dishes cooked, drew attention to potential savings from converting to using LPG. Charcoal was especially relied upon for cooking beans, and long-cooking dishes, where e-cooking devices such as EPCs are considered to have an advantage from a time, cost and energy efficiency perspective. Planned studies in Rwanda, by organisations such as Electrocook and MECS partners Energy 4 Impact (E4I), may start to generate information that sheds further light on the viability of EPCs, social fit and cost effectiveness of electric devices for Rwandan cuisine and culture.

3.3 E-cooking policy context: international and national overview

Since MININFRA took over developing energy policies and strategies in 2015 it has aligned closely with many global aims such as the SDGs, especially with regard to SDG7, which seeks to achieve universal access to electricity by 2030 and is considered key to tackling many issues associated with other SDGs. Sustainable Energy for All (SE4All), the multi-stakeholder partnership with a focus on SDG7, has guided aspects of subsequent national policymaking and strategic planning. See Section 3.4 for further details on relevant energy policies.

Regionally, Rwanda energy and climate policy has linkages to initiatives developed by the East African Community (EAC) including EAC Vision 2050, which focusses on environmental protection and sustainable development enablers, the EAC Climate Change Policy, which addresses climate change measures and the EAC Climate Change Master Plan (2011-2031) prioritising several key sectors, including energy.

On the domestic front, a range of robust energy policies have significantly strengthened the framework for on-grid and off-grid electrification, and steady progress is being made towards universal access. The 2015 Rwanda Energy Policy set out a legal and regulatory framework to ensure access to modern, sustainable and affordable energy services for Rwandans. Notably, this pays heed to moving away from biomass towards electricity and LPG, and recognises the importance of domestic energy services to this transition, explicitly mentioning cooking. It also promotes the important role of the private sector in the clean cooking sector. That said, in the domestic space, the technologies and fuels highlighted include LPG, green charcoal and ICSs, with electricity as an energy carrier of interest only implied.

In addition, there are several strategy documents, detailed below, that entirely or partially discuss expectations and plans concerning electric and, more broadly, clean cooking. The Biomass Energy Strategy (BEST) 2018, the Energy Sector Strategic Plan 2018 and the forthcoming Rwanda LPG Masterplan stand out in this regard. Rwanda generally has supportive policies towards equipment and accessories for development and generation of solar and wind energy, and solar power batteries (United States Agency for International Development, 2019).

Rwanda also hosted the first Clean Cooking Investment Forum, inaugurated in 2018 in Kigali, with the Energy Private Developers association (EPD) Rwanda. The event was organised by the Clean Cooking Alliance, with the support of the EU and other donors. It brought together key industry players and government officials to discuss market-based solutions. The event coincided with the publication of a flurry of government documents, in that and subsequent years, which deal with clean cooking explicitly: for example, BEST 2018 and the Rwanda LPG Masterplan (which is likely to be finalised in 2021/22).

Despite political will, a nascent administrative mandate and tentative steps by the private sector, the move towards clean or electric cooking is in its early stages. LPG, biogas and ICSs, and to a lesser extent e-cooking, are part of a group of energy carriers and technologies referenced to reduce the reliance on biomass. A combination of Government, development partners and private sector funding is required to advance the clean cooking agenda, which, despite a large influx of financial resources in recent years (see Section 4), remains inadequately financed given the scale of the challenge in Rwanda, where only 1 percent of households use clean fuel stoves (Development Bank of Rwanda, 2021).

3.4 Summary of national policies relevant to e-cooking in Rwanda

Four key policies are described below but Table 2 provides a summary of a larger range of policies, regulations and acts relevant to e-cooking.

Rwanda Energy Policy (REP) 2015

The 2015 Rwanda Energy Policy guides and influences decision-making on the extraction, development and use of Rwanda's energy resources through a set of governing laws and regulations, strategic directions and guiding principles designed for the adoption and adherence of Rwanda institutions and partners. It aligns with other sectors to support Rwanda's development and is reinforced by documents such as the Energy Sector Strategic Plan (ESSP) and the Economic Development and Poverty Reduction Strategy (EDPRS I).

National Strategy for Transformation (NST) 2017

NST 1 serves as the Seven Year Government Programme (7YGP) and works to move forward from Vision 2020 to a longer-term plan in accordance with Vision 2050. It aims to lay the foundation for sustained growth and transformation towards high living standards for Rwanda. Where it pertains to cooking, it references cooking gas and biogas. The range of cooking technologies subsequently being considered imminently broadens in subsequent documents (to include, for example, those that use green charcoal and those that use electricity).

The Biomass Energy Strategy (BEST) 2018

In BEST 2018, GoR recognises the importance of promoting and transitioning to clean cooking fuels. An update to BEST 2009, this strategy document aims to tackle the reliance on biomass by outlining the steps that will be taken by the Government to ensure Rwandan households have access to clean cooking technologies, by developing markets, removing barriers to entry, and engaging the private sector.

Table 2: Summary of Rwanda energy policies, regulations and acts relevant to e-cooking

Year	Policy/Regulation/Act	Details
2009	Biomass Energy Strategy (BEST)	The strategy aimed to ensure a more sustainable supply of biomass energy, more efficient combustion technology and to promote access to modern fuels
2009	Electricity Access Roll-out Program (EARP)	A key early driver of ambitious on-grid access growth
2015	Rwanda Energy Policy	High-level policy document to guide and influence decisions on the use of Rwanda's energy resources, it sets out governing laws, regulations, and strategic sector priorities
2016	Rural Electrification Strategy	Sets out the programme for off-grid solutions (for example, SHSs and mini-grids)
2016	SE4All Action Agenda	Sets out to bring the renewable energy mix to 60% of population by 2024, with a strong focus on policies and regulations encouraging private sector participation
2017	National Strategy for Transformation (NST)	Succeeded the Economic Development and Poverty Reduction Strategy and is geared towards Vision 2050
2018	National Biomass Programme (NBP)	Promotes the use of efficient and alternative cooking technologies and works to establish sustainable biomass consumption
2018	Energy Sector Strategic Plan (ESSP)	Presents the status of, and plans for, the energy sector, covering three subsectors: electricity, biomass and petroleum. ESSP outlines targets and an implementation framework against which to measure progress towards the realisation of the Rwanda Energy Policy
2018	Biomass Energy Strategy (BEST)	An update to BEST 2009, it targets reducing the percentage of households using firewood for cooking
2018	Electricity Law of Rwanda	Outlines the rules for the generation, distribution and trading of electricity
2018	Renewable Energy and Energy Efficiency Law	Governs renewable energy sources and efficiency in Rwanda
2019	National Environment and Climate Change Policy	This policy supersedes the National Environment Policy of 2003 to reflect the changing landscape, incorporate climate change and provide strategic direction to emerging issues and critical challenges in environmental management

Sources: SE4All & CPI (2019), MININFRA (2018)

Energy Sector Strategic Plan (ESSP) 2018

The ESSP presents the current status and plan of the energy sector, covering electricity, biomass and petroleum. It builds on the Economic Development and Poverty Reduction Strategy II, guides the implementation of the REP 2015, and seeks delivery of targets identified in the NST. With regard to cooking, it reinforces targets reducing traditional cooking technologies and fuels for cooking by half, through a range of actions including modelling, awareness campaigns, data gathering and storage requirements. Yet it highlights the obstacles and explains slow progress for LPG and electricity, namely the high cost, lack of access, low incentives and deeply ingrained cultural cooking practices.

3.5 Key national actors relevant to e-cooking

The main oversight for energy in Rwanda comes from MININFRA, which is responsible for developing energy policy and strategy, monitoring and evaluation of projects and programme implementation (MININFRA, 2018). Key to managing energy targets is the Rwanda Energy Group (REG), a private company, part-owned by the government, whose mandate is to expand, maintain and operate the energy infrastructure. It translates energy sector policies predominantly through its subsidiaries, the Energy Development Corporation Limited (EDCL) and the EUCL. EUCL operates and maintains publicly owned power plants (e.g., Nyabarongo I), the transmission and distribution networks and retail of electricity. EDCL aims to develop and implement new energy project plans in line with policy and strategic objectives. The unit responsible for advancing the clean cooking agenda also sits within REG. In addition, the Rwanda Utilities Regulatory Authority (RURA) regulates the sector and determines approaches to state subsidies in the energy sector in coordination with the Ministry of Finance and Economic Planning (MINECOFIN), which sets budgets, avails subsidies, and determines resource mobilisation.

Other government bodies and public institutions that are relevant to clean and electric cooking include the Forestry Authority, Rwanda Environment Management Authority (REMA), and parent institution the Ministry of Environment. They pioneer efforts against deforestation, including the long-trailed charcoal ban or levy, delayed partially due to a current lack of accessible and viable alternatives. EPD brings together and coordinates private sector actors, many involved in off-grid electrification and other energy initiatives, advocating for their needs. The Rwanda Development Board (RDB) aims to accelerate Rwanda's economic development by enabling private sector growth. The Rwanda Standards Board (RSB) is responsible for the development of standards for clean cookstoves, although no electric cooking devices are manufactured in country.

Several financing bodies may prove important to electric cooking albeit currently as an extension of wider clean cooking investments. The Rwanda Development Bank (Banque Rwandaise de Développement , BRD) in partnership with EDCL manages the Clean Cooking Results-Based Financing (CC-RBF) subsidy scheme, financed by the World Bank EAQIP project (see Section 4 for more details), which aims to improve access to clean cooking technologies to at least 500,000 households by 2026 (Development Bank of Rwanda, 2021). The African Union and European Union joint Research and Innovation Partnership on Renewable Energy fund (LEAP-RE EU/AU) has funded e-cook pilot studies. The MECS Programme deems Rwanda a Tier One

priority country[21], and funds e-cook research, mainly through partner E4I. Other organisations such as the GIZ EnDev Programme, the Nordic Development Fund, and the Energy and Environment Partnership Trust Fund (EEP Africa) are interested, or actively investing, in innovative modern energy cooking service projects (see Section 4 for more details).

3.6 The national e-cooking development trajectory

Since the end of the 2000s, electricity access developments have been impressive. The GoR has managed to create a supportive policy and enabling environment that has generated significant interest and investment in the energy sector and has attracted numerous private sector actors to drive rapid development, both on- and off-grid. There is predicted to be a greater surplus of electricity as more powerplants come online, and mini-grids proliferate, in line with demand forecasts and targets. Whereas generation targets appear on track, electricity use is currently falling below projections, due to lack of significant uptake, especially by commercial and industrial actors. E-cooking could have a role to play in making use of excess power, and generating revenue, if challenges to its adoption can be overcome, namely limited access, low awareness and high appliance and electricity unit costs.

The most prominent cited constraint – relatively high tariffs for electricity (relative to the region and GDP per capita) that have resulted from high production costs – has not been addressed. While revenues fall below costs, there is a fiscal burden on the government. It is unclear when or whether price drops or further consumer support (e.g., subsidies) may occur. This has impeded serious consideration of using electricity for cooking, at least in the short term. However, the cost of electricity is not orders of magnitude different when making regional comparisons – for instance, in USD equivalent, the lifeline tariff in Rwanda is below that of Kenya, albeit with a lower kWh allowance – and there is some evidence from Kenya that cooking with electricity can be cheaper than purchased biomass, even using the regular higher tariff.

Building evidence from pilot trials and research that is being conducted by some organisations such as Electrocook, the MECS Programme through partner E4I and others, is clearly needed to strengthen the argument for electric cooking, if access to electricity, as predicted, continues to improve in the coming years. Further research and trials that take into account the specific cultural and social context in Rwanda could bolster the promising findings that demonstrate cost savings and suitability with a good proportion of commonly cooked dishes in neighbouring countries, proving especially effective for long-cooking foods such as beans, bananas and beef, which form a central part of the Rwandan diet.

Concurrently, and especially since the Rwanda Energy Policy was adopted in 2015, there has been a concerted effort to reduce the reliance on biomass in the domestic space, and to encourage use of modern and clean cooking fuels and technologies. This is evidenced by the number of GoR policy and strategy documents published in the latter part of the last decade that reinforce clean cooking targets and aims outlined in the REP 2015. The suite of potential technologies and fuels is broad, entailing biomass cooking

[21] MECS Tier One priority countries are those in which it has both an interest and a collective connection, and fulfils four key criteria including a supportive government seeking to change the cooking and modern energy landscape.

fuels such as green charcoal, pellets and briquettes, and modern energy carriers such as biogas, LPG and electricity, all of which have their advantages and disadvantages.

LPG is the clean cooking fuel considered as the most likely to penetrate and scale in the short term, and much current effort, including implementing the Rwanda LPG Masterplan, is focussed on developing the market. The policy target for LPG adoption is 40% of the population by 2024 (Čukić et al., 2021). Electricity is cautiously embraced and deemed more suitable in the near term in certain settings: for example, in urban households, public institutions, and the commercial food industry. Despite recent efforts, adoption of LPG, electricity and indeed progress with all other fuels and technologies, including ICSs (which have been promoted for decades) has been slow, as the hold of traditional biomass stoves sustains.

4 Socio-technical innovation system actors and relations

4.1 Technologies in the e-cooking innovation system

Rwanda's population is, according to the National Institute of Statistics of Rwanda, 12.9 million, and its households rely on various fuel types. More than 99% of households use biomass for cooking, with a majority using three-stone wood-burning hearths, while the rest use ICSs. The remaining households use petroleum, electricity, and other fuels to smaller degrees (Koo et al., 2018). As noted in Section 3.2, electricity access in Rwanda stands at about 63% of households, with 46% connected to the national grid and 16% accessing it through off-grid systems (Rwanda Energy Group, 2021).

The National Survey on Cooking Fuel Energy and Technologies in Households, Commercial and Public Institutions in Rwanda estimates that only 0.21 percent of households use electricity for cooking (MININFRA & MINECOFIN, 2020). Even so, there are electric cooking appliances in the Rwanda market, many of which were identified in the Pinnsmapping workshops and follow-up interviews (see Table 3).

Table 3: Electric cooking appliances identified during the Pinnsmapping exercise

Electric cooking appliances	
Blender	Induction stove
Coffee maker	Kettle
Deep fryer	Microwave
Electric coil	Multicooker
Electric match igniter	Panini maker (grill)
Electric oven	Popcorn maker
Food mixer	Rice cooker
Hotplate	Toaster
Ice cream maker	Yogurt maker

The low portion of households using electricity to cook might be explained by the high electricity tariff in Rwanda, where both on-grid and off-grid access are concerned. Apart from this, the cost of electric cooking appliances can be prohibitively high, discouraging households from making the initial investment. Table 4 gives the price ranges of various appliances as found in the market in Kigali.

There are different cooking patterns for households in urban and rural areas. Within urban areas, charcoal is predominantly used by up to 59% of households, followed by firewood and ICSs. Up to 26% of households use clean fuel stoves, primarily LPG. In rural areas, 95% of households use firewood, 22% use ICSs, and there is negligible use of clean fuel stoves. Beans and cassava are at the heart of many Rwandese meals, also featuring other ingredients such as rice, chapatti, cabbage, boiled beef, sweet potatoes, cassava, bananas and pineapple. Many of these ingredients have long cooking times, thus the reliance on fuelwood and charcoal as many consider these more economical than other options (Accenture, 2012).

Table 4: Prices of e-cooking appliances available in Kigali

Cooking appliance		Approximate price range (USD)	
		Minimum	Maximum
Electric pressure cooker		140	151
Electric oven (4 gas tops + electric oven)		248	250
Rice Cooker		35	75
Electric Kettle		19	84
Electric hot plate		30	40
Induction stove		41	85
Microwave			
	20 litres	75	80
	23 litres	107	130
	30 litres	130	155
Air Fryer		25	95
Toaster		17.50	45

Source: Authors' Compilation

4.2 Actor-network visualisations

Based on the Pinnsmapping workshops and follow-up interviews, Figure 3 depicts the Rwanda e-cooking STIS actor-network. The actors are colour-coded based on their category: e.g., private sector, regulatory authorities, funders/financiers, and so on, as shown in Figure 3. The connections between these actors are depicted with arrows, which indicate the primary 'direction' of the relations. In some cases, the relationship is reciprocal, indicated by a bi-directional arrow. Findings from our interviews and further analysis reveal that this map also captures all those actors who are already doing some work around clean cooking in Rwanda, but are yet to start concrete projects, programmes or initiatives specifically on e-cooking. These actors are enthusiastic about e-cooking and are supportive of any new developments in this area. However, due to their current strategic focus, budgetary constraints, capacity issues and, sometimes, uncertainty or scepticism on when e-cooking efforts are likely to yield measurable outcomes, they are yet to take concrete steps to invest in or promote e-cooking.

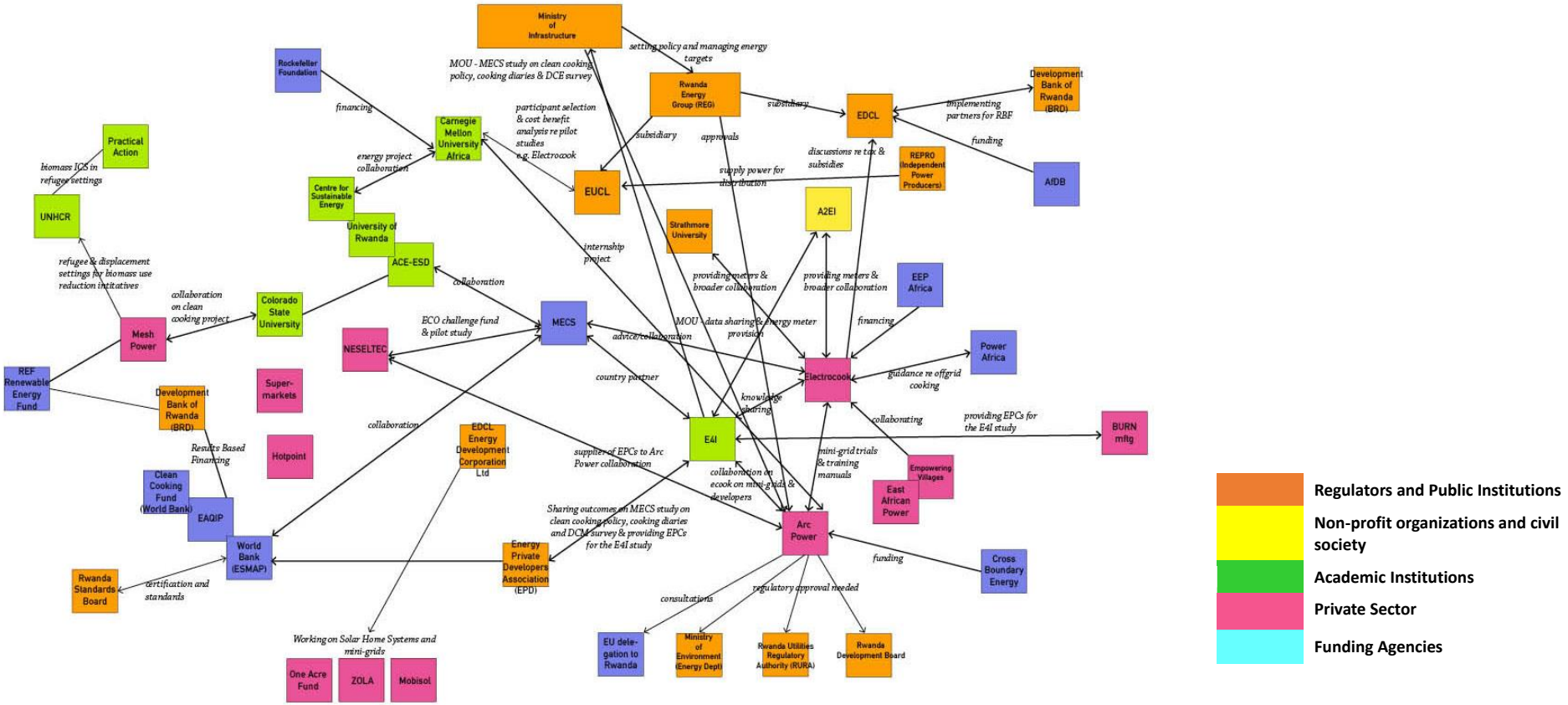


Figure 3: Actor-network map of the Rwanda e-cooking socio-technical innovation system.
Source: Authors' construction based on Pinnsmapping and stakeholder interviews

To identify specific actors from the map in Figure 3 who are currently running active projects, programmes of initiatives in e-cooking, we progressively validated this map with each actor interviewed in our study. Our respondents first confirmed if they are doing anything on e-cooking and identified those with whom they are working in these efforts. They also confirmed – to the best of their knowledge – which other actors in the sector were active in e-cooking, and in which specific initiatives or programmes. Figure 4 depicts the resulting 'core' network of players who are actively promoting e-cooking in some way in Rwanda. The actors are colour-coded in a similar way to Figure 3. This map further captures the nature of the relationships between actors: e.g., funding flows, collaborations in efforts such as cooking demonstrations, product supplies or distribution, and so on. In the following sections, we describe the actors in both visualisations and elaborate on their efforts related to e-cooking, and the relationships in the STIS.

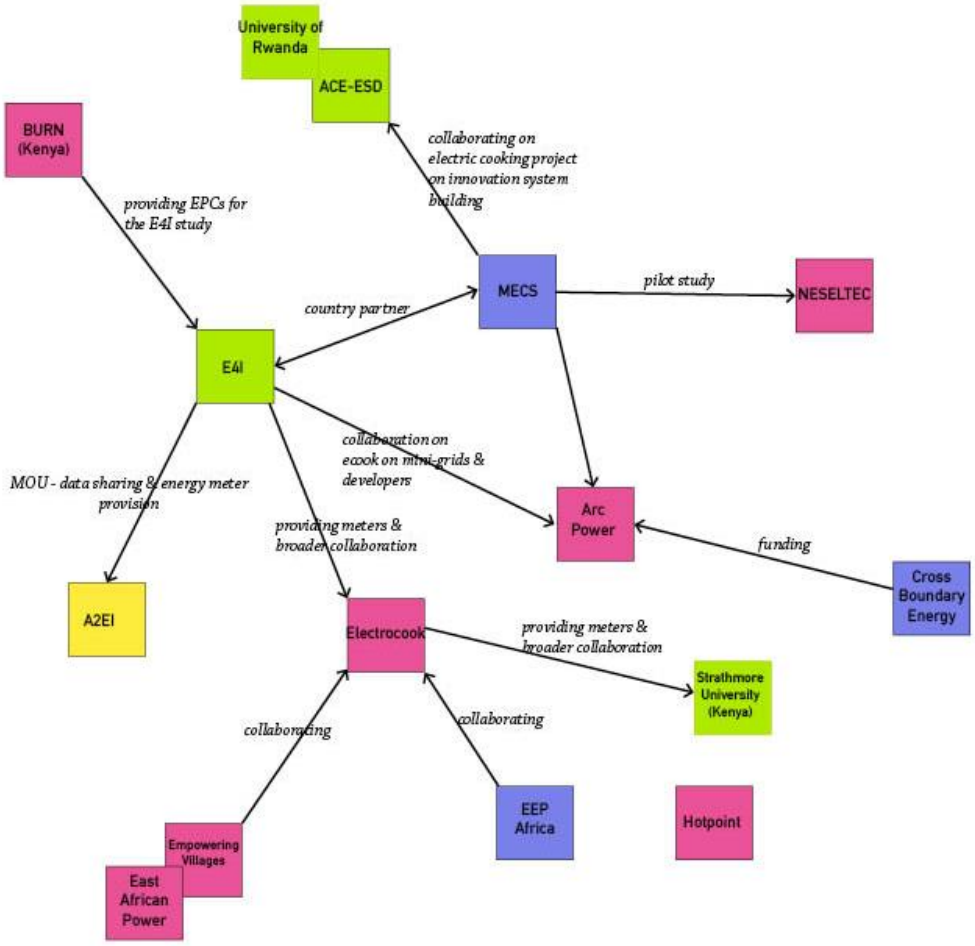


Figure 4: Core actor relations in the Rwanda e-cooking socio-technical innovation system
Source: Authors' construction based on Pinnsmapping and stakeholder interviews
Note: The map shows only those who are active in e-cooking in Rwanda and the nature of their relations

4.3 Key actors in the e-cooking innovation system

The electric cooking innovation system in Rwanda, as illustrated in Figure 4, comprises several core actors whose work revolves around conducting research on cooking with electricity, piloting related technologies at household level, and developing markets for e-cooking appliances.

4.3.1 Non-governmental and non-profit organisations

The clean cooking landscape in Rwanda comprises several NGOs and development organisations, among whom the main actors are the German Gesellschaft für Internationale Zusammenarbeit (GIZ), the Netherlands Development Organization (SNV), the United Nations High Commissioner for Refugees (UNHCR), Practical Action, and E4I. GIZ in Rwanda has a programme dedicated to facilitating a transition from traditional fuel use. The programme aims to reduce the reliance on fuelwood by providing solutions around cleaner energy for cooking. SNV – which has ongoing work on clean cooking in Kenya and Tanzania – entered Rwanda's ICS sector in 2013. It has since focussed on developing the market for improved wood and charcoal stoves fabricated locally from mud. Further to this, SNV has been involved in projects to develop markets for more efficient cooking fuels such as biogas by providing training opportunities for technical and skilled workers offering clean cooking alternatives (SNV, 2018).

Practical Action, through the project 'Renewable Energy for Refugees', has been facilitating people in refugee camps to access sustainable energy for lighting, cooking, and productive uses. Working in partnership with Practical Action is the UNHCR, which has been promoting sustainable cooking technologies and fuels within refugee camps. The organisation's mission has been the improvement of the living standards of refugees and forcibly displaced communities. As part of this mandate, UNHCR has been addressing issues around the use of firewood for cooking and supporting the Government's aim to end the distribution of firewood within refugee camps. In this regard, UNHCR has mainly focussed on promoting alternative fuel options – including ICSs that use briquettes and pellets, and LPG stoves – within refugee camp settings.

Finally, E4I is a charity organisation registered in the United Kingdom that operates in several countries in Africa, among them, Kenya, Tanzania, Uganda, and Rwanda. In Rwanda, E4I works in various energy subsectors, with recent projects focussed on solar irrigation, productive use of energy in refugee camps, and clean cooking. E4I is the in-country partner for MECS in Rwanda and, as part of this role, E4I is working on the clean cooking national policy and market review.

4.3.2 Private sector

Local distributors and retailers dominate the supply of electric cooking appliances in Rwanda. A quick survey of the locally available appliances identified in Table 3 reveals the following brands: Von Hotpoint, Mika, Black and Decker, Femas, Smifer, and Bosch, among others. These brands are imported from Dubai, China and Europe via Dubai and distributed through local retail stores.

Apart from commonly stocked appliances such as free-standing cookers, electric ovens and microwave ovens, EPCs have entered the Rwandan urban market, also imported for local distribution. Some of the

locally available brands include Ewant and Nutricook. There are some new-entrant private companies that focus on EPC importation and distribution. Electrocook is one such player, founded by a Canadian social entrepreneur, and is piloting 50 EPCs within a mini-grid in Nyamata village with a view to eventually scaling up to 100 EPCs. Further, the company is conducting training in and around Kigali on how to cook with an EPC. The company is currently in the process of sourcing EPCs from Midea, a manufacturer based in China. A unique feature of this EPC is that it has a second pot for cooking to facilitate the simultaneous cooking of multiple dishes. Electrocook's EPCs will also be accompanied by a cooking manual and a recipe book tailored to Rwandan dishes. And the company is exploring how to assemble EPCs in Rwanda (see more in Section 4.6.1).

Neseltec Ltd is another local company that has been in the off-grid market and clean cooking space, and is now venturing into electric cooking. It has been implementing solar mini-grids and selling SHSs in urban and rural areas since 2012. The company has also been selling LPG cannisters, and more recently innovating around PayGo cannisters in Kigali. Additionally, Neseltec has developed various biomass projects such as briquetting plants and gasification. The company is now importing branded EPCs for distribution in Rwanda, and had received funding from the MECS Programme to conduct an EPC pilot study to accelerate the uptake of efficient electric cooking appliances in the country. But, as far as we are aware, the funding has since been cut.

The electric cooking space also comprises private mini-grid developers looking to increase power usage within their various mini-grids and, therefore, considering electric cooking as a possible means to achieve this objective. ARC Power – a British start-up established in Rwanda in 2017 – has, for example, piloted the use of EPCs and electric hotplates within their mini-grids and has been selling electric cooking appliances from other retailers to the households served by the mini-grids. East African Power is a renewable energy development company based in Kigali, focussed on the development, finance, construction and operations of hydro and solar power projects in sub-Saharan Africa.

4.3.3 Financing organisations

Our fieldwork in Rwanda has so far revealed that the vast majority of the financing for clean and electric cooking projects has originated from foreign sources, primarily development funding institutions. The largest fund established so far for clean cooking projects in Rwanda has originated from the World Bank. In September 2020, the Bank approved USD 150 million (a USD 75 million grant and a USD 75 million loan) for its largest clean cooking operation in Africa, the Rwanda Energy Access and Quality Improvement Project (EAQIP) (see Section 4.5.2 for more). In addition, the Clean Cooking Fund, which is hosted by the World Bank's Energy Sector Management Assistance Program (ESMAP), will provide USD 20 million for clean cooking, with USD 10 million provided as a grant and USD 10 million extended as a loan. The project will leverage an additional USD 30 million in public and private sector investments.

Under EAQIP, the Rwanda Development Bank (BRD), in partnership with EDCL, has launched a Clean Cooking Results-based Financing (CC-RBF) subsidy scheme. BRD provides development finance in the form of short, medium- and long-term investment loans to projects in the priority sectors of the Rwandan economy – especially agriculture, exports, energy, housing and education. In the energy sector, BRD is

managing the Renewable Energy Fund (REF) project to facilitate private sector investment in off-grid renewable energy in order to meet the goals of the Rural Electrification Strategy[22].

Another institution funding clean cooking programmes is the Nordic Development Fund (NDF), a multilateral fund established by the governments of Denmark, Finland, Iceland, Norway and Sweden, funding endeavours around climate change and development in low-income countries. Together with the Austrian Development Agency, NDF are hosting and managing EEP Africa, a clean energy financing facility. EEP Africa provides early-stage grant and catalytic financing to innovative clean energy projects, technologies and business models in 15 countries across Southern and East Africa. In Rwanda, the fund is currently financing projects in different subsectors including hydropower, solar PV, and clean cooking. For example, EEP Africa has funded a Bboxx pilot project in PayGo Biogas that provides customers with a biodigester, a smart cookstove that enables households to pay as they cook. EEP will also be funding a project by Electrocook called *Bye Bye Makara*[23] (EEP Africa, n.d.).

More funding for clean cooking in Rwanda has recently come from the Green Clean Cooking Fund[24] through the European Union delegation in Kigali. This grant aims to close the affordability gap, increase productive uses, develop social institutions, and ramp up fuel production. EUR 5 million have been allocated to disseminate 500,000 stoves over five years starting from 2021. The programme adopts a market-development rationale, specifically, creating demand for more efficient stoves (i.e., stoves that save households at least 40% of fuel) and increasing stove production to about 250,000 stoves annually by the end of the period. As an extension to this project, the EU is in discussion with MININFRA to include clean cooking in public schools with a proposed line of funding of EUR 10 million (Development Bank of Rwanda, 2021).

The MECS Programme is the first one of its kind in Rwanda, focussing exclusively on modern energy cooking services. The approach of the programme in Rwanda has been to promote the uptake of cooking with electricity by funding relevant innovations and related research activities into the cooking practices of households in the country. MECS provided funding through the ECO Challenge Fund, in which Neseltec was participating prior to the cuts – as we understand it – to the Programme funding. Further, there is funding for organisations conducting research into e-cooking such as E4I, which is undertaking research studies to shed more light on cooking practices in Rwanda.

GIZ, through the Energizing Development (EnDev) Programme has also supported clean cooking projects. Until 2011, EnDev Rwanda supported the biogas sector by building digesters to supply rural households. The target group for the domestic biogas programme was households in rural areas that own cattle in a stable near the homestead. EnDev supported the National Domestic Biogas Programme through technical

[22] See https://www.brd.rw/brd/energy-investments/ [accessed 10 August 2021].

[23] See https://eepafrica.org/Portfolio/empowering-villages/ [accessed 10 August 2021].

[24] This is different to and precedes the Clean Cooking Fund of the Rwanda EAQIP facility. See (Development Bank of Rwanda, 2021, p. 7).

advice and partial subsidies for such digesters. As of 2019, the GIZ EnDev clean cooking programme aimed at strengthening market capacity and improving demand, focussing on all stove types ranging from clay stoves to gasifiers. The programme is also investing in labelling, testing and complementary procedures. The funding level is EUR 1 million with a target of 100,000-120,000 beneficiaries.

The description above suggests that Rwanda is awash with external funding for clean cooking, especially opportunities that have come only recently, although, as we state in Section 3, the levels of funding and finance are not necessarily adequate to meet the challenge. Many of these programmes are still largely targeted at developing the market for ICSs, with mention of modern energy services only in the EAQIP and MECS programmes, and the *Bye Bye Makara* project funded by EEP Africa. This indicates that the institutions involved believe in developing the ICS ecosystem first, as indicated in EAQIP, and transitioning into modern energy services once most rural households are no longer relying on firewood as their primary fuel source.

4.4 The enabling environment

4.4.1 The regulatory context

Regulatory authorities in the energy sector form a key part of the e-cooking STIS environment. Section 3 highlights the key policies that guide development in the energy sector, among them the Rwanda Energy Policy (2015), and institutions such as MININFRA and the Rwanda Energy Group (REG) with whom the clean cooking agenda and mandate lie. MININFRA is a department of government tasked with the formulation of infrastructure policy and development. It is responsible for overseeing the operations of a number of sectors within the country, among them the energy sector. It carries out its mandate by directing and supervising the functions of subsidiary public institutions. The agency that is directly responsible for the energy sector is REG. The clean cooking agenda has been recently moved to MININFRA and REG has the mandate to implement it.

REG was incorporated to expand, maintain and operate the energy infrastructure in the country. It also provides oversight in generation, transmission, distribution, enhancing access to energy and off-grid solutions. As explained in Section 3, it implements its mandate through its two subsidiaries. The first is EUCL, which provides energy utility services by operating and maintaining existing generation plants, distribution and transmission networks and retailing electricity. The second is EDCL, which plans and executes energy access projects geared towards meeting national targets, develops transmission infrastructure and increases investment for new energy development projects. EDCL is implementing a Clean Cooking Results-Based Financing (CC-RBF) subsidy scheme that aims to trigger access to clean cooking technologies for at least 500,000 households (discussed further in 4.5.2).

Efforts around standards and testing of cooking appliances in Rwanda seem to focus only on charcoal and fuelwood stoves. The Rwanda Standards Board (RSB) is tasked with certifications and setting standards for cooking products. RSB has provided standards awareness, testing and certification services for kerosene cookstoves. So far, there is no evidence of activity around the testing and certification of electric cooking appliances. Before 2020, the College of Science and Technology (CST) at the University of Rwanda, formerly

the Kigali Institute of Science and Technology (KIST), operated the only independent cookstove testing lab, and it collaborated with CARE International and Practical Action (Accenture, 2012). CST could only test the fuel efficiency of stoves, as it did not have equipment to measure emissions. However, as CST was also selling its own cookstoves, there were conflict of interest issues. Private sector actors, NGOs, and Government also designed their own requirements for cookstoves and conduct their testing independently. In October 2020, Rwanda launched the RSB Cook Stove Testing Laboratory funded by the World Bank through the project 'Improving the Efficiency and Sustainability of Charcoal and Woodfuel Value Chains in Rwanda', implemented by REMA. This lab is capable of conducting efficiency and emission tests (Rwanda Energy Management Authority, 2020).

With regard to tax and import duty, kitchen appliances are classified under home and garden and furniture, and these currently attract taxes on the total cost of the item, insurance cost and shipment cost. Given that at present, all electric cooking appliances in Rwanda are imported, import duty is applied, and import goods are subject to a sales tax of 18%. However, it is worth noting that Rwanda, like its neighbouring East African countries, has friendly policies towards equipment and accessories for development and generation of solar and wind energy, and solar power batteries (United States Agency for International Development, 2019). Clean energy projects do have to pay a 5% cost, insurance, and freight tax. To facilitate the productive use of energy from the grid and off-grid systems, tax exemptions may need to be extended to electrical appliances (including e-cooking appliances) to address the prevailing affordability constraints.

4.4.2 Academic research, education and training

There is not much evidence of significant investments in research, education and training on clean cooking technologies in Rwanda, apart from work by CST. As a research institution linked to the government, CST offers the potential to act as a centre of excellence on clean cooking. However, the institution lacks adequate funds to expand its laboratory, and it is yet to develop relationships with other testing facilities or research centres in East Africa (Accenture, 2012).

The University of Rwanda has been doing research on energy access through the African Center of Excellence in Energy for Sustainable Development (ACE-ESD). ACE-ESD, which was established in 2018, is funded by the World Bank under the Eastern and Southern Africa Higher Education Centers of Excellence Project (ACE II), and is supported by the Rwandan Government. ACE-ESD undertakes interdisciplinary research and training in smart and micro-grid energy technologies tailored to serve remote and rural areas[25] and offers doctoral and master's programmes on renewable energy, electrical power systems and energy economics. It also hosts a Grid Innovation and Incubation Hub (GIIH) project that has supported entrepreneurs developing improved cookstoves that burn alternative fuels derived from rice husks and sawdust[26]. Research on clean cooking at ACE-ESD has so far focussed on biogas technologies, briquettes

[25] See https://aceesd.ur.ac.rw/about-us [accessed 10 August 2021].

[26] See https://aceesd.ur.ac.rw/node/3585 [accessed 10 August 2021].

and, more recently, collaboration in the research and writing of this paper mapping the e-cooking STIS in Rwanda.

Our review indicates that some of the research and development work around clean and electric cooking is being done by foreign-affiliated institutions. Among them is E4I, a UK-affiliated non-profit organisation with branches in several countries in East and West Africa that works with local businesses to extend energy access. The organisation has been working in Rwanda since 2012 and is the country partner for the MECS Programme in Rwanda. The organisation's role is conducting research geared towards promoting clean cooking activities in Rwanda in three broad areas: national policies and market review into the potential for clean cooking; cooking diaries survey looking into cooking practices, which involves training participants on the use of electric cooking appliances and then observing their cooking habits over time; and discrete choice modelling on preferences towards different cooking appliances.

Another foreign affiliate is Carnegie Mellon University Africa (CMU), which has been doing research on clean cooking in collaboration with other actors including EUCL and the University or Rwanda in the clean cooking innovation system. CMU's research includes but is not limited to studying participant selection and conducting a cost-benefit analysis of pilot studies. CMU also offers a course on 'integrated energy systems' that focusses on Africa's energy transitions towards low carbon futures, wherein cooking with electricity features[27]. Students from the university have also been involved in biogas construction with a local community[28].

Finally, researchers from Colorado State University, working in partnership with MeshPower, are collaborating with the University of Rwanda in a 5-year project (2019-2024) that investigates whether replacing biomass with cleaner modern energy will produce meaningful reductions in household air pollution and health benefits in rural Rwandan homes. The project is running a randomised controlled trial in rural Rwanda that substitutes biomass for cooking with LPG stoves and kerosene for lighting with solar power. The project is funded by the US government through the National Institute of Environmental Health Sciences (National Institute of Environmental Health Sciences, 2019).

In sum, as the electric cooking STIS in Rwanda is still underdeveloped, and academic research and training on clean cooking is to a large extent still focussed on ICSs. Efforts around modern energy are driven by foreign research institutions and externally funded research projects. However, there is potential to leverage institutions such as ACE-ESD and CST, which are already promoting clean cooking in their work, with the hope of reorienting their work towards modern energy services. Institutions such as CMU could be co-opted in this endeavour.

[27] See https://www.africa.engineering.cmu.edu/education/programs/courses/18-883-L4.html [accessed 10 August 2021].

[28] See https://www.africa.engineering.cmu.edu/news/2016/12/12-bugesera-biogas.html [accessed 10 August 2021].

4.5 Relations between actor categories in the e-cooking innovation system

Actors often coalesce around collaborative projects or initiatives. In Rwanda, these tend to be multilateral donor-funded projects spearheaded by the local government or by large NGOs that then involve local companies, financial institutions or academic institutions. Most of these projects are focussed on market development and business model research through cooking trials. While there are several projects that focus on the ICS sector in Rwanda, here we highlight projects and programmes that have a modern energy services dimension or have the potential for such a focus.

4.5.1 The Energizing Development Programme

The EnDev Programme is a multi-stakeholder partnership in 25 countries in the Global South between 2009 and 2022. Its overall aim is to address issues of energy access especially affecting poor populations. EnDev is implemented by GIZ and is commissioned by a number of organisations globally, including German Federal Ministry for Economic Cooperation and Development (BMZ), Directorate-General for International Cooperation of the Dutch Ministry of Foreign Affairs (DGIS), Norwegian Ministry of Foreign Affairs (MFA), UK Foreign, Commonwealth and Development Office (FCDO), Swiss Agency for Development and Cooperation (SDC), Swedish International Development Cooperation Agency (Sida), and US Agency for International Development (USAID).

In Rwanda, EnDev has been working since 2006 in collaboration with MININFRA, REG and EDCL to help achieve the national energy supply targets. EnDev works with private sector players to promote electrification, biogas, and modern cooking solutions to reduce the climate impact of cooking in Rwanda through improved cooking systems. The work of EnDev so far has focussed on market-based approaches for ICSs. For example, SNV working under EnDev between 2019 and 2020, organised local workshops and supported the production and dissemination of approximately 20,000 ICSs. With co-financing from the European Union until 2025, EnDev has launched a project called 'Reducing climate impact of cooking in Rwanda through improved cooking energy systems (ReCIC)', which will use a market-based approach to overcome barriers in the ICS market and create an enabling environment. These efforts aim to contribute to the BEST strategy by 2024 (GIZ, 2020).

EnDev has also supported electrification efforts in Rwanda by using FCDO funds (then DfID) in an RBF scheme for private solar companies and mini-grid developers. It is currently running a 'Pro Poor RBF' between 2019 and 2021. Local organisations such as Urwego Bank, a local micro-finance institution, and REG were involved in these projects. EnDev, together with Power Africa and EDCL, are developing a national off-grid monitoring database.

4.5.2 The Rwanda Energy Access and Quality Improvement Project

The Rwanda Energy Access and Quality Improvement Project (EAQIP) is a World Bank-funded project that aims to improve electricity access by providing funding for the country's ongoing programme of expanding grid connections for residential, commercial, industrial, and public sector consumers. The project will also give grants to reduce the costs of off-grid SHSs. The project adopts a market-based approach to expand access to affordable clean cooking solutions in Rwanda by bridging the affordability

gap, providing cost-sharing to enterprises, developing improved stove technology and fostering innovative business models. To achieve this, the project will incentivise the private sector through a Clean Cooking RBF (CC-RBF) subsidy scheme to be implemented by BRD and EDCL (Development Bank of Rwanda, 2021). The subsidy is designed to address the affordability of clean cooking technologies through the reduction of system prices. The project targets 2.15 million people to reduce the proportion of households that use firewood for cooking in Rwanda from a baseline value of 79.9% in 2017 to 42% by 2024 (REG, 2018).

The project will begin with a more modest objective of supporting lower-tier solutions with the aim of graduating to higher tiers as they become more available in the market. Specifically, the RBF will first focus on phasing out charcoal in urban areas and replacing it with Tier 3+ clean cooking solutions[29]. In rural areas, the project will slowly introduce Tier 2+ and Tier 3+ to reduce the reliance on firewood. Laboratory testing and field-based data will be used to determine performance of eligible cooking technologies (World Bank, 2020). The RBF incentive levels will be issued based on Ubudehe categories: i.e., consumer income categories, with the most vulnerable category receiving up to 90% subsidy. Additionally, incentives will also be based on the performance level of the cooking technology (Development Bank of Rwanda, 2021).

4.5.3 Various cooking trials and field studies

Several e-cooking trials are ongoing in Rwanda. Some of them are organised in a more formal way, while others are commercial pilots of newly developed EPCs in the market.

Neseltec, which has sourced and self-branded an EPC manufactured in China, has been piloting its EPC in grid-connected urban areas and in mini-grids in rural Rwanda. For the rural pilots, Neseltec has collaborated with ARC Power to test five EPCs in the community. ARC Power identified nine influential women in the community and issued four of them with a hotplate, and the other five with a Neseltec EPC. This pilot was also designed to explore women as influencers and agents for e-cooking appliances, such that the women would earn a commission on any new EPC or hotplate customers. In this pilot, E4I brokered the connection between ARC Power and Neseltec. While this pilot did not succeed as planned (see Section 4.6.1 for more), ARC Power is exploring a similar pilot with Electrocook, targeting 50 households with EPCs, funded by CrossBoundary. In the meantime, Neseltec is conducting another pilot study with 15 users in its own AC mini-grid.

Under the LEAP-RE Europe-Africa Partnership for Renewable Energy programme, Electrocook and Strathmore University will be conducting a pilot cooking trial with 50 EPCs within mini-grids managed by ARC Power in Nyamata village. With the help of ARC Power, Electrocook will identify enumerators who will serve as ambassadors for cooking with EPCs. Electrocook will train the enumerators on the benefits of cooking with electricity and on the efficiency of EPCs. Thereafter, the enumerators will invite ten family members and/or friends from the community for an in-depth training with EPCs. After that, data will be collected for six months. The participants of the study will only pay for the electricity costs during the

[29] For an explanation of these tiers, see https://www.worldbank.org/en/topic/energy/brief/fact-sheet-multi-tier-framework-for-cooking [accessed 10 August 2021].

conduct of the pilot study and will be given financing options to purchase the product when the pilot study ends. In case there is more demand for the EPCs generated from the pilot, ARC Power will look to scale up distribution through hire purchase agreements. Another option is to find subsidies for the product so that it can be offered for a lower total price.

Finally, E4I was to conduct a cooking diaries survey between April and August 2021 with support from the MECS Programme, although the start may have been delayed until June because of a lockdown. The study, which has three sub-components, will address cooking habits and their financial implications on 25 households organised in five clusters of five households scattered across urban and peri-urban areas of Kigali city. The baseline survey focusses on how households cook and what they cook, how long they cook, the cooking fuels they use, and the amount of fuel they need for cooking. The second component of the study is a transition phase, where households will be expected to use electricity for cooking 100% of the time for three weeks, for which they will be supplied with EPCs and electric hotplates, and smart meters from A2EI in Tanzania will be used to record data. For the last phase, which is the end-line phase, participants will have the opportunity to cook with whichever appliance they prefer. E4I has used Electrocook's EPCs for training and intends to partner with Electrocook for the subsequent study focussed on discrete choice modelling.

4.5.4 Summary of actor-relations in the e-cooking innovation system

It is evident that large clean cooking projects are driven by development partners such as the World Bank, EnDev, Sida, NDF, the European Union and MECS in collaboration with the GoR. Most of these projects have a multi-donor structure with some involvement of local financial institutions such as BRD. Technical and market development capabilities in Rwanda are still underdeveloped. Thus, funded projects are set up in a way that facilitates technical support from institutions such as EEP or E4I to enable knowledge spillovers and skill development in local organisations.

Projects with an e-cooking focus so far involve a few private companies collaborating in e-cooking trials, specifically Electrocook and mini-grid developers such as Neseltec, MeshPower and ARC Power. There are many other organisations in the off-grid energy sector that remain in the periphery of e-cooking initiatives, among them, One Acre Fund, Mobisol, Zola, Bboxx, RENERG and Absolute Energy. These companies, and the mini-grids they run, offer further opportunities to diffuse EPCs in the future. Electrocook is further involving other East African partners such as Strathmore University and BURN Manufacturing in Kenya, and A2EI in Tanzania. This is an interesting development as it opens up further opportunities for knowledge exchange between Rwanda and its neighbours.

There is seemingly no interaction between local established distributors of electric cooking appliances such as HotPoint Rwanda and the rest of the e-cooking STIS. Similarly, beyond providing training to engineering and business students who are eventually employed in the energy sector, academic institutions are only weakly connected to the core actors.

4.6 Emerging issues in the e-cooking innovation system in Rwanda

4.6.1 Technological research and development

Like other Eastern African countries, most electric cooking appliances in Rwanda are imported from Asia or Europe. Local research and development for electric cooking appliances, and EPCs specifically, is still at an early stage. Further, local manufacturing of EPCs – even in the form of assembly of parts – has proved to be challenging, as explained by Electrocook:

> [Our] initial idea was to produce electric pressure cookers here, but then we realized quite quickly when we got into contact with suppliers, we asked them, "Hey, can you ship individual parts, and we can assemble them here?" Most of them said, "We can't do that. It's way too dangerous. We don't know how experienced you are with doing that." So we said, okay, then we first go with the importation of a complete product. But as we move forward, still the idea is to at least build some additional things here that would make the product more Rwandan (Electrocook interview)

We see a similar approach being adopted by Neseltec, the other company venturing into electric cooking. Neseltec has already begun importing and distributing self-branded EPCs in Rwanda.

Product design of appliances has become a critical issue in the e-cooking STIS. Findings from the initial ad hoc field studies and cooking trials done by these companies show that affordability and user friendliness of appliances are critical. Further, the energy consumption of these appliances has to be in line with what low- and middle-income earners would perceive as affordable. So far, the user-friendliness of branded EPCs available in retail stores such as HotPoint has proven to be a significant challenge for customers. First, households can struggle with appliances designed for English speakers. To address this, Electrocook is developing a cooking manual in Kinyarwanda to be bundled with its own EPC, customised to Rwandan cuisine. The cooking manual lists common Rwandan foods and their cooking times, for both pressure and water settings. There are also concerns around the size of the EPCs, which are often too small for the amount of food that is usually cooked in Rwandese households. Small canteens and restaurants would also like to use the EPC, but they needed a larger size. Thus, both Electrocook and Neseltec are seeking to source larger EPCs. Electrocook is also including a second aluminium interchangeable pot to enable households to cook multiple dishes for one meal.

Further, there is a perception that EPCs cannot be used to cook all foods: e.g., those that need to be deep fried. In its cooking diaries baseline survey, E4I for instance opted to provide an EPC and a hotplate despite its inefficiency because they "*realised that we might need to supply an additional appliance that might supplement the EPC for some foods which are incompatible with the EPC*" (E4I interview). ARC Power similarly adopted the hotplate alongside the EPC in their cooking trial. To lower the amount of electric power that would otherwise be used while cooking with the hotplate, ARC Power explored whether supplying a heat retention bag alongside the hotplate would help. As they explained, "*We've done quite a bit of training where we try and make sure that customers understand that the hotplate is just to get things to boiling, and then you put it into the heat retention bag. But what we're seeing increasingly is that people aren't following that, and they're finding it to be restrictively expensive to use the hot plate*" (ARC Power

interview). This finding provides indications that hotplate use is not sustainable, but the appliance may be used as a transition device to introduce households to electric cooking.

Some actors in the STIS believe that EPCs with a rotary dial are easier to use than those with a digital display. This is evident in the response to Neseltec's digital EPC, which was being trialled in a mini-grid environment. Some interviewees reported that this EPC's digital display had many buttons with different options for cooking different meals, and an instruction manual that was difficult to follow as it was in Chinese. The respondents further explained, "*I would say, … it's fairly scary technology with the pressure and it stays shut, and so if you don't feel very confident in using it, it's quite overwhelming technology*". Electrocook is now looking to source a rotary dial EPC from Midea (the EPC that has a double pot). It is worth noting however that E4I, which is also conducting a cooking diaries study, has opted to use a digital display EPC called the Ecoa, manufactured by BURN Manufacturing in Kenya. Surprisingly, they discovered that their users have challenges using the rotary dial EPC especially with regard to setting the exact time. The digital Ecoa EPC brand was user friendly because its calibration is done in Swahili, which has a few similarities with the local language used in Rwanda. In addition, this EPC has been designed with East African foods in mind.

EPC product development in Rwanda needs to take into account the challenges of developing EPCs that work off-grid: e.g., issues around affordable energy storage solutions to facilitate cooking at night, and robustness of the EPCs when used in weak-grid environments with fluctuating power levels. The GoR efforts to increase off-grid access to electricity have mainly focussed on solar mini-grids and SHSs. In fact, the Government's strategy is to target 48% of households with at least a Tier 1 off-grid connection: i.e., energy that can be used for household lighting, radio, and phone charging (MININFRA, 2016). While it is likely that the electrification solutions eventually deployed may be able to support electric cooking with an EPC, Tier 1 solutions do not provide enough power for e-cooking.

In sum, there is a clear nascent but productive and enthusiastic effort to develop appliances that align with behavioural and technical realities of the Rwandan on-grid and off-grid environments. The current rationale, as expressed by Electrocook, is to "*test the market and have one simple model at first and then explore the market a little bit further down the road*".

4.6.2 Sales and business models

Conventionally, e-cooking appliances are obtained and used by households in urban areas based on factors such as access to electricity, awareness of e-cooking appliances, and the related proximity to stores that sell these appliances. Kitchen appliances such as microwaves, hotplates, and infrared burners, to name a few, are readily available in retail platforms, including brick and mortar stores and online shopping sites. While shopping from these platforms, customers are required to pay the full amount upfront. A major disadvantage in this approach is that it prevents low-income earners from purchasing electric cooking appliances that are already perceived as more expensive than ICSs, and harder to access in rural areas. This is also tied to the ease of accessing services to repair and maintain appliances.

With growing electricity access, occasioned by the expansion of the national grid and the introduction of off-grid solutions, a section of players has demonstrated interest in promoting electric cooking. In Rwanda, off-grid access is dominated by SHSs and further comprised of mini-grids. In recognition of the household financial barriers to obtaining e-cooking appliances, interests in increasing electricity consumption within mini-grids have led to service providers engaging in innovative measures to facilitate their purchase. ARC Power, for example, purchases appliances from retailers and then proceeds to sell them to households being served by the mini-grids on a PayGo basis. This allows customers to take electric cooking appliances home and pay for them over time. Interestingly, companies engaged directly in the importation and distribution of the appliances have retained the cash-first sales model. This is attributable to the unsustainable nature of the PayGo model to their businesses. As Electrocook explained:

> At the beginning when we started to explore how customers can finance our product when the initial costs are too high, and they have some sort of pay-as-you-go scheme that you can implement within an electric pressure cooker. However, what we see is that, especially in the early phase that we're in right now, it would be not ideal for us to look into pay-as-you-go immediately. Because you give out the product, and then only get like small, monthly instalments back. I would say this gives us a headache a little bit because in the end you act like a bank, basically, so you give out loans to others and they have to pay you back. There are some companies also here in Rwanda, which you can collaborate with, some SACCOs [Savings and Credit Cooperatives] or other forms of banks that give out loans, but you still want to have your money back and to keep operational and to keep economically sustainable. It is not feasible for us now to look into pay-as-you-go. (Electrocook interview)

Hire purchase agreements, which are popular in Rwanda for acquiring electric appliances, are under consideration for electric cooking appliances as an alternative to PayGo. Neseltec, for instance, is considering a model whereby:

> [Customers] pay some amount upfront and then pay the balance in small instalments, say over 12 months. But the upfront payment has to be at least half of the price because we have to ensure that we recover at least the purchase price of the EPC. Because otherwise in rural areas people default many, many times. They default a lot. (Neseltec interview)

4.6.3 Market development and company financing

In the recent past, Rwanda has built some experience in conducting market development activities in the energy sector, especially around off-grid solutions and ICSs. Examples include the GIZ EnDev programmes, where one aimed at strengthening the market capacity and improving demand for all stove types, and another aimed to increase the use of improved stoves through strengthening the value chains from production to usage. The EU delegation in Kigali, using funding from the Green Clean Cooking Fund, intends to create demand for stoves so that there will be a gradual increase in their production (World Bank, 2020). The African Development Bank has also issued an RBF loan to scale up electricity access.

Results-Based Financing has been demonstrated as an effective approach to using public resources to incentivize the market and can be designed to fit the country context and market conditions (Stritzke et al., 2021). The key feature of such programmes is providing payment upon delivery of results, meaning that private implementers must bear the risk of service delivery. The RBF approach is quite new in the cookstoves sector in Rwanda but has been used with success in the SHS and mini-grid sector. Among the lessons learned are that 100% subsidies to households (free distribution) do not work as they result in low adoption rates and reselling of products, otherwise known as subsidy leakages (World Bank, 2020). Thus, in the EAQIP RBF, for example, customer contribution is between 10% and 55%. Further, programme inefficiencies, such as delays in disbursement of subsidies, increases cost for customers, thus negating the intended goal of the RBF. Quality control of cooking technologies through testing, evaluation and certification is important to build trust. Similarly, verification – which has proven to be challenging, especially in rural and remote areas – is key to the success of the programme. All in all, the main partners in the RBF scheme expect a significant positive impact on Rwandan market development for clean cooking appliances as expressed by a respondent from BRD:

> On the side of stimulating market, we expect this results-based financing programme will have a significant contribution in the market. This RBF is of course new for the Rwanda market, but in general, RBF concept is not new elsewhere. […] RBF is really being a great market facilitator in terms of stimulating the demand and then creating more market opportunities. In Rwanda also we expect like due to this RBF concept there would be a significant increase in the demand from the final households, and since there is a high demand, then we expect there would be a number of private sector players, private companies, coming in to tap that growing demand. Going forward, our expectation is there would be a good market development in clean cooking sector in Rwanda. (BRD interview)

The respondents also explained that, in their previous energy development projects, the uptake increased significantly whenever subsidies were introduced and so they expect a similar impact from the RBF.

In Rwanda, market development activities are intricately tied to poverty reduction programmes. Subsidies are designed with the socio-economic metric "Ubudehe" in mind such that different subsidy amounts are applied to each Ubudehe[30] category. Ubudehe 1, which comprises the most vulnerable households that make up 16% of the population, receives the most assistance. For the other households, 30% are in the Ubudehe 2 category, who own their own homes but are not fully employed; 53% are in Ubudehe 3, who are employed full-time or are small-scale commercial farmers; the rest (1%) are in Ubudehe 4, the wealthiest, who tend to live in urban areas. Experience from SHSs shows that the difference in spending between the categories 1-3 is relatively small and so, in principle, the price of products needs to be subsidised or consumer financing offered to all three categories.

Apart from grant funding, debt financing has also been used in the energy sector. A pertinent example is the USD 48.9 million World Bank Renewable Energy Fund (REF), which was designed to provide funding to

[30] As noted in Section 3, the Ubudehe categories will change to 5 alphabetical groups instead of 4 numeric ones.

commercial banks, Savings and Credit Cooperatives, and microfinance institutions, and also provide direct lending to SHS companies and mini-grid developers. Similarly, to support companies that need upfront capital in order to participate in the RBF scheme, BRD and other commercial financial institutions provide a line of credit facility. As a respondent from BRD explained:

> For example, if one clean cooking company needs a credit facility, and then if that company applies through [a] commercial bank or maybe through BRD, and then if the bank, [while going] through the credit appraisal process [finds] that business is good, and … is interested to provide money, then the bank can finance … from their own capital. (BRD interview)

Consumer financing remains a significant barrier in the diffusion of clean cookstoves, which then affects the potential for demand for electric cookstoves. According to various respondents, there are limited financing schemes commercially available in the market, and local financial institutions are sceptical about financing clean cooking technologies. These institutions lack knowledge in terms of understanding the clean cooking sector and how to identify the risks, thus financing clean cooking is perceived as a risky market.

It is worth noting the need for entrepreneurship capacity building in rural communities to support any market development activities that would stimulate adoption of electric cooking appliances in those communities. One respondent noted that "*business and entrepreneurial skills are quite problematic in the community that we're working in*" (ARC Power interview) and, in this regard, initiatives such as Empowering Villages have helped.

4.6.4 The gender dimension

Gender equality is key in GoR programmes and priorities, and this is reflected in the high number of women in parliament and in leadership roles. However, there is a significant underrepresentation of women in the energy sector. Further, the National Gender Policy acknowledges that women suffer more from energy poverty because they are responsible for many household activities that would otherwise be easier with electricity or other modern energy carriers and technologies. Preparing meals is one of these activities.

The gender dimension is also unique in Rwanda due in part to the 1994 genocide against the Tutsi. Women head 32% of households. Of these households, 62% are below the poverty line and many women are widows. Due to their socioeconomic circumstances, these women lack access to capital to acquire household goods such as cookstoves. In recognition of this, MININFRA launched an Infrastructure Gender Mainstreaming Strategy in 2017 to support employment of women in the energy sector while facilitating energy access for women. Women are increasingly playing a big role in the cookstove sector, not just as consumers, but also in raising awareness, mobilising their networks, in product development, marketing and sales. Experiences from ICS diffusion also show that women tend to be inherently invested in stove improvements, and that training women has more long-term benefits (Accenture, 2012). Women are also integral to any consumer awareness and education campaigns as they are viewed as having more credibility. A similar rationale could be adopted in developing e-cooking STIS as exemplified in the planned *Bye Bye Makara* project. Further, consumer financing mechanisms and business models should recognise and reflect the needs of low-income women, especially the disadvantaged female-headed households.

In male-headed households in Rwanda, women are often involved in household purchasing decisions. However, the man usually controls the budget. This means that men must also be involved in any campaign to stimulate adoption of modern energy cooking appliances. Previous programmes have shown that female-headed households are less willing to pay for a clean cooking appliance than male-headed households, especially if full upfront payments are required. The willingness to pay increases when a payment plan is offered (World Bank, 2020). However, 25% of female-headed households will not pay for a cookstove under any given terms, compared with 19% of male-headed households.

4.6.5 Actor attitudes on the trajectory of development around e-cooking

In Rwandan energy policy, there seems to be a preference for LPG over electricity. The national strategy to transition to cleaner cooking fuels aims at reducing biomass use from 83% in 2017 to 42% in 2024, with the vast majority of the biomass reduction replaced by LPG and the rest to be replaced mainly by biogas. The logic of this policy goal is perhaps illustrated by a comment from one of our interviews:

> Many other countries in Africa have managed to scale up LPG, and there's examples from Asia and Latin America where LPG has become the predominant fuel in a very short number of years, because of the infrastructure needs and the type of costs involved in scaling up LPG as compared to electricity, etc., and the fact that it can meet most, if not all, the cooking needs, even in a country like Rwanda. (Eliza Puzzolo and Daniel Pope interview)

Insights from what could be considered the largest health-based randomised control trial – the Household Air Pollution Intervention Network (HAPIN) trial – conducted in the Kayonza district in rural Rwanda has shown that almost all of the 400 intervention households could cook with LPG and meet all of their cooking needs. Further, cooking beans, which is the staple food in Rwanda that takes a long time to cook, was not considered a challenging issue because the fuel was provided for free. The main challenge therefore is supply of LPG by building the relevant market infrastructure to enable households to access LPG by building up cylinder inventories and storage facilities across the country and lowering the cost of acquisition and refills. Further, Rwanda can easily access LPG from Tanzania and Kenya even when transportation costs are taken into account. Respondents also emphasised that there is plenty of LPG produced globally and, given that it is a by-product of other refinery processes, it is unlikely that LPG supply will become a barrier. The focus therefore has been on finding ways to scale up LPG use rapidly to reach the national target of 40% household adoption by 2024. Respondents suggest this target is very ambitious and that the 2024 LPG target may be achieved more realistically in 2030 unless there is another intervention such as a charcoal ban.

Nevertheless, there are actors such as Electrocook who are more optimistic about the potential for mass adoption of electric cooking given the speed of electrification in Rwanda.

> So currently we are on 60% electrification, with 15% off-grid and 45% on grid. So most of those [Government] policies are in favour of electric cooking. And also, there are some other initiatives and plans like the ones on banning the charcoal use, especially in Kigali city. That is a move, should

> it be implemented, which will also work in favour of e-cooking development. (Electrocook interview)

Most respondents expressed a positive attitude towards the Government's policies and regulatory approach with regard to rapid electrification and electric cooking. For instance, the Government is committed to providing an enabling environment for private sector actors to establish businesses, and to develop energy generation infrastructure. As respondents from Electrocook explained:

> The style of the Government is to encourage private sector taking over these infrastructures for electricity generation. And some of them has even signed a concession agreement with the Government to manage Government power plants …. And the Government is also encouraging private sector to enter into off-grid area, where companies are now developing mini-grids". (Electrocook interview)

However, some respondents expressed concerns about meeting regulatory demands that may affect the sustainability of commercial off-grid infrastructure. A pertinent example is tariff setting, where the expectation is that tariffs in mini-grids should match those of the national grid.

Given the scale of multi-actor initiatives in the sector, a key issue in the development of the electric cooking STIS is partner organisation. For instance, for a mini-grid developer to successfully distribute EPCs in one of their installations, there must be willingness (on the part of some supply-side actor) to invest in community-level training: e.g., through cooking demonstrations. It was also suggested that these partnerships or networks should be established in a more formalised way to encourage commitment and ensure clarity in the interactions. In this regard, one of the mini-grid developers remarked:

> Our core business really is generating electricity. We don't have the time or the skillset to be doing these other things properly, hence bringing in these partner organisations. So certainly, around the cooking, I think I have a lot of hope for the EPCs if they're done properly, the training is done properly, and it's easy to understand the technology, that there'll be quite a lot of uptake around that. (ARC Power interview)

5 Socio-technical innovation system analysis and discussion

5.1 Actors, networks and central technologies

The clean (or cleaner) cooking challenge in Rwanda has been receiving active attention for the best part of two decades, with mainly international development actors providing the funding or being centrally involved in interventions. Correlating with the international policy agendas on climate change and the SDGs, funding and financing have ramped up considerably over the past few years. According to our research, the longest-standing international actors in the clean cooking space are Practical Action (including work with UNHCR), GIZ (through EnDev) and SNV. The World Bank, including ESMAP, have intensified their activities in the clean cooking space more recently and are providing hugely significant funds – in both grant and loan facilities – to promote clean cooking action. Apart from Practical Action and UNHCR, whose activities have been focussed on promoting sustainable cooking technologies and fuels in refugee camps, the stated aims of most efforts are to seek market-based approaches to the clean cooking challenge. Given the overwhelming practice for cooking of burning biomass in three-stone fires, Rwanda's widespread poverty levels, and the historically low rates of electrification, these market-based efforts have been mainly targeted at promoting relatively cheap and simple solutions such as ICSs. And the promotion of ICSs has been accompanied by some efforts to develop their local manufacture. More recently, LPG has received increased attention as a potential solution, but there has also been some effort to develop the use of cleaner alternative fuels such as briquettes and pellets, derived from sawdust and agricultural residues such as rice husks. In short, clean cooking seems to have been understood so far as best achieved by incremental innovations to fuel-based cooking practices and technologies, aiming to increase their efficiencies and reduce their harmful impacts in the simplest and cheapest ways possible.

Most, and perhaps all, of the efforts described above have been conducted in some degree of cooperation with the GoR whose policy agenda around clean cooking appears to be driven primarily by climate change action and addressing indoor air pollution. In the case of climate change action, several ministries are relevant and, together with the issue of indoor air pollution, it means there are many policy actors involved in the clean cooking STIS. Apart from the dominant role played by international development actors and many policymakers, there is some involvement in clean cooking in the local university sector, most notably by the University of Rwanda through ACE-ESD, our collaborating partner for this paper. Other university interest is from foreign affiliates: Carnegie Mellon University (CMU) and Colorado State University (CSU). Less clear is the extent to which local private sector actors are involved beyond those entrepreneurs and others who have participated in clean cooking projects funded by international donors.

In e-cooking, and specifically in terms of EPCs, there are currently very few actors in Rwanda, whether international or local. According to our research, Electrocook are the most active among those in the private sector, and are currently importing Chinese-made appliances but with a stated aim to nurture local manufacture of suitable devices in the future. The solar PV mini-grid developer ARC Power may become one of the more active private sector players in EPC promotion depending on how the pilot study unfolds with Electrocook. If considered successful, this experiment could form a strong basis for designing EPC

promotion in other mini-grids, including with mini-grid providers other than ARC Power, and so help generate more learning and an expanding e-cooking STIS.

The other main actor locally embedded in the Rwanda e-cooking STIS is E4I, the MECS Programme country partner. E4I has been working in Rwanda since 2012 and is well-connected with many others in the clean cooking space. And the organisation is already linked to Electrocook, ARC Power, the Energy Private Developers association and MININFRA as well as energy actors across the East Africa region. Their deep and extensive experience with clean cooking in Rwanda should prove to be invaluable as they conduct the various pieces of research they have been commissioned to undertake around e-cooking. In particular, the cooking diaries and discrete choice modelling on different cooking appliances should elicit crucial and much-needed evidence with which to steer, and on which to build, the evolution of the e-cooking STIS. And the research being conducted by CSU on the impact of clean cooking on indoor air pollution and health in rural households, although in relation to LPG rather than EPCs, could also be crucial for building support for e-cooking.

The actor-networks around e-cooking, then, are growing and connecting but there is a long way to go, especially in terms of enrolling local actors beyond the start-ups and universities. The networks are currently dominated by donors and international players. Little evidence of the benefits and challenges of EPCs exists at present but this could change soon, depending on how well the current trials and pieces of research unfold.

5.2 Social practices and narratives

It is clear that the dominant cooking practice in Rwanda centres on burning biomass in three-stone fires and other simple cookstove technologies. Much less clear is whether there is any systematic knowledge and understanding of cooking culture beyond knowing which kinds of foods are commonly consumed. Some of the research currently underway, as noted above, will be important for developing a better understanding of some aspects of cooking practice but other kinds of research may be necessary. It will be interesting to see, for example, the extent to which ordinary Rwandans are willing to incorporate EPCs into their daily cooking, whether as part of a fuel-stacking strategy or as a complete replacement. The technical data generated by the various studies we have mentioned will be important in themselves, but it is also important that deeper insights are sought. In Tanzania, for example, we have seen that some who have tried EPCs have begun to associate positive and attractive meanings with e-cooking – cleanliness, empowerment, welfare, among others (Byrne, Onsongo, Onjala, Fodio Todd, et al., 2020) – and so it could be important to investigate what meanings and values those in the various Rwandan studies might attach to e-cooking appliance use.

One important reason for developing this deeper understanding of cooking practice, in the wider sense of the term that includes its cultural qualities (see Section 2.1 for an explanation of the practice concept as we use it here), is that it can help to construct powerful narratives for use in persuading different kinds of actors to support and/or adopt e-cooking. As we noted in the preceding section, the clean cooking narrative in Rwanda appears to be centred on the issues of climate change and indoor air pollution. Judging by the level of GoR policy action and the funding and finance flowing to clean cooking, this narrative would

appear to be powerful among policymakers and development organisations. While this is certainly important, and the issues of climate change mitigation (e.g., avoiding deforestation) and lower indoor air pollution are important strengths of e-cooking, it is less clear whether this specific narrative is powerful for other kinds of actors. For example, beyond a few private sector actors who are motivated to some degree by a social agenda, we could ask in what ways their interests would be served by entering the untested e-cooking space. One hopeful development in this regard lies in the Electrocook-ARC Power study. There is potential in this trial to generate knowledge to inform a narrative that could be persuasive to other mini-grid providers by demonstrating how EPCs could raise electricity consumption and so increase the business viability of mini-grid systems. This could also be useful to the MECS Programme objective to change the narrative on electric cooking more generally: i.e., it could feed into the Programme's goal to bring the electricity access and clean cooking constituencies together wherever they may be working, not just in Rwanda.

For ordinary Rwandans, we could ask why they would be persuaded to buy what are currently expensive and unfamiliar e-cooking appliances – assuming there is an adequate electricity connection to enable the use of such appliances – when there may be more familiar and less expensive technologies and techniques they can use to achieve cleaner cooking. The fit-stretch notion comes into play here. If e-cooking appliances can be shown not only to 'fit' with normal cooking needs but also to create 'stretch' opportunities for ordinary Rwandans – e.g., reduced cooking costs and time-savings, or ways of expressing identity, or means to achieving other valued outcomes – then there is a greater chance they will be adopted. Some of the fit-stretch aspects, such as the extent to which EPCs can meet the normal cooking needs of Rwandans as well as cost and time data, should become clearer from the studies currently underway or planned – the Electrocook-ARC Power, CSU and E4I work – but understanding how e-cooking may speak to values and meanings might require further research.

5.3 Policy narratives and enabling environment

There is something of a mixed picture of whether the policy environment – in terms of both policy narratives at play and the specific policy instruments in operation or planned – is conducive to promoting e-cooking. Two broad sets of dynamics can be seen as positive. One, the intensified push to reach universal electricity access by 2024, if achieved, is certainly essential for the possibility to promote e-cooking. The results achieved so far in terms of connections to an electricity supply – SHSs, mini-grids or the national grid – are highly encouraging. Two, there is clearly a highly active policy push to promote clean cooking and significant amounts of international funds are now available to help realise this goal. But, from the perspective of e-cooking, there are also several challenges within both these generally positive developments. For electrification, the big push has meant a rapid increase in power generation and infrastructure investments alongside obligations to pay private investors for electricity supplied regardless of whether it is consumed (and there may now be an electricity over-supply so the burden on public funds may be substantial). This has resulted in high electricity production costs and high prices for grid-connected consumers, with similarly high tariff demands for mini-grid systems. The GoR is reducing the cost to low-income consumers through subsidies (World Bank, 2020) but it is an open question as to how sustainable this will be. And, without evidence of the cost of cooking using EPCs, it is not clear the extent to which

electricity prices will create difficulties to promote e-cooking. As for the clean cooking policy push, this is focussed most strongly on promoting relatively incremental innovations around ICSs, LPG and some other alternative fuels. Again, without the evidence of the benefits of e-cooking, it is unclear the extent to which policymakers will be persuaded to strengthen policy instruments to promote the use of e-cooking appliances. As we have noted several times above, much therefore rests on what emerges from the various studies being conducted on EPCs in real settings.

Nevertheless, there are ways in which e-cooking actors can begin to influence the policy narrative in their favour, depending on what evidence does emerge from the studies already described and any further research that might be conducted. Reducing indoor air pollution and mitigating climate change by avoiding deforestation, especially if electricity is generated from renewable energy sources, are clearly strengths for e-cooking compared with fuel-based cooking technologies. E-cooking actors can certainly make more of these benefits when addressing policymakers. But the cost to ordinary Rwandans of e-cooking is also an important issue. If the trials we have described do show it can be cheaper to cook using EPCs then this will be important to strengthen the e-cooking policy narrative. Research elsewhere in East Africa demonstrates lower costs for EPC-based cooking compared to more traditional techniques and technologies (Leary et al., 2019; Scott et al., 2019) so the conversation with policymakers could already begin with reference to this work. The cost to the public finances of dealing with the electricity over-supply could be reduced, if only over the longer term, by widespread use of e-cooking devices. Indeed, the widespread use of such devices on mini-grids could enhance their viability and so encourage stronger support among policymakers for mini-grid installations. Looking to the sources of funds for achieving e-cooking promotion, all of the above arguments could be used to construct a narrative persuasive to donors who might then include e-cooking more strongly in their current support projects. In fact, the World Bank is including EPCs and rice cookers in their EAQIP facility (Development Bank of Rwanda, 2021).

5.4 Discussion

Considering both the opportunities and challenges facing the promotion of e-cooking in Rwanda, a realistic strategy e-cooking advocates may wish to pursue involves taking a long-term approach to nurturing the e-cooking STIS. This long-term approach includes positioning e-cooking as a complementary practice to other clean cooking options and one that stands a better chance of early adoption by wealthier households, most of which are in urban areas with national grid connections, although some may be found in areas served by mini-grids. An argument for seeing e-cooking as a complementary practice arises from at least three observations of the challenges facing e-cooking in Rwanda. One, the policy momentum is firmly with fuel-based clean cooking – whether cleaner biomass, ICSs, or the more recent push for LPG – supported with considerable levels of funding and finance from international donors and efforts from a range of development actors. Two, current cooking practice in Rwanda is almost universally fuel-based. Three, electricity is relatively expensive and many Rwandans have little income to spend on electricity consumption. We would suggest that positioning e-cooking as complementary to other clean cooking options, at this stage, means acknowledging the challenges while recognising and building on the opportunities, each of which we now discuss with respect to the three observations just noted.

Although the policy momentum is with fuel-based clean cooking solutions, there is, as we mentioned in Section 3, a cautious embrace at the policy level for e-cooking in Rwanda. This sees e-cooking as something more suitable, at present, in a small range of settings such as in urban households, public institutions and the commercial food industry. These are three quite distinct settings for the use of EPCs, where there is potential for three significantly different sets of challenges to be overcome. In terms of developing a strategy and actions to promote e-cooking, it would be important to reflect on whether attempting to experiment simultaneously with EPCs in all three settings would be too complex or whether it would be better to try EPCs in many different settings to see where they may fit most easily (and create opportunities for users to 'stretch' their practices). Given there are existing trials to test EPCs in mini-grids (which may to an extent be considered similar to grid-connected urban households), we would suggest the early trajectory of the Rwandan e-cooking STIS is consistent with the policy interest in e-cooking in the urban household context and so it may make most sense to continue concentrating efforts in this way. A focus on national grid-connected households would also mean the evidence that will be generated by the existing EPC trials (and any evidence from further research) can be mobilised more readily to develop a policy narrative that can argue for stronger commitment at the policy level and among donor and development actors. This narrative can acknowledge the importance of current efforts to promote fuel-based clean cooking as effective in realising change quickly, but it can argue that some 'fuel stacking' – where e-cooking can be one of a set of household cooking practices – can also play a role in helping to meet the climate change and indoor air pollution policy goals, as well as start to address some of Rwanda's electricity over-supply (and therefore reduce the burden on public finances). And, judging by the fact that there seems to be a well-coordinated clean cooking policy response in place across several parts of the Government, the deployment of a strong e-cooking policy narrative could mean a rapid and accommodating change for e-cooking across the same suite of policies. In turn, this could have helpful influences on donors and development actors, enabling e-cooking advocates to realise action on the ground more effectively.

The strength of policy momentum for fuel-based solutions to the clean cooking challenge in Rwanda is likely a result of the near-universal fuel-based cooking practice in the country, where more than 99% of households cook using biomass. With this in mind, and the levels of poverty, the simplest, cheapest and quickest ways to reduce the impacts of fuel-based cooking are to improve its efficiency with ICSs, promote the use of higher quality biomass (e.g., briquettes and pellets), and seek to achieve widespread use of modern energy carriers such as LPG. In this context, introducing e-cooking at scale (as in large numbers of people adopting the practice) could be too great a challenge in the short to medium term. An immediate focus on (wealthier) grid-connected households, as we argue above, seems more realistic. In terms of opportunities, this would provide space to develop technologies that can work well in Rwanda. Such a space could, with suitable policy and other kinds of protection, generate important evidence on the costs of e-cooking compared with fuel-based options, and elicit understandings of the kinds of meanings and values with which e-cooking practice can resonate that are attractive in the Rwandan context. In the course of research and experimentation in this protective space, there will be numerous opportunities to nurture the e-cooking STIS by, among other activities, bringing into the STIS more and diverse actors, among them householders and the as yet disconnected distribution and retail supply chain actors. This will also help to

localise the constituency of support for e-cooking, counterbalancing the current dominance of foreign players. And, finally with regard to creating an e-cooking STIS that bridges the clean cooking and electrification efforts, the evidence from research and experimentation will help to develop a consumer-focussed e-cooking narrative that can enjoy wider support within the growing constituency, a narrative that the members of the constituency will be likely to promote outside the e-cooking actor network.

The third main aspect of our argument in favour of focussing e-cooking efforts in the short to medium term on wealthier households is the cost of electricity. Compared to neighbouring East African countries, the cost of electricity is high and per capita income is low in Rwanda. As discussed in Section 3, the high cost of electricity is in part due to the investment costs of the rapid expansion of electricity access. In time, the impacts of these investments on the cost of producing electricity are expected to fall but it is unclear how long this will take. The Government is attempting to mitigate the high costs in several ways, and to make it cheaper to get an electricity connection, but we do not yet know whether these mitigation measures will be enough to ensure electricity is considered affordable by the majority of the population. Once again, the evidence from the trials with EPCs is going to be important for generating knowledge about the costs of cooking with electricity, especially as compared with fuel-based cooking. An important example question that might be answered by such trials is the extent to which e-cooking can meet common food preparation needs within the 'lifeline' tariff allowance of USD 0.09 up to 15 kWh. This evidence, if favourable and deployed together with a persuasive e-cooking policy narrative, could be helpful for creating stronger e-cooking policy action such as a raised lifeline tariff allowance, perhaps implemented in tandem with other 'Ubudehe' kinds of support and policies that work against biomass use such as the anticipated charcoal ban. If such measures can be realised then e-cooking advocates can begin to target poorer households more effectively. In the meantime, working with wealthier households would enable the immediate development of the e-cooking STIS.

5.5 Summary

The overwhelming dominance of biomass-based cooking practice in Rwanda, the prevailing policy momentum to promote cleaner fuel-based cooking, and the currently high cost of electricity in a country with very low per capita income, suggests the strategy most likely to work in the short to medium term for developing the currently small e-cooking STIS should be focussed on wealthier grid-connected households. This would enable various STIS-building activities to strengthen and broaden around the small network of enthusiastic e-cooking actors currently present in the country, especially activities aimed at (1) refining e-cooking appliances, (2) generating evidence on their viability and attractiveness in the Rwandan context, (3) recruiting more and diverse local actors to the e-cooking network, (4) connecting to actors in the distribution and retail supply chain, and (5) crafting narratives targeted at policy makers and ordinary Rwandans. The extent and speed with which the e-cooking STIS can develop will depend on the persuasiveness of the evidence base that will begin to emerge from the trials currently underway, any further research and evidence that will emerge, how this evidence is deployed, and how this will be reflected in policy responses around clean cooking and electricity access.

Although these comments reflect a lot of uncertainty for e-cooking's development trajectory in Rwanda, the core e-cooking advocates are optimistic about the possibilities, and experience elsewhere in East Africa suggests that e-cooking – especially with appliances such as EPCs – does have an important role to play in Rwanda's clean cooking future. In the short term, at least, we argue that achieving the successful development of an e-cooking STIS requires a targeted strategy in which e-cooking is positioned as complementary to other clean cooking solutions. In time, and with an expanding e-cooking STIS, cooking with electricity could become more important in Rwanda, displacing many, if not all, fuel-based solutions.

6 Recommendations for the MECS Programme

Having discussed our assessment of the nascent e-cooking STIS in Rwanda, we finish the paper with some recommendations for the MECS Programme. It is possible that MECS is already pursuing some or all of these recommendations. But we offer them here in any case.

1. **Focus e-cooking efforts for now on wealthier grid-connected households**

   The MECS Programme and other electric cooking advocates in Rwanda could first focus on a strategy of targeting wealthier grid-connected households with e-cooking interventions, generating evidence on e-cooking costs (especially in comparison with fuel-based options), social practices and the kinds of values and meanings with which e-cooking can resonate. This is the low-hanging fruit in making interventions in such a challenging sector and may set the stage for further experimentation, which would provide opportunities to broaden and deepen the nascent e-cooking networks. Further, through experimentation with wealthier households – including, potentially, highly active household participation in EPC design – there would be opportunities to develop narratives that are persuasive to householders as well as stronger policymaker-focussed narratives that draw on evidence from such experimentation.

2. **Move to research and development with more vulnerable households once the e-cooking STIS has begun to stabilise**

   Subsequently, as the e-cooking STIS strengthens and begins to stabilise, research and development among the more vulnerable households in Rwanda – especially those in Ubudehe 1 to 3 (or their equivalent once the new categorisation is operational) – to explore conditions for electric cooking adoption would be useful to make a business case for why other development partners and the private sector should invest in these segments. Given that initiatives such as EAQIP offer significant subsidies to vulnerable households, there is an opportunity now to explore how households can rapidly rise through the energy access tiers. Further, given the relative success of poverty alleviation programmes that adopt the targeted Ubudehe categorisation in programme design, MECS could explore how such an approach may be useful in its own interventions. Such an approach can provide evidence to support causality between e-cooking and improvements in health and welfare outcomes.

3. **Enhance efforts to coordinate the emerging e-cooking STIS**

   The e-cooking STIS needs coordination, as currently there are fragmented activities implemented by different actors, with information-sharing happening mostly at an informal level. There is a lack of awareness of the capabilities that different actors bring to the STIS, and the possibilities for collaboration and interaction. Even within projects where actors seem to be working together, for instance in cooking trials, there has been some frustration regarding how the existing knowledge asymmetries could be addressed. MECS has only recently appointed a country partner to take up this task.

4. **Investigate the potential to develop EPC and other manufacturing capabilities in Rwanda**

   There is a need to develop the manufacturing capabilities in Rwanda to enable the development of homegrown e-cooking appliances that align to local conditions: e.g., cultural practices, language, literacy and infrastructural constraints. Foreign manufacturers have already expressed concern about the local assembly of e-cooking appliances due to lack of capabilities. However, there is evidence there are local capabilities related to traditional pressure cooking that could be built upon, technical capabilities from local training institutions, and enthusiastic actors who are interested in local manufacture. Lessons can be drawn from East African countries such as Kenya that are currently manufacturing EPCs.

5. **Improve and further develop the evidence base on e-cooking in Rwanda**

   Our study revealed there is a significant lack of accessible and usable evidence on the Rwandan clean cooking sector in general. E-cooking advocates could help mobilise an evidence base and aid in the codification of tacit knowledge. Further, this knowledge needs to be disseminated broadly in order to inform actor strategies and attract more investment.

6. **Strengthen intra-regional interactions amongst e-cooking advocates and promote a more coordinated approach to regional policy**

   There is positive preliminary evidence of Rwandan enterprises interacting with other actors across the border in e-cooking initiatives through, for example, sourcing of appliances. E-cooking advocates such as MECS could deepen and encourage such interactions. Further, working with others across the East Africa region would draw on their experiences with e-cooking, especially in terms of how ordinary citizens are adopting the technologies and practices, but also in terms of persuading actors at the regional policy level to coordinate their policy support for e-cooking.

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Annex I: Interview guide for organisations in the Pinnsmap

MECS Interview Guide for Organisations in the Pinnsmap

[Name of organisation]

SECTION A. General questions

1. About the respondent
    a. Name
    b. Role/designation in the organisation
    c. No. of years worked in current organisation
    d. No of years worked in the energy sector; e-cooking subsector
    e. Previous organisations and roles on those organisations (related to energy and cooking)
2. About the organisation
    a. When was the organisation founded?
    b. What is the scope of work done by [the organisation] in the country? What are the focus areas of the organisation?
    c. Involvement in e-cooking:
        i. When did the organisation first get involved in the cooking sector?
        ii. Which departments are involved in projects or initiatives in the e-cooking sector? How large are those departments?
        iii. List and describe the organisation's independent projects on e-cooking
        iv. List and describe the organisation's multi-partner/multi-stakeholder projects on e-cooking
            1. When did it start? Ongoing? Has it ended? When?
            2. Which partners does the organisation work with in these projects?
            3. What stimulated the formation of the partnership/ project? e.g. which events, new policies/policy changes, opportunities, etc?
            4. What were the objectives of the partnership/interaction?
            5. What technology(ies) was (were) being focused on in the project/partnership?
            6. What were the achievements of the project? Successes and failures in the interaction?
            7. Was there any resistance within the project/partnership?
            8. What were the lessons learned?
            9. Next steps
    d. Beyond the projects above, what activities has the organisation engaged in to advocate/lobby for e-cooking diffusion and adoption?

3. Do you have any documents with information on the projects discussed? Including but not limited to:

a. Project reports
b. Links to web pages
c. Research papers
d. Other publications
e. Etc.

SECTION B: The Wider Operating Environment

1. What other factors in the operating environment have influenced the development of e-cooking projects/initiatives/partnerships in the organisations? e.g. specific events, policies, opportunities, technological developments, etc.

Probe on:

a. Electrification initiatives in Rwanda
    i. How has electrification rate contributed to or hindered e-cooking
    ii. Will growing electrification rates see a corresponding increase in uptake of e-cook. Why/ why not?
    iii. Who are the actors in electrification initiatives that have the most potential
    iv. How has the changing policy landscape impacted e-cook?
b. Entrepreneurial landscape that supports discourse on the potentials for e-cook
    i. Policy around entrepreneurship and innovation
    ii. Innovation incubators focusing on ecook innovations… or that show potential

2. Who/what is missing from the current innovation system? Ie. What organizations or organization groups do you think need to be brought into the fold? (*possibly do a recap of what has already been covered*)
3. Which actors are creating resistance in the development of e-cooking in Rwanda?

SECTION C. Specific questions (based on the Pinnsmap)

- Show the printed Pinnsmap to the respondent
- Probe the respondent to respond to their organisation's position on the map, the identified partners, and description of interactions
- If there are interactions in the map that were not mentioned in Section A, part 2, move on to question 3 below.

1. Please expound further on this organisation's relationship with:

[Point out the previously omitted organisations that interact with the respondent, and probe further based on the specifics of that interaction. The questions below would help pre-empt some answers on the relationship on the Pinnsmap]

Example for Electrocook

a. Power Africa on guidance in off-grid ecooking:
b. EEP Africa financing
c. A2EI provision of meters and collaboration
d. Strathmore University provision of meters and collaboration
e. MECS collaboration
f. Energy Development Corporation Limited (EDCL) discussions regarding taxes and subsidies
g. E4I collaboration regarding EPCs and cooking manuals
h. Arc Power mini grid trials along with the improvement of training and manuals
i. East African Power Empowering Villages collaboration

SECTION D. The bigger picture

1. To the best of your knowledge, is the rest of the map accurate? Are there stakeholders or players that are key to e-cooking in Rwanda that were left out of the map?
2. Who else should be included in efforts to develop and promote e-cooking in Rwanda?
3. Are the interactions between the players captured accurately? Do you know of collaborations that are not highlighted within the map?
4. Which actors on the map are the most powerful? What is their influence?
5. Which ones have potential to influence the map (the e-cooking innovation system) significantly in the future?
6. What are your thoughts on the trajectory of the e-cooking innovation system in Rwanda?
7. What other elements of the operating environment or context are missing on the map?
8. Who else can you recommend that we speak to for a richer understanding of e-cooking in Rwanda?

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Annex II: List of organisations and persons interviewed

Organization	Name of Representative	Designation
ARC Power	Penny-Jane Cooke	Environmental Management Officer
Development Bank of Rwanda	Alida Ikuzwe	Investment Manager
	Umesh Acharya	Renewable Energy Financing Expert
Electrocook	Maximilian Schulz	Business Development Manager
	Daniel Shijaku	Business Development Manager
Energy for Impact	Innocent Ndayishimiye	Technology Specialist
	Divin Ntivunwa	Project Coordinator
MECS Rwanda	Iwona Bisaga	Research Associate MECS Programme
	Bridget Menyeh	Research Associate MECS Programme
MeshPower	Richard Mori	CEO
Ministry of Infrastructure	Peace Kaliisa	Donor Coordinator
Neseltec	Aloys Ntihemuka	Managing Director
Rwanda Energy Group	Oreste Niyonsaba	Manager Clean Cooking Technologies Unit
University of Liverpool	Elisa Puzzolo	Senior Research Fellow
	Daniel Pope	Professor of Global Public Health

Annex III: Online workshop participants

Name	Organization	Date
Iwona Bisaga	MECS	23 March 2021
Bridget Menyeh	MECS	23 March 2021
Telesphore Kabera	University of Rwanda, ACE-ESD	23 March 2021
Daniel Shijaku	Electrocook	7 April 2021
Maximilian Schulz	Electrocook	7 April 2021
Barry Rawn	Carnegie Melon University	7 April 2021
Patrick Nzabamwita	Carnegie Melon University	7 April 2021
Jean Damascene Habimana	Carnegie Melon University	7 April 2021
Innocent Ndayishimiye	Energy 4 Impact	7 April 2021
Andrew Mbangukira	Energy Private Developers association	7 April 2021
Lin Lawrence	Power Africa Off-Grid Advisor in Rwanda	13 April 2021
Penny-Jane Cooke	ARC Power	13 April 2021
Philbert Dusenge	Biomass Cookstoves Entrepreneur	13 April 2021
Richard Mori	MeshPower Limited & Xpowere Inc	13 April 2021
Oreste Niyonsaba	Energy Development Corporation Limited	13 April 2021